VIRTUAL SYMPOSIUM

WEATHER AND CLIMATE SERVICES OVER MOUNTAINOUS REGIONS

14 - 17 DECEMBER 2020

Souvenir cum Abstract Volume

TROPMET 2020

Organized by

Indian Meteorological Society

New Delhi

Hosted by

North Eastern Space Applications Centre (NESAC)

Dept of Space, Govt. of India, Umiam, Shillong, Meghalaya

and

Indian Meteorological Society – Shillong Chapter

Shillong, Meghalaya

Virtual Symposium

on

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Indian Meteorological Society – Shillong Chapter
Shillong, Meghalaya

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डॉ. एम. राजीवन
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SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
PRITHVI BHAVAN, LODHI ROAD, NEW DELHI-110003

MESSAGE

I am glad to learn that the Indian Meteorological Society (IMS) is organizing its national conference (TROPMET-2020) using virtual platform on "Weather and Climate Services over Mountainous Regions" at North East Space Application Centre (NESAC), Shillong, India during 14-17 December, 2020.

The South Asian regions show large scale spatio-temporal variability in weather & climate due to its varied physiographic conditions. The region is dominated by the orographical features with the Himalayas in the north and the Ghats in both the eastern and western parts of India. The weather and climate characteristics over these mountainous regions are more challenging in terms of its monitoring, prediction and warning services. This has put a new threat not only to National Meteorological and Hydrological Services (NMHS) but also to the disaster managers.

Considering all these, Indian Meteorological Society (IMS) in collaboration with North Eastern Space Applications Centre (NESAC), Shillong, India is organizing the Virtual Symposium on Tropical Meteorology (TROPMET-2020) on "Weather and Climate Services over Mountainous Regions" at NESAC, Shillong, India during 14 - 17 December, 2020. This conference will make efforts to bring together atmospheric scientists, research professionals, policy makers, disaster managers and other related experts to discuss and share information for the benefit of the society.

I am confident that the National conference "TROPMET-2020" will provide a common platform to the academicians, scientists, numerical modeling, communities and industrialists from different organizations and help in drawing purposeful recommendations on the issues of the weather and climate services over the Mountainous Regions.

I convey my best wishes for the success of this conference.

(M. Rajeevan)

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डॉ.कै. शिवन
Dr K. SIVAN

अध्यक्ष, अंतरिक्ष आयोग
व
सचिव, अन्तरिक्ष विभाग
Chairman, Space Commission
&
Secretary, Department of Space

MESSAGE

I am happy to note that North Eastern Space Applications Centre (NESAC) and Indian Meteorological Society – Shillong Chapter are jointly organizing ***TROPMET-2020***; the annual National Symposium of Indian Meteorological Society (IMS), based on the theme "**Weather and Climate Services over Mountainous Regions**", during 14th - 17th December, 2020.

Space based inputs play an important role in different aspects of weather and climate related research, particularly for mountainous regions, where terrain also introduces complexities into the system. Data from Meteorological and Earth Observation Satellites are extensively used for Numerical Weather Prediction modelling towards facilitating weather advisories, severe weather now-casting, and for climate studies. Advanced techniques like Machine Learning, Artificial Intelligence, Cloud Computing, Big Data Analytics, etc. play catalytic role in improving these services. Involvement of Academia and Industry has also contributed towards better understanding of the complex processes of weather and climate.

I am sure that during the Symposium, experts will deliberate on these aspects and provide innovative solutions to many of the challenges in weather & climate system research.

I convey my best wishes for the success of the symposium and extend warm greetings to all the delegates.

कै.शिवन
10/12/2020

(कै. शिवन / **K. Sivan**)

Dated : December 10, 2020

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सत्यमेव जयते

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NORTH EASTERN COUNCIL
MINISTRY OF DEVELOPMENT OF
NORTH EASTERN REGION
NONGRIM HILLS, SHILLONG - 793003

MESSAGE

I am very glad to learn that the Annual national symposium of Indian Meteorological Society (IMS), TROPMET-2020 is being organized virtually with the theme **"Weather and Climate Services over Mountainous Regions"** during 14-17 December, 2020 by North Eastern Space Applications Centre (NESAC) and Indian Meteorological Society – Shillong Chapter.

North Eastern Region (NER) of India is rich with diverse natural resources. At the same time, the region is prone to different forms of hydro-meteorological disasters. NER hosts the site receiving highest rainfall in the world, but at the same time there is a decreasing trend in rainfall over many places in this region leading to agricultural drought over some parts in some seasons. The theme of the symposium has been aptly chosen to understand complex processes of weather nowcasting and forecasting services, climate change mitigation and adaptation techniques, and hydro-meteorological disaster management services. I am confident that this 4 day symposium will help to understand many aspects of weather and climate leading to providing solutions for difficult challenges faced.

I extend my appreciation to IMS for planning this symposium at Shillong and wish the symposium a grand success.

11/XII/2020

(Shri K. Moses Chalai)

WMO OMM

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

World Meteorological Organization
Organisation météorologique mondiale
Organización Meteorológica Mundial
Всемирная метеорологическая организация
المنظمة العالمية للأرصاد الجوية
世界气象组织

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Message from WMO

WMO congratulates the Indian Meteorological Society for organizing the virtual symposium on weather and climate services over mountain regions.

WMO attaches great importance to the development of better climate services for the mountainous Hindu-Kush region, known as the Third Pole, which provides water supplies for about 45% of the world's population.

Mountains are often referred to as "the water towers" of the world. Rising global temperatures are causing changes to mountain meteorology, hydrology, and ecology, and increasing the risk of local and downstream disasters.

In this context, the symposium is an important event for fostering coordination on adapting the weather and climate services to meet evolving needs of mountain and downstream regions.

We wish you a successful event.

Dr Elena Manaenkova, the Deputy Secretary General of WMO, will be pleased to address the symposium during the concluding segment.

डॉ. मृत्युंजय महापात्र
मौसम विज्ञान विभाग के महानिदेशक,
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि
एवं कार्यकारी परिषद के सदस्य

Dr. Mrutyunjay Mohapatra
Director General of Meteorology,
Permanent Representative of India with WMO,
Member of Executive Council, WMO

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम भवन, लोदी रोड
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Government of India
Ministry of Earth Sciences
India Meteorological Department
Mausam Bhawan, Lodi Road
New Delhi - 110003

Message

It gives me immense pleasure to know that Indian Meteorological Society (IMS) is organizing its National Symposium on Tropical Meteorology (TROPMET-2019) with special focus on **"Weather and Climate Services over Mountainous Regions"** at North East Space Application Centre (NESAC), Shillong, India during 14 - 17 December 2020.

Recently, India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) has undertaken major steps in improving the weather and climate services in the country. With the improvement in observational and forecasting tools including augmentation of NWP Models, Radar network & satellite products, forecasting/warning services in respect of severe weather like tropical cyclones, thunderstorms, heavy rainfall, heat/cold waves, flash/urban floods, fog etc have been further strengthened. There have been also significant improvements in sectoral applications like agriculture, health, surface transport, aviation, environment, power & energy sectors.

The Atmospheric processes over **Mountainous Regions** are different and therefore needs a different analysis and modeling approach to address the complexities of such regions. Such terrains are also more prone to extreme weather and climate change causing the population in such terrains more vulnerable. Scientists of IMD in collaboration with other institutes of MoES are working in an integrated approach in providing better weather and climate services to all users by further augmenting modeling and observational network and special focus is also being given to the mountainous regions through its programme on Mountain Meteorology.

I am very optimistic that the TROPMET-2020 symposium organized by IMS will provide an excellent opportunity for interaction among weather scientists, academician, numerical weather modeling communities and professionals to discuss different aspects of weather and climate forecasts and share information for the benefit of the society with special focus on Mountainous Regions.

I wish the event a grand success.

(M. Mohapatra)

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श्री पी एल एन राजू / Shri P L N Raju
निदेशक / Director, NESAC / Chairman, IMS-Shillong Chapter

MESSAGE

I extend my sincere greetings to all the delegates participating in the four days National Virtual Symposium on "Weather and Climate Services over Mountainous Regions" being organized at NESAC, Shillong during 14 - 17 December, 2020. The symposium is being organized jointly by Shillong Chapter Indian Meteorological Society (IMS) along with North Eastern Space Applications Centre (NESAC).

NESAC, since its inception in September 2000, have initiated various projects for mapping and monitoring of natural resources which were used as inputs for planning and decision making processes. The centre has also been providing single window delivery of space based support for management of all major disaster affecting NE region of India. Recently the centre has put greater emphasis on UAV remote sensing and capacity building and outreach activities, in line with ISRO's vision. The centre has also set up a state-of-the art atmospheric science laboratory to study on improvement of numerical weather prediction, characterize major drivers of climate change in NE region, improve ground based monitoring of atmospheric parameters, demonstrate utilization of satellite data in Atmospheric sciences, etc.

NE region of India, being dominated by hills and mountains, has unique features for weather and climate. While the mountains are a great resource for this region, the mountains also modulate the local and regional weather and cause several hydro-meteorological disasters in this region. The advent of newer tools like Artificial Intelligence, Big Data Analytics, Crowd sourcing, etc along with advanced graphical processing units have enabled the utilization of numerical weather and climate models at a scale that can represent and address the fine scale physical processes taking place in complex mountainous regions.

The COVID-19 pandemic has given an opportunity to participate in such symposium without any movement. The response has been overwhelming with almost 450 registered delegates presenting more than 310 research papers. I am confident that this symposium shall bring eminent academicians, scientists, and engineers on a single platform to deliberate and evolve strategies for more innovative solutions to improve the weather and climate services and research over the mountainous region.

As Chairman of the local organizing committee, I once again extend a very warm welcome to all the delegates and invited speakers. We have made all efforts to host a seamless experience for the online symposium to make it a memorable experience and hope that it will prove to be a good learning platform for all the participants.

(P L N Raju)

Dr Shyam S Kundu
Organizing Secretary
TROPMET-2020, Shillong

Acknowledgement from the Organizing Secretary

On behalf of the Local Organizing committee of the TROPMET-2020, I extend my sincere thanks to all the Patrons, Chairman and Members of the Advisory Committee, Chairman and Members of the National Organizing committee for their guidance and encouragements in organizing this program. I specially thank Dr M Mohapatra, President, Indian Meteorological Society (IMS) and Dr D R Pattanaik, Secretary, IMS for their support and critical review on the preparedness for this program. I also sincerely thank to the IMS National Council to taking the reviews and providing timely suggestions to prepare for the program. Thanks are also due to Dr S K Dash, president and members of IMS NC during 2018 for giving us the opportunity to organize the TROPMET-2020 at Shillong.

COVID-19 pandemic brought lot of uncertainties about hosting of this event and finally forced us to host this year's Tropmet on a virtual platform. I am thankful to Shri P L N Raju, Director, NESAC for agreeing to jointly host the symposium along with the IMS – Shillong Chapter despite the current restrictions. He has been the main driving force in organizing the event. My special thanks to the conveners, co-conveners and members of various sub-committees whose continuous effort has made it possible to host the event in this difficult time of COVID-19 pandemic.

We are honored by the gracious presence of Dr Madhavan Nair Rajeevan, Secretary, MoES, Government of India and Shri Moses Chalai, IAS, Secretary, NEC, Government of India, Dr M Mohapatra, Director, General, IMD during the inauguration program. We are extremely fortunate to have received the message from Secretary General of World Meteorological Organization wishing success of the event. We are extremely thankful to Dr Elena Manaenkova, Dy Secretary-General, WMO for agreeing to deliver a special talk during the valedictory program.

I sincerely thank all the eminent plenary speakers from Indian and abroad for agreeing to deliver talks on different themes. I extend my thanks to all the session Chairs, Co-chairs, and invited lead talk speakers. My special thanks to all the registered delegates and authors of submitted abstracts.

Funding is very important for such an event. I sincerely acknowledge and thank the funding support provided by our sponsors, particularly, Antrix Corporation Ltd, Earth Networks, Alpha Design and Technologies Ltd, ONGC, BMG Informatics Pvt. Ltd, and others by participating in the digital exhibition.

Finally I wish to thank the NESAC management and IMS office, NESAC IT support team, CMD, Security, Canteen, and all those who have supported to host this event.

Shyam Sundar Kundu

(Shyam S Kundu)

TROPMET-2020: National Virtual Symposium on Weather and Climate Services over Mountainous Regions

Summary Program

Time (Hrs)	14-Dec-2020	15-Dec-2020	16-Dec-2020	17-Dec-2020
10:00 - 11:15	**Inaugural Session** (Venue: Himalaya Hall)	**Plenary Session – 2** (Venue: Himalaya Hall) Honorary Speakers •Dr. R. S. Nanjundiah, IITM •Dr. R. Krishnan, CCCR, IITM •Dr. A. K. Sahai, IITM	**Plenary Session – 3** (Venue: Himalaya Hall) Honorary Speakers •Dr. B. N. Goswami, Cotton University •Dr. Sunil Singh, NIO •Dr. S. K Behera, JAMSTEC, Japan	**Plenary Session – 4** (Venue: Himalaya Hall) Honorary Speakers •Dr. V.K. Dadhwal, IIST •Dr. Akhilesh Gupta, DST •Dr. Kala Chand Sain, WIHG
11:15 - 11:30	Break (visit to e-posters, digital exhibition)			
11:30 - 11:45	**Plenary Session – 1** (Venue: Himalaya Hall) Honorary Speakers •Dr. M N. Rajeevan, Secretary, MoES •Dr. M. Mohapatra, DG, IMD •Dr. Satish Shenoi, INCOIS	Break (visit to e-posters, digital exhibition)		
11:45 - 13:15		**Technical Session – 2** TS-2A (Himalaya Hall) Dynamics and Physics of orographic clouds and precipitation TS-2B (Brahmaputra Hall) Boundary layers and turbulence TS-2C (Ganga Hall) Weather & climate services for farmers & Impact of Climate Variability/Change on Agri.	**Technical Session – 4** TS-4A (Himalaya Hall) Aerosol-cloud-precipitation interactions TS-4B (Brahmaputra Hall) Numerical weather prediction, data assimilation, and forecasting TS-4C (Ganga Hall) Indigenous instrumentation for atmospheric profiling	**Technical Session – 6** TS-6A (Himalaya Hall) Aerosol-cloud-precipitation interactions TS-6B (Brahmaputra Hall) RS of Atmosp. geophysical parameter retrieval, calibration, and validation TS-6C (Ganga Hall) Climate change and climate variability
13:15 - 14:15	Lunch break			
14:15 - 16:15	**Technical Session – 1** TS-1A (Himalaya Hall) Lightning Physics and Forecasting TS-1B (Brahmaputra Hall) Numerical weather prediction, data assimilation, and forecasting TS-1C (Ganga Hall) Monsoon prediction and dynamics	**Technical Session – 3** TS-3A (Himalaya Hall) Land-Ocean-Atmosphere Interactive Processes TS-3B (Brahmaputra Hall) Hydro-meteorological disasters and management TS-3C (Ganga Hall) The Mountain Cryosphere & Climate change and climate variability	**Technical Session – 5** TS-5A (Himalaya Hall) AI, ML & DL in weather & climate research and services TS-5B (Brahmaputra Hall) RS of Atmosp. geophysical parameter retrieval, calibration, and validation TS-5C (Ganga Hall) Climate change and climate variability	**Technical Session – 7** TS-7A (Himalaya Hall) Severe weather and complex terrains TS-7B (Brahmaputra Hall) Weather and Climate for human health TS-7C (Ganga Hall) Impact of Climate Variability/Change on Agriculture
16:15 - 16:30	Break (visit to e-posters, digital exhibition)			
16:30 - 17:30	Industry presentations (Venue: Himalaya Hall)	**Dr. G. B. Pant Memorial Lecture** by Dr. Rupa Kumar Kolli, Executive Director, ICMPO (Venue: Himalaya Hall)	**Popular Lecture** by Dr. Shailesh Nayak, Director, NIAS & Former Secretary, MoES (Venue: Himalaya Hall)	**Special Lecture** by Dr Elena Manaenkova Dy Secretary-General, WMO
17:30 - 18:30	IMS GB Meeting (https://meet.google.com/ybj-vyrc-prc)	Visit to e-posters and digital exhibition	Meeting with IMS local chapters	**Closing and valedictory Session** (Venue: Himalaya Hall)
18:30 - 19:30	**Dr S Raghavan Memorial Lecture** by Dr. V. Chandrasekar, Colorado State University, USA (Venue: Himalaya Hall)			

Contents

Indian Meteorological Society and Its Activities

D. R. Pattanaik

Secretary, Indian Meteorological Society, New Delhi

Email: drpattanaik@gmail.com

1. Establishment of IMS

The Indian Meteorological Society (IMS) established in 1956 during the Session of the Indian Science Congress, has made more than 3500 members at present. It was registered as a Society under the Societies Registration Act in 1972 in New Delhi. The society has its head Quarter in Delhi with 32 chapters spread across the country. The society is a non-profit organization and none of its income or assets shall accrue to the benefit of its members. A well discussed constitution is its major assets of IMS. The constitution is available at IMS website at the following URL: http://www.imd.gov.in/ims/

IMS local chapters

2. Objectives:

- Advancement of Meteorological and allied sciences in all their aspects.
- Dissemination of the knowledge of such sciences both among the scientific workers and among the public.
- Application of Meteorology and allied sciences to various constructive human activities, such as, agriculture and land uses, irrigation and power development, navigation of sea and air, engineering and technology, medicine and public health etc.

3. Membership of IMS

Any person who is interested in the aims and objectives of the Society is eligible to become a Member. He shall apply for membership in the prescribed form available in the website and shall be notified on acceptance by the Council.

- ***Life Member (LM)***

A Member who pays all his dues in a lump sum as prescribed by the General Body shall be a Life Member. The society has about 3000 life members.

- ***Annual Member (AM)***

A Member who pays all his dues in a lump sum as prescribed by the General Body shall be a Life Member. The society has about 3000 life members.

- ***Student Members (SM)***

In order to encourage students to becomes IMS member, IMS recently introduced student membership where a student can become IMS student member by paying Rs. 1000/- along with the forwarded application from head of the institution where he/she is working. The membership will be valid till the time he/she becomes 30 years of age or get some employment in any place whichever is early. He/she can become a regular life member of IMS by paying the balance amount.

- ***Institutional Members (Annual)***

Any institution which is interested in the aims and objectives of the Society is eligible to become an Institutional Member on payment of an annual subscription. The institution shall apply for Membership and shall be notified on acceptance by the Council. The Institutional Member may nominate its representative to exercise the Membership privileges.

- ***Patron***

A person or an institution who is interested in the aims and objectives of the Society and makes a donation of substantial sum to the Society will, at the discretion of the Council, be admitted as Patron.

SUBSCRIPTION

Annual Member	Indian : Rs.300
Life Member	Indian : Rs. 3000; Foreign : US$ 150
Entrance Fee	Indian : Rs. 00 ; Foreign : US$ 10
Student Member	Indian : Rs. 1000
Institutional Member	Indian : Rs. 10000 (annual); : US$ 250
Patron	Indian : Rs. 100000 ; Foreign : US$ 2500
Institutional Patron	Indian : Rs. 1000000 ; Foreign : US$ 25000

4. IMS Fellows

Honorary Fellow and Fellow

- Persons of acknowledged eminence in Meteorology and allied fields of Science and Technology or in their furtherance may be elected as honorary fellows by the General Body on proposal from the Council.
- Life members, who have made outstanding contribution of Meteorology and allied fields of Science and Technology, may be elected as Fellows by the General Body on proposal from the council. The following outstanding members of the society have been elected as Fellows/ Honorary.
- IMS has also given Life Time Achievement Awards to three eminent scientists.

IMS LIFE TIME ACHIEVEMENT AWARDS

S. No.	Name
1	Prof. P. V. Joseph
2	Shri Soundararajan Raghavan
3	Late Shri Dev Raj Sikka

List of IMS Honorary Fellows

S. No.	Name
1	Late Dr. A. P. J. Abdul Kalam
2	Late Dr. J. S. Fein
3	Dr. P. S. Goel
4	Late Prof. V. R. Gowariker
5	Prof. Murli Manohar Joshi
6	Dr. Ramesh Kakar
7	Dr. K. Kasturirangan
8	Late Prof. T. N. Krishnamurti
9	Prof . G. O. P. Obasi
10	Dr. Kamal Puri
11	Prof. V. S. Ramamurthy
12	Prof. Veerabhadran Ramanathan
13	Dr. P. Krishna Rao
14	Dr. M. V. K. Siva Kumar
15	Dr. M. S. Swaminathan
16	Dr. Petteri Taalas
17	Er. Avinash Chand Tyagi
18	Dr. Upendra Narayan Singh

List of IMS Fellow

SN.	Name	SN.	Name
1	Late Dr. R Ananthakrishanan	29	Prof. U.C. Mohanty
2	Late Dr. G.C. Asnani	30	Late Dr. D.A. Mooley
3	Dr. Swati Basu	31	Dr. Shailesh Nayak
4	Prof. G. S. Bhat	32	Prof. P.C. Pandey
5	Dr. V. K. Dadhwal	33	Late Dr. G.B. Pant
6	Late Prof. P. K. Das	34	Late Prof. P.R. Pisharoty
7	Late S. K. Das	35	Late Mr. S. Raghavan
8	Prof. S. K. Dash	36	Dr. M. Rajeevan
9	Dr. R.K. Datta	37	Late Dr. Y. Ramanathan
10	Dr. U. S. De	38	Dr. K. J. Ramesh

11	Dr. B. L. Deekshatulu	39	Dr. DV Bhaskar Rao
12	Late Dr. O.N. Dhar	40	Dr. L. S. Rathore
13	Prof. S.K. Dube	41	Late Prof K. R. Saha
14	Prof. (Mrs.) Sulochana Gadgil	42	Late Dr. R. P. Sarkar
15	Dr. B. N. Goswami	43	Dr. N. Sen Roy
16	Dr. Akhilesh Gupta	44	Prof J. Shukla
17	Dr. George Joseph	45	Late Sh. D.R. Sikka
18	Prof. P.V. Joseph	46	Prof. J. Srinivasan
19	Dr. P.C. Joshi	47	Dr. S.K. Srivastav
20	Dr. A.K. Kamra	48	Dr. H. N. Srivastava
21	Dr. R.R. Kelkar	49	AVM. Dr. Ajit Tyagi
22	Prof. R. N. Keshavamurthy	50	Dr. G.Viswanathan
23.	Late Dr. P. Koteswaram	51	Prof. B. Padmanabha Murty
24	Dr. R. Krishnan	52	Prof. Ravi Sankar Nanjundiah
25	Dr. S. M. Kulshrestha	53	Dr. Mrutyunjay Mohapatra
26	Dr. Rupa Kumar Kolli	54	Prof. S. K. Satheesh
27	Sh. A. S. Kiran Kumar	55	Dr. (Mrs.) N. Jayanthi
28	Dr. Santosh Kr. Mishra	56	Dr. G. Srinivasan

List of IMS Presidents

SN	Name	Period
1	Dr. P. Koteswaram	1971-74
2	Sh. Y. P. Rao	1974-78
3	Dr. P. K. Das	1978-83
4	Sh. S. K. Das	1983-86
5	Dr. R. P. Sarkar	1986-89
6	Dr. S. M. Kulshrestha	1989-91
7	Prof. P.R. Pisharoty	1991-93
8	Dr. N. Sen Roy	1993-95
9	Dr. R.K. Datta	1995-97
10	Dr. R. R. Kelkar	1997-99
11	Dr. S. K. Srivastav	1999-2001
12	Prof. S. K. Dube	2001-2003
13	Dr. S.K. Srivastav	2003-05
14	Dr. G. B. Pant	2005-07
15	Sh. R. C. Bhatia	2007-09
16	Dr. L. S. Rathore	2010-12
17	Dr. Shailesh Nayak	2012-14

18	Dr. Akhilesh Gupta	2014-16
19	AVM Dr. Ajit Tyagi	2016-18
20	Prof. S. K. Dash	2018-20
21	Dr. M. Mohapatra	2020-22

List of IMS Associate Fellow

S. No.	Name
1	Prof. Sandeep Pattnaik
2	Dr. Ayantika Dey Choudhury

IMS National Council (2020-22): The IMS new National Council took over the charge from the previous council on 10th July, 2020

Indian Meteorological Society National Council 2020-22	
President	Dr. Mrutyunjay Mohapatra
Immediate Past President	Prof. Sushil Kumar Dash
Vice President	Dr. Atul Kumar Sahai Sh. Anand Kumar Sharma
Secretary	Dr. D R Pattanaik
Jt. Secretary	Dr. S I Laskar
Treasurer	Dr. Ananda Kumar Das
Member	Ms. Samanti Sarkar Prof. P V S Raju Dr. R K Giri Sh. Sanjay Bist Sh. Sikandar M Jamadar Dr. Satyendra M. Bhandari Dr. Ranjeet Singh Dr. K. Satheesan

The new IMS council (2020-2022) took over the charge on 10th July, 2020 in the General Body meeting conducted virtually. Dr. S. K. Dash, the outgoing IMS president congratulated Dr. M. Mohapatra, the new president of IMS (left). The IMS GB meeting was organized virtually on 10th July 2020 for the new IMS NC to take over the charge from previous IMS NC (right)

Release of Brain Storming Workshop Report:

Indian Meteorological Society (IMS) with joint support from the Ministry of Earth Sciences (MoES), Department of Science and Technology (DST) and India Meteorological Department (IMD) organised a two-day Brain Storming Workshop on ***"Climate Services Workshop: Stake Holder Perspectives"*** during 22-23 March, 2019. These two days happened to be the World Water Day and World Meteorological Day respectively. The five priority areas vulnerable to climate change were discussed during this meeting, those include: (i) Agriculture and Food Security, (ii) Disaster Risk Management, (iii) Energy Availability and Use, (iv) Human Health Impacts and (v) Water Availability and Use.

The meeting was inaugurated by the Secretary MoES, Dr. M. Rajeevan in the presence of President IMS, Prof. S. K. Dash; Director General IMD, Dr. K. J. Ramesh, Climate Scientist Dr. Akhilesh Gupta and Secretary IMS Dr. D. R. Pattanaik.

Participants and invited experts during the workshop

5. General IMS Activities

To achieve the objectives the society stated above involve in carrying out the following work.

- Encourages research activity.
- Organizes lectures, meetings, symposia, discussions etc.
- Arranges to publish suitable pamphlets, books, periodicals, brochures etc.
- Promotes Co-operation in scientific work.
- Encourages the members to foster common interests of the Meteorological professions
- Give awards and fellowship to distinguished scientists.

6. Sponsor Scientific Events and Organization of Symposia/Conferences

To Sponsor Scientific Events

- The Society sponsored for the first time a scientific event in April 1970. This was a symposium on Satellite Meteorology held at Pune.

- Later on it sponsored the International Symposium on Monsoons which held in March 1977 at New Delhi.
- It also sponsored the National Symposium on Early Results of Monsoon Experiments held at New Delhi in March 1981.

Organisation of Scientific Symposia

- With a beginning in 1976 the Society has organised the following National Symposia/Seminars so far:
- Seminar on Weather Modification New Delhi February **1976**
- Symposium of Local Severe Storms Calcutta February **1982**
- Symposium on Tropical Cyclones and Disaster Preparedness Bhubaneswar January **1984**

Annual National Symposia Series on Tropical Meteorology (TROPMET)

- Monsoon Variability, Satellite Application and Modelling, Ahmedabad, February **1992**
- Meteorology for National Development, New Delhi, February **1993**
- Climate Variability, Pune, February **1994**
- Advanced Techniques in Meteorology, Hyderabad, February **1995**
- Meteorology and Natural Disasters, Visakhapatnam, February **1996**
- Symposium on Monsoon, Climate and Agriculture, Bangalore, February **1997**
- Meteorology beyond 2000, Chennai, **1999**
- Ocean & Atmosphere, Cochin, February **2000**
- Meteorology for Sustainable Development, Mumbai, February **2001**
- Forecasting & Mitigation of Meteorological Disasters: Cyclones, Floods & Droughts, Bhubaneswar, February **2002**
- Role of Meteorology in National Development, Pune, **2006**
- Advances in Meteorology and their Applications, Bhopal, **2007**
- Meteorology, Atmospheric Science, Weather & Climate and allied services and disaster management, Kolkata **2010**
- Meteorology for Socio-economic Development, Hyderabad, **2011**
- National Symposium on Frontiers of Meteorology with special reference to the Himalayas. Dehradun **2012**
- National Symposium on Weather & Climate Extremes, Chandigarh – **2015**
- National Symposium on Tropical Meteorology: Climate Change and Coastal Vulnerability, Bhubaneswar **2016**
- National Symposium on Tropical Meteorology: Understanding Weather and Climate Variability: Research for Society, Varanasi **2018**
- National Symposium on Tropical Meteorology: Land, Ocean and Atmosphere Interactive Processes in the Context of Weather and Climate, Visakhapatnam **2019**

- National Symposium on Tropical Meteorology on "Weather and Climate Services over Mountainous Regions" at NESAC, Shillong during 14 - 17 December **2020**.

International TROPMET (INTROPMET) Organised by IMS

- International Symposium on Asian Monsoon & Pollution over Monsoon Environment, (INTROPMET-1997) New Delhi, December 2-5, **1997**
- International conference on monsoon (ICOM) and WMO Workshop on forecasting monsoons from days to years, New Delhi. March 21-26, **2001**
- International conference on Seismic Hazard with particular reference to Bhuj Earthquake of January 26, 2001. New Delhi, 3-5 October, **2001**
- International Symposium on Natural hazards (INTROPMET 2004) February 24-27, 2004, Hyderabad.
- Monex-25, Celebrating 25th Anniversary of Summer Monsoon Experiment-**1979** (Monex-25 and its Legacy), New Delhi, 3-7 February, **2005**
- International symposium on Challenges & Opportunities in Agro-meteorology (INTROPMET – 2009), New Delhi, 23-25 February **2009**.
- International Tropical Meteorology Symposium on Monsoons- Observation, Prediction and Simulation (MOPS) (INTROPMET -2013), Chennai, Originally scheduled in 2013 but was organized during 21-24 February, **2014**.
- International Tropical Meteorology Symposium on Advancements in Space-based Earth Observations and Services for Weather and Climate (INTROMET- 2017), 03-07 November, **2017**, Ahmedabad.

On behalf of NSF, Jay Fein accepts a bouquet expressing thanks from the Indian research community for NSF's support of MONEX-1979. Also pictured are (left to right) Late D. R. Sikka, V. S. Ramamurthy (India Department of Science and Technology), S. K. Dube (Indian Institute of Technology), and Peter Webster (Georgia Institute of Technology). IMS function, Delhi 2005.

Popularisation of Meteorology and Atmospheric Sciences

The various Chapters of the Society Organise the following Programmes :

- Scientific lectures on important topics Weather Quiz for students Publication of Illustrative Weather Calendar-cum-book/Chart etc.
- Publication of articles in newspapers Production of educative video programmes.
- IMS Pune (IMSP) chapter oganises Annual Monsoon Review of southwest monsoon each year regularly.
- Some special events like WMO Day, Earth Day, National Science Day, etc are being arranged by different chapters.

7. IMS Publications

To popularize Meteorology and Atmospheric Sciences, the Indian Meteorological Society (IMS) brings out the Research journal "Vayu Mandal", which is the official Bulletin of IMS. This is brought out twice a year since 1971 to encourage research work and provide information on latest developments in the atmospheric sciences. At present the Chief Editor, Managing Editor and Executive Editor are given below.

Chief Editor:	Prof. S. K. Dash, skdash@cas.iitd.ernet.in, IIT Delhi, New Delhi
Managing Editor:	Dr. D. R. Pattanaik, drpattanaik@gmail.com, IMD, New Delhi
Executive Editor:	Dr. Kamaljit Ray, kamal.ray@nic.in, MoES, New Delhi

The article can be submitted to: **Executive Editor**, Vayu Mandal ***(Email: vayumandal.ims@gmail.com)***

8. IMS Awards and Fellows

8.1 IMS International Award: "Sir Gilbert Walker Gold Medal"

IMS has instituted "Sir Gilbert Walker Gold Medal" In 2001 to be given biennially to an eminent Indian or foreign scientist of international recognition in the field of monsoon studies. There is no bar on the age and nationality. Now the Prize money for this award is Rs. 100000/- and a gold plated silver medals (100 gm weight) and a Citation. The selection will be made by a judging committee with IMS President and minimum two Fellows of IMS as members. Sir Gilbert Walker, the legendary meteorologist who did pioneering and monumental work on long range forecasting of Indian monsoon, was the Director General of India Meteorological Department for 20 years (1904-1924).

List of Sir Gilbert Walker Gold Medal Awardees so far are:

(1) Prof. J. Shukla, COLA, USA

(2) Late Prof. P. K. Das, Former DGM, IMD

(3) Prof. U. C. Mohanty, IIT Delhi

(4) Late Shri. D. R. Sikka, Former Director, IITM, Pune

(5) Late Prof. T. N. Krishnamurti, Professor FSU, USA

(6) Prof. (Mrs) Sulochana Gadgil, IISC, Bangalore

(7) Prof. R. N. Keshavmurty, Former Director IITM, Pune

8.2 IMS National Biennial and Annual Awards

The IMS had instituted three biennial research awards from the endowment gifted by the sponsors viz., Dr. B.N. Desai Award, V. Bhavnanayana Award, J. Das Gupta Award, Dr. P. Krishna Rao and Prof. A.D. Vernekar awards. In 2011 IMS re-designed these awards by increasing the prize money by contributing from IMS along with the endowment gifted earlier by the sponsors. These awards are as per the details given below.

(i) ***IMS Award for Best Paper Published on Monsoon Research (Formerly B.N. Desai Award:*** A Citation and cash prize of Rs.15,000/-.

(ii) ***IMS Award for Best Paper Published on Instruments (Formerly J. Das Gupta Award):*** A Citation and cash prize of Rs.15,000/-.

(iii) ***IMS Award for Best Paper Published on Agrometeorology (Formerly Bhavanarayana Award):*** A Citation and cash prize of Rs. 15,000/-

(iv) ***IMS Award for Best Paper Published on Satellite Meteorology (Formerly P. Krishna Rao Award)***: A Citation and cash prize of Rs. 25,000/-

(v) ***IMS Award for Best Paper Published on Modelling Study (Formerly A. D. Vernekar Award):*** A Citation and cash prize of Rs. 25,000/-

(vi) In addition to above five awards, IMS has also introduced another biennial award viz., **"Vayu Mandal Award"** from (2016-2017) for the best paper published in IMS journal – VayuMandal (Citation & Rs. 15,000/-).

(vii) ***IMS Young Scientist Awards (Annual)***

- ***IMS young scientist award for best paper published on Tropical Meteorology.*** (Citation & Rs. 50,000/-; At least the 1st author should be below 45 years of age)

8.3 IMS National Annual Award Winners

During 2012 IMS has also instituted a young Scientist award (Below 45 years) to be given annually for the Best Paper Published in Tropical Meteorology with a Citation and award money of **Rs. 50,000/- .** List of "IMS Young Scientist Awardees" so far are :

S. No.	Name	Year
1	Dr. Hemant Chaudhary, IITM, Pune	2012
2	Dr. Randhir Singh, SAC, Ahemedabad	2013
3	Dr. D. R. Pattanaik, IMD, New Delhi	2014
4	Dr. Roxy Mathew, IITM, Pune	2015
5	Dr. (Ms.) P Rohini, IITM, Pune	2016
6	Dr. (Ms) Gayatri Kulkarni, IITM, Pune	2017
7	Dr. Siddarth S Das, VSSC, Trivandrum	2018

9. Recent Activities of IMS and Photo Gallery

9.1 TROPMET-2019 in Vsakhapatnam during 11-14 December, 2019

Indian Meteorological Society (IMS) has the tradition of organising Annual Symposium named

TROPMET in one of its 32 Local Chapters. Once in every four years, the same event is held as INTROMET with participation of scientists from countries outside India. The theme of this event alters from year to year depending on the importance of the topic in contemporary weather and climate situation. The main objective of this annual symposium is to provide a platform to students and early career scientists in India to present the scientific results coming out of their research activities during the year and thereby get chance to interact with the experts in the field. The symposium is usually structured in such a way that all the members of IMS get chance to actively participate in it either as chairmen of sessions, plenary speakers, invited speaker, oral paper presenter or poster presenter. This annual event has been the flagship event of IMS for the last several years since 1992 with tremendous success.

TROPMET-2019 entitled *'National Symposium on Land, Ocean and Atmosphere Interactive Processes in the Context of Weather and Climate'* was organized by IMS at Andhra University, Visakhapatnam during 11th to 14th December, 2019. As per the title of TROPMET-2019, the main themes identified for the symposium were; (1) Observations in Climate Variability and Changes, (2) Atmospheric Modelling at Regional and Global Scales, (3) Land-Ocean Interactive Processes, (4) Role of Surface Boundary Conditions in Climate Modelling, (5) Climate, Water and Energy Connections, (6) Impact of Climate Variability/Change on Agriculture, (7) Extreme Weather Events, (8) Weather Forecasting Services at Different Time Scales & Sectoral Applications and (9) Impact of Aerosols on Climate Changes.

This IMS symposium was jointly organised along with IMS Visakhapatnam Chapter and hosted by the Department of Meteorology & Oceanography, Andhra University, Visakhapatnam. TROPMET-2019 was inaugurated on 11th December, 2019 at the Convention Centre of Andhra University by Dr. M. N. Rajeevan, Secretary, Ministry of Earth Sciences (MoES), Government of India (GoI) as Chief Guest in the presence of Prof. P.V.D.G. Prasad Reddy, Vice-Chancellor, Andhra University who was the Distinguished Guest. Dr. S. K. Dash, President IMS presided over the Inaugural Function. The event took place in the presence of Dr. M. Mohapatra, Director General IMD and Dr. Akhilesh Gupta, Advisor Department of Science and Technology (DST), GoI on the dais. The symposium had the international flavor with the participation of Prof. T. Hayashi, DPRI and Prof. T. Narita both from Kyoto University, Japan; Dr. Michael Caruso, USA and Prof. Ibrahim Hoteit, KAUST, Saudi Arabia.

Prof. SSVS Ramakrishna, Chairman of IMS Visakhapatnam Chapter welcomed the dignitaries and participants to the event and gave a glimpse of the origin of TROPMET-2019 starting from the proposal to hold it in Visakhapatnam to the detailed scientific programme. Dr. D.R. Pattanaik, Secretary IMS narrated the activities of IMS highlighting the themes of TROPMET-2019. In his opening presidential address Prof. S. K. Dash, President of IMS stressed on the importance of Meteorology Education and Training programmes by the local chapters of IMS by organising various courses of different durations targeted towards school children, teachers, stake holders and general public. He mentioned about Global Campus Initiative of WMO and also COMET programme. Prof. P. Suneetha, Head, Department of Meteorology & Oceanography, Andhra University narrated the activities of the department. Dr. Akhilesh Gupta in his remarks highlighted the contribution of the Department of Meteorology & Oceanography, Andhra University in producing several world class Meteorologists and Oceanographers. He encouraged Andhra University to set up a Centre of Excellence in Climate Studies. Dr. M. Mohapatra reiterated the commitment of India Meteorological Department to Weather Forecasting in particular and Meteorology

Education and Research in the country in general and briefly elucidated the measures taken in these directions. Prof. Prasad Reddy in his speech promised that Andhra University will welcome setting up of a Centre of Excellence on Climate Studies if sponsored by the Government of India. He also promised all sorts of institutional support for such an effort.

In his Inaugural address Dr. M. Rajeevan emphasized the need for extensive climate studies since the world is experiencing a sea change in terms of climate change and weather extremes. He expressed the interest of MoES in the growth of weather and climate related activities in India. He congratulated IMS for various types of activities undertaken and also assured all sorts of support for further growth. Finally, Dr. C.V. Naidu proposed vote of thanks. The inaugural function included the presentation of IMS International Award called Sir Gilbert Walker Gold Medal, IMS Fellowships & Associate Fellowships and Annual & Biennial Awards to the young researchers for best papers published in reputed journals. The list of awards/fellowships presented to distinguished scientists are given in Table 1. IMS thank NCMRWF, Noida on becoming an institutional patron and in this regard a certificate of appreciation was presented by IMS to Dr.. E. N. Rajagopal, Head NCMRWF in this function The book entitled 'Basics of Atmospheric Dynamics' written by Prof. R. N. Keshavamurty was released in the Inaugural Function along with the recent issue of VayuMandal.

S. No.	Award/Fellowship	Awards Winners
1	Sir Gilbert Walker Gold Medal	**Prof. R. N. Keshavamurty** Former Director, IITM, Pune
2	IMS Fellowship	**Dr. Mrutyunjay Mohapatra** Director General, India Meteorological Department
3	IMS Fellowship	**Prof. S.K. Satheesh** Indian Institute of Sciences (IISc), Bangalore
4	IMS Fellowship	**Dr. (Mrs.) N. Jayanthi** Former, Additional DGM, IMD
5	IMS Fellowship	**Dr. Govindarajalu Srinivasan** Chief Scientist, Climate Applications RIMES, Thailand
6	IMS Associate Fellowship	**Prof. Sandeep Pattnaik** Indian Institute of Technology, Bhubaneswar
7	IMS Associate Fellowship	**Dr. Ayantika Dey Choudhury** Indian Institute of Tropical Meteorology, Pune

AWARDS FOR BEST PAPERs		
8	IMS young scientist award for best paper published on Tropical Meteorology	**Authors : Siddarth Shankar Das, K.V.Suneeth, M.V. Ratnam, I.A.Girach and S.K.Das** **Paper :** "Upper tropospheric ozone transport from the sub-tropics to tropics over the Indian region during Asian summer monsoon, Climate Dynamics, Vol No.52 Issue: 7-8 , Page No. 4567-4581, 2018.

9	IMS Award for best paper published on monsoon research (Formerly B N Desai Award)	**Authors : Supriyo Chakraborty, A. R. Belekar, A. Datye and N. Sinha** **Paper :** entitled "Isotopic study of intra-seasonal variations of plant transpiration: an alternative means to characterize the dry phases of monsoon, Scientific Reports, Vol No. 8, Page No.8647, 2018.
10	IMS Award for best paper published on Atmospheric observations and Technology (Formerly J Das Gupta Award)	**Authors : P. P. Leena, V. Anilkumar, N. Sravanthi, R. Patil, K. Chakravarty, S.K. Saha and G. Pandithurai** **Paper :** entitled "On the precipitation susceptibility of monsoon clouds to aerosols using high altitude ground-based observations over Western Ghats, India, Atmospheric Environment, Vol No. 185, Page No.128-136, 2018".
11	IMS Award for best paper published on Weather and Climate Services (Formerly Bhavanarayana Award)	**Authors : H.R.Biswas and P.K. Kundu** **Paper :** A principal component analysis based model to predict post-monsoon tropical cyclone activity in the Bay of Bengal using oceanic Niño index and dipole mode index, International Journal of Climatology, Vol No. 38, Page No.2415-2422, 2017".
12	IMS Award for best paper published on Application of Satellite data in Meteorology and Remote Sensing (Formerly P Krishna Rao Award)	**Authors : K. V. Subrahmanyam and Karanam Kishore Kumar** **Paper :** "Vertical structure of stratocumulus clouds and associated dynamics over the Arabian Sea during Indian summer monsoon season, Journal of Applied Remote Sensing, Vol No. 12(1), Page No. (016018)1-10, 2018."
13	IMS Award for best paper published in IMS Journal Vayumandal	**Authors : Sanjib K. Deb, Dineshkumar, K. Sankhala and Chandra M. Kishtawal** **Paper :** "Retrieval of Atmospheric Motion Vector using INSAT-3D and INSAT-3DR Imager Data in Staggering Mode, VayuMandal, Vol No. 44 No.2, Page No. 32-47, 2018."

Fellows, Associate Fellows, Life Members, Senior Scientists and Young Researchers and Students from various Indian Universities and research organizations participated in this symposium. In addition, selected scientists from the industries such as IBM and Skymet also attended the symposium.

To recognize the contributions of late Prof. P. Koteswaram to the field of meteorology, a memorial lecture was organized by IMS in his name. After the inauguration of TROPMET-2019, Prof. P. Koteswaram's Memorial lecture was delivered by Dr. M. N. Rajeevan on "Global Climate Change: Causes, Concerns and Commitments".

During the 4 days of the Symposium, there were 15 Plenary Talks delivered by several eminent scientists which include Dr. M. Mohapatra from IMD, Dr. Akhilesh Gupta from DST, Dr. E.N. Rajagopal from

NCRMWF, Prof. S.K. Satheesh from IISc, Dr. G. Srinivasan from RIMES, Thailand, Dr. R.K. Mehajan from DST-SERB, Prof. A.D. Rao from IIT Delhi, Prof. Hayashi from Japan, Prof. Ibrahim Hoteit from Saudi Arabia, Dr. A.K. Sahai from IITM, Prof. T. Narita from Japan, Prof. D.V. Bhaskar Rao from Andhra University, Dr. R.R. Rao from NPOL (Retd) and Dr. K. Rupa Kumar from IITM. Special invited talks were also given by Dr. R. K. Dutta from IMD, Prof. K. Ashok from University of Hyderabad, Dr. A. Suryachandra Rao from IITM, Dr. M.V. Ratnam from NARL, Dr. D.R. Pattanaik from IMD and Prof. Someshwar Das from University of Rajasthan.

There were 260 Oral presentations and there were 80 poster presentations spread over four days.

The organizing committee conducted all the oral presentations under the above said themes in three parallel sessions each equipped with 10x20 LED screen. 40 Poster presentations were arranged every day of the symposium from 12th December, 2019. The researchers from Northeast India especially from Kohima University actively participated and one of the participants also got the IMS Best Paper Presentation award.

The valedictory function of the TROPMET-2019 was conducted in the afternoon of 14th December, 2019. Sri. N. Sambasiva Rao, Chief Executive Officer-Gangavaram Port, Visakhapatnam was the Chief Guest and the Distinguished Guest was Prof. V. Krishna Mohan, Registrar, Andhra University. The Organizing Committee distributed the Awards for Best Paper and Best Poster Presentations to the Research Students, Researchers and Young Scientists. All the participants express their views and appreciations to the organizing committee for the Grand Success of the TROPMET2019. Overall, TROPMET2019 left behind a good example for the next TROPMET-2020 to be held at Shillong.

The Organizing Committee unanimously thanked the major sponsors of the symposium: MoES, DST, IMD and NCMRWF. Thanks are also due to the Weather Company IBM, Skymet Weather-wise and also some local sponsors: Gangavaram Port and K. Kumar Raja Projects (P) Ltd, Visakhapatnam for their financial supports for successful completion of the mega event TROPMET-2019.

Dignitaries during the Inaugural Function of TROPMET-2019 (left) and Chief Guest, Dr. M. N. Rajeevan, Secretary, MoES addressing the audience (right)

Photos of Award Ceremony during TROPMET-2019

Presentation of Gilbert Walker Award to Prof. R. N. Keshavamurthy (left) and Award of IMS Fellowship to Dr. M. Mohapatra, DGM IMD.

Delegates attending the TROPMET-2019 proceedings

9.2 TROPMET-2020:

TROPMET-2020 is being jointly organized and hosted by North Eastern Space Applications Centre (NESAC) and IMS – Shillong Chapter at Shillong, popularly known as the Scotland of the east. TROPMET-2020 is organized under the theme "Weather and Climate Services over Mountainous Regions". During 2020, due to the COVID-19 pandemic, the TROPMET is planned virtually for the first time. The Atmospheric processes over Mountainous Regions are different and therefore needs a different analysis and modeling approach to address the complexities of such terrains and provide weather and climate services. Such terrains are also more prone to extreme weathers and climate change causing the population in such terrains more vulnerable. Keeping these facts in mind, TROPMET-2020 will make efforts to bring together atmospheric scientists, oceanographers, agricultural scientists, policy makers, disaster managers and other related experts to discuss and share knowledge, experience, and information for the benefit of the society.

TROPMET-2020 has the following sub-themes:

T - 1	:	Dynamics and Physics of orographic clouds and precipitation
T - 2	:	Lightning Physics and Forecasting
T - 3	:	Numerical weather prediction, data assimilation, and forecasting in complex terrain
T - 4	:	Monsoon prediction and dynamics over complex terrain
T - 5	:	Boundary layers and turbulence in complex terrain
T - 6	:	The Mountain Cryosphere (snowpack, glaciers, avalanches, etc.)
T - 7	:	Climate change and variability over complex terrain
T - 8	:	Land-Ocean-Atmosphere Interactive Processes
T - 9	:	Weather and climate services for farmers
T - 10	:	Impact of Climate Variability/Change on Agriculture
T - 11	:	Hydro-meteorological disasters and management
T - 12	:	Artificial Intelligence, Machine Learning, and Deep learning in weather and climate research and services
T - 13	:	Remote Sensing of Atmosphere, geophysical parameter retrieval, calibration, and validation
T - 14	:	Aerosol-cloud-precipitation interactions
T - 15	:	Weather and Climate for human health
T - 16	:	Indigenous instrumentation for atmospheric profiling (Radars, Sodars, Lidars, weather station, etc.)
T - 17	:	Severe weather and complex terrains

10. IMS Lectures

1. Dr. Jeffrey Kargel, Senior Scientist at the Planetary Science Institute in Tucson, Arizona, USA was invited to deliver IMS Lecture on 14th November, 2019 at ARNAV Hall, Ministry of Earth Sciences, Prithvi Bhawan. The title of his lecture was "Changing Climate is causing several very different kinds of hazardous glacier and landslide dynamics in High Mountain Asia" He discussed on the changes in climate happening world over emphasizing on the state and recent dynamics of glaciers in the Himalaya-Karakoram. He described difficulties in accessing Indian glaciers and reconciling glaciological and

Dr. Jeffrey Kargel, Senior Scientist at the Planetary Science Institute in Tucson, Arizona, USA during the IMS seminar geodetic mass balances based on objective data quality assessment. He dwelt on several published papers on climate change related issues such as diarrhea out break in Nepal, agricultural stubble waste burning in Punjab and other major sources of air pollution based on satellite imagery. The important messages from his lecture are the secular trends in 30-year climate and changes in (i) Short-term weather which indicates that previously uncommon weather phenomena are becoming common, (ii) Extreme weather is becoming more frequent and more extreme changing weather and new weather patterns are a part of climate change and (iii) Every region of the globe has its unique climate change story since every part of the globe is feeling the effects of changing atmosphere and oceans. Not only we observe the changes in the data but also people feel these unusual weather themselves. The good point is that the Earth scientists are working creatively to fill in the gaps in knowledge and understanding.

2. Mr. R. C. Bhatia, Retired ADGM, IMD was invited to deliver IMS Lecture on "Recent Satellite-based Observations on Western Disturbances: their genesis, evolution, interactions, movements and impact on Indian Weather" on 13th February 2020 at DGM Conference hall, IMD. He discussed the developments in the last 5 years on the availability of satellite based data and products. He focused on the details of few recent Western Disturbance cases highlighting some important satellite related features seen in those events. Mr. Bhatia very lucidly described how critical monitoring & analysis of 15 mt/ 1hr animation sequences of M-8 images /RGB products of M-8 coverage provides lot of useful inputs for better understanding of WDs. He further stated that AMVs and Rain rate products are also useful. He inferred that a large number of WDs quite often indicate preferred areas for initial genesis of WDs in the Eastern periphery of large upper-air anticyclones over Europe & adjoining Northern parts of Asia. Indications of their possible initiation can be very well seen in WV images and air mass products right from the early stages. Genesis in the form of a trough in the Weserlies and/or in the form of a circulation which forms at the tip of the trough can generally be very well delineated from the satellite derived wind products. As per his seminar, use of other satellite products such as divergence, convergence, relative vorticity at various levels is also found to be beneficial for improved analysis.

3. IMS Fellowship to Dr. (Mrs.) N. Jayanthi

Due to the availability of Dr (Mrs.) N. Jayanthi in IMD, New Delhi on 13th Feb 2020, a special event was organised by IMS to present IMS Fellowship to her. It may be noted here that although her Fellowship was announced in Tropmet-2019 held at Visakhapatnam, it could not be presented to Dr. Jayanthi since she could not attend the annual symposium.

Award of IMS Fellowship to Dr. (Mrs.) N. Jayanthi

ACTIVITIES REPORTS OF DIFERENT IMS CHAPTERS

11. IMS Ahmedabad (IMSA) Chapter

11.1 Annual Monsoon Lecture 2019 on November 15, 2019: Every year after the completion of Indian summer monsoon (June-September) season, IMSA organizes popular lecture by inviting an eminent scientist involved in monsoon forecasting from IMD. This year also, IMSA organized a popular talk on the topic "2019 South West Monsoon Season: Rainfall Features and Long Range Forecast" at SAC Ahmedabad. The lecture was attended by around 80 students, research trainee and scientists of SAC and Physical Research Laboratory (PRL) Ahmedabad along with members of IMSA. On this occasion Secretary IMSA, Dr. Sanjib K. Deb welcomed all members who have assembled for the function. The Chairman IMSA, Dr. C. M. Kishtawal introduced the speaker of the event, Dr. D. S. Pai, Head, Climate Research and Services, IMD, Pune. The prizes to the winners of Monsoon Photography Contest 2019 were also distributed after the lecture. IMSA newsletter E-Megha Monsoon 2019 issue was also released.

Dr. A. K Varma delivering the lecture

11.2 Vikram Sarabhai Birth Centenary Programme on February 18, 2020: IMSA and Christ College, Rajkot jointly organized a half-day outreach programme on February 18, 2020 at Christ College, Rajkot to celebrate the birth centenary of Dr. Vikram A. Sarabhai. Around 80 participants including students and faculties from Christ College Rajkot attended the event. Dr Sanjib K. Deb, Secretary IMSA briefed about the activities of IMSA to the audience, Dr C. M. Kishtawal, Chairman IMSA briefed about Dr. Vikram Sarabhai and his contribution to Indian Space programmes and narrated as to why IMSA celebrated this event. It was followed by a popular lecture on "Applications of remote sensing for meteorological phenomena" delivered by Dr. A. K Varma. At the end of the programme, one documentary on contribution of Dr. Vikram Sarabhai to Indian Space programmes was screened for the student of Christ College. This event was appreciated by both students and faculties of Christ College, Rajkot.

12. IMS Chennai (IMSC) Chapter

12.1 Monsoon Seminar: The Seminar on Monsoons held annually was organised for the Monsoon 2019 on 10 February 2020 jointly by IMS Chennai Chapter and Regional Meteorological Centre, Chennai. 30 students from two city colleges, Women's Christian College and Loyola College were invited to attend the Monsoon 2019 seminar as part of the Outreach Programme to popularise Meteorology. Two Ph.D. research scholars from SRM University also attended the meeting. The students interacted with the experts present and posed various questions to the Chief Guest Dr K. Satyagopal, IAS, Chairman & Managing Director, Tamil Nadu Water Resources Conservation and Rivers Restoration Corporation, Government of Tamil Nadu. The Review of South West Monsoon 2019 was also presented by Dr. N. Puviarasan, RWFC and Dr. S. Balachandran, Head, RMC Chennai. Further, the performance of Northeast Monsoon 2019 was reviewed.

12.2 The Newsletter of IMS Chennai Chapter "Breeze": Two issues of Breeze Vol.19-2 & Vol.20-1 were circulated to the members on 2 May (http://www.imdchennai.gov.in /IMSWEB/imsimd/ims_imd.html) 2020. Articles written and the collection of photographs featured in Breeze are tribute to Late Shri. S. Raghavan, IMS Fellow and Life Member who received appreciation from all the members. A list containing names of Chairman, Secretary and Treasurer from 1997-1999 up to 2018-20 was prepared and included in Breeze.

Dr. S.Balachandran felicitated by Dr. R.Suresh

13. IMS Guwahati (IMSG) Chapter

National Science Day was celebrated in the Regional Meteorological Centre, Guwahati on 28th February 2020. The theme of this year was 'Women in Science'. Dr. Rousy K. Baruah, State Project Manager, Assam State Rural Livelihood Mission, Guwahati was the Chief Guest of the function. Sri Ajay Narayan, PGT, Geography, Kendriya Vidyalaya, Borjhar, Guwahati was the Guest-of-Honour. On this occasion, Dr. Sanjay O'Neill Shaw, DDGM, RMC

Ajay Narayan, Dr. Sanjay O'Neill Shaw, Dr. Rousy K. Baruah and Ms Sandipa Bhattacharya

Guwahati delivered a lecture on the contribution of women in the field of Science and Technology. Dr. Rousy K. Baruah, in her presentation, stressed on giving opportunities to females in their families to expand their wings. The programme was anchored by Ms. Sandipa Bhattacharya. Vote of thanks was proposed by Ms. Anamika Sarma, Scientific Assistant.

14. IMS Pune (IMSP) Chapter

14.1 Lecture: IMSP organized a Special Lecture by Prof. Sulochana Gadgil (renowned Monsoon Meteorologist & Professor, CAOS, IISc., Bengaluru) on 23rd September 2019 at Meghdoot Complex of IITM Pune. The title of her lecture was "Summer Monsoon of 2019: How and Why?".

14.2 One-day Workshop: In association with NRSC-ISRO Hyderabad and IITM Pune, IMSP organized an one-day workshop on "National Information system for Climate and Environment Studies (NICES) and its activities" at Meghdoot Complex of IITM Pune on 8th January 2020. The workshop was sponsored by NRSC (ISRO) Hyderabad and was jointly organized by NRSC, IMS Pune Chapter (IMSP) and IITM Pune. The workshop had been a grand success. About 400 participants attended the workshop. Lectures were delivered by 3 NRSC (ISRO) Scientists (Faculty: Dr. Hareef Baba Shaeb, Dr. S. S. Prijith and Dr. S. Rajesh) and 3 IITM Scientists (Mr. Mata Mahakur, Mr. Somnath Mahapatra and Dr. Amita Prabhu) and were highly appreciated by the audience. The event was coordinated by Dr. Dibyendu Dutta, Dr. M.V.R. Seshasai and Dr. Hareef Baba Shaeb from NRSC side and Mr. S. Mahapatra, Dr. J. R. Kulkarni and Dr. G. Pandithurai from IMSP side. IMSP received great support from Director IITM and IITM administration for organization of this event.

14.3 Colloquium: In association with IITM Pune, IMSP organized a Colloquium by Dr. Francesco Doblas Reyes, Director, Earth Sciences Department, Barcelona Super Computing Center, (Centro Nacional de Supercomputacion, BSC), Barcelona (Spain) at Varahamihira Hall of IITM Pune on 22nd February 2020 (Saturday), during 14.30 to 15. 30 Hrs. IST (2:30 - 3:30 pm) Topic of the talk was " FROM THE BYTE TO THE SERVICE: TRANS-DISCIPLINARY CLIMATE RESEARCH ".

IMS Pune Chapter organising the Annual Monsoon Workshop

14.4 Special Lecture: In association with IITM, IMSP organized a Special Lecture by Dr. Eng Lim

Goh, Senior Vice President of Hewlett Packard Enterprises (HPE) USA, at Meghdoot Auditorium of IITM Pune on 2nd March 2020. The Title of the talk was "From IoT to Machine Learning, Simulation and Exa-scale". Dr. Eng Lim Goh is Senior Vice president and Chief Technology Officer for Artificial Intelligence at Hewlett Packard Enterprise (HPE) and has vast experience in in Artificial Intelligence. The lecture was attended by about 250 participants.

14.5. Pisharoty Distinguished Lecture: In association with IITM, IMSP organized Prof. P. R. Pisharoty distinguished lecture by Shri Ashish Lahiri, famous writer and Lexicographer from Kolkata at Meghdoot Auditorium of IITM Pune on 6th March 2020. The title of the lecture was "Life and works of Sri Radhanath Sikdar: a Pioneer Indian Meteorologist of 19th Century, who measured the height of Mt. Everest". The above lecture was preceded by an introductory address & short lecture by Dr. R. R. Kelkar, Former DGM, IMD. The event was attended by about 250 persons and was highly appreciated by the audience.

14.6 Bulletin of IMSP (BIMSP): So far, IMSP has made online publications of several issues of BIMSP such as "April 2019 issue, Vol. 18, No. 4", "May 2019 issue, Vol. 18, No. 5", Vol.18, No. 6-9, June-September 2019 Special issue etc. Mr. S. Mahapatra contributed in editing & preparing these issues of BIMSP and Mr. Sanjay Sonporate contributed for uploading these on IMSP website.

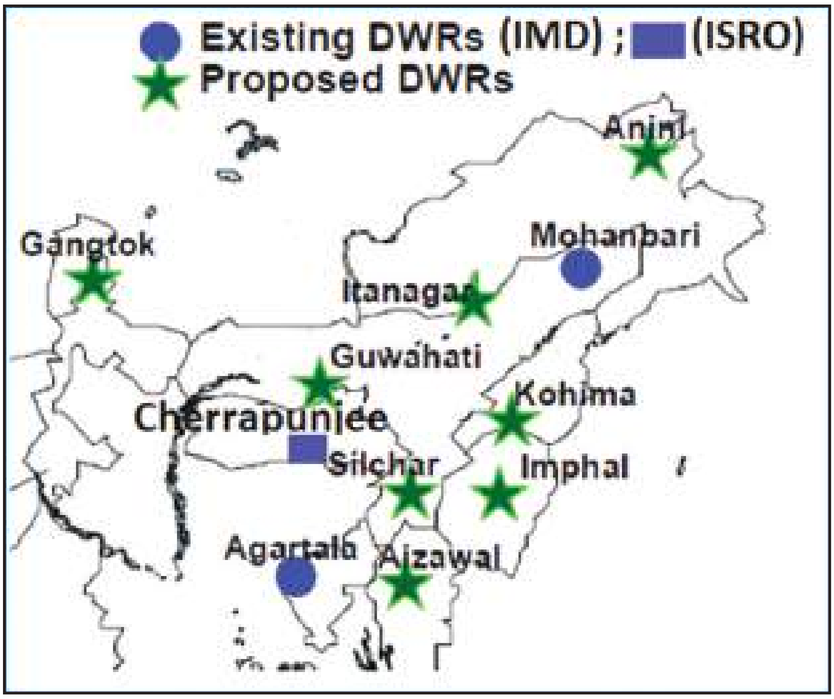

Mr. Ashish Lahiri visiting Faculty IISER, Kolkata delivering the lecture

14.7 WhatsApp Group: IMSP has been maintaining a WhatsApp group and information sharing (on scientific matters, especially related to Earth Sciences) among the IMSP Life members. This group has more than 170 members (including some members from IMS NC also). Mr. Sikandar Jamadar, NEC Member, IMS NC has been very active in coordinating and administrating this WhatsApp group and Dr. J. R. Kulkarni, Chairman IMSP has been very active in explaining various science questions in the group.

14.8 In association with IITM and Co-organizers S. P. Pune University, IMSP EC made lot of efforts for organization of "Annual Monsoon Workshop (AMW-2019) and National Symposium on Cloud and precipitation processes" (which was scheduled during 12-14 March 2020) and there were several EC meetings of IMSP in this regard, with consultations from Dr. A. K. Sahai, Vice President, IMS, Mr. Sikandar Jamadar, Member, IMS NC and S. P. Pune University organizing team. IMSP EC, especially Dr. Devendraa Singh, Joint Secretary and Mr. Samuel Jose, Treasurer had contributed a lot for organization of this event. However, the event was postponed. The decision to postpone the event was taken in view of Covid-19 outbreak and corresponding Government advisories in the interest of the nation. The decision was communicated to IMSP members and other stakeholders immediately on 9th March 2020.

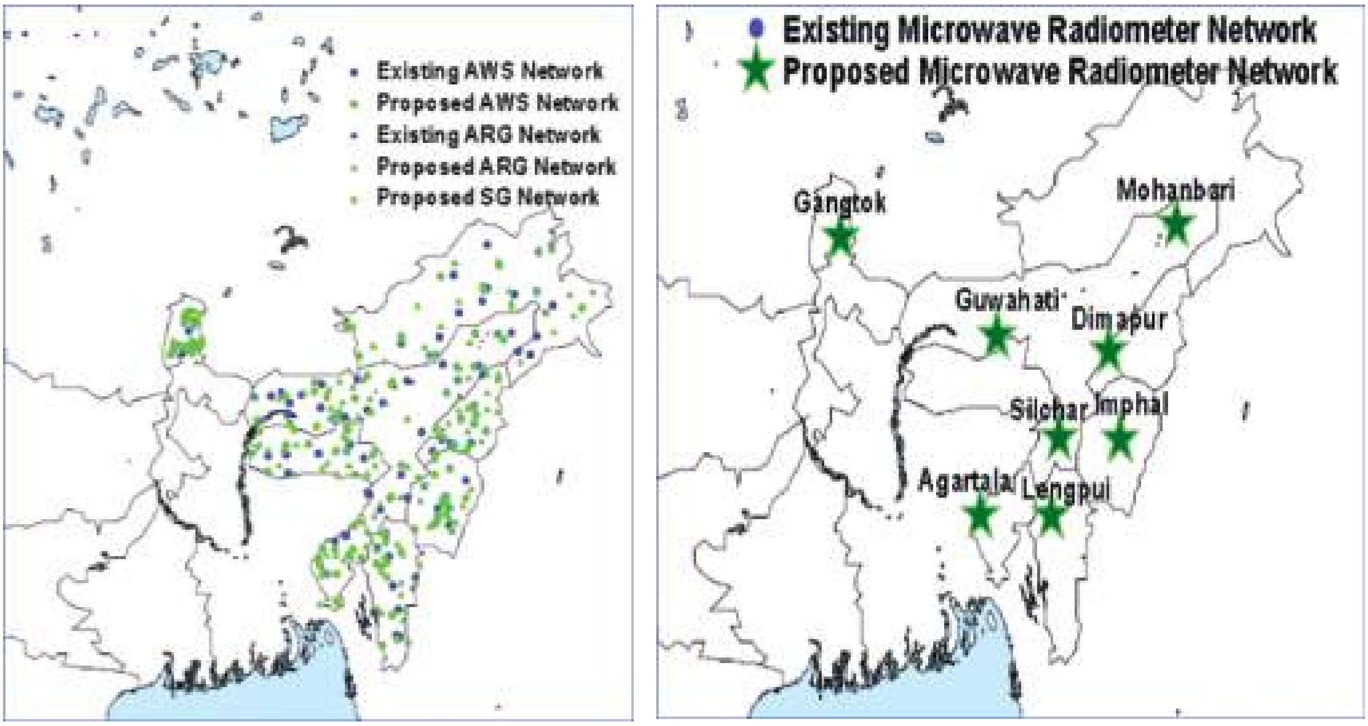
Integrated Meteorological Services for North-East (NE) region aimed at improving weather and climate services over the region

There is an urgent need of integrated approach for improving the meteorological services over northeastern region in a holistic manner. More precise local forecasts need to be generated by assimilating additional observations locally and running a very high resolution model. Entire observational networks need to be augmented to improve the weather & forecasting skills over the region by commissioning of state of art systems like Doppler Weather Radar, GPS sonde systems, Snow Gauges, and augmentation of Automatic Weather Stations, Automatic Rain Gauges etc in NER. This will include setting of observational network required for meeting aviation & other requirements, setting up Meteorological Centres (MCs) and other facilities over the region. Improved weather & forecasting skills will enable to meet the demands of various specific requirements related to weather and climate for Agriculture, Tourism, Mountaineering, Disaster Authority, Sports & Adventure, Voyages, Transport, Government Authority, NGO and Public in general.

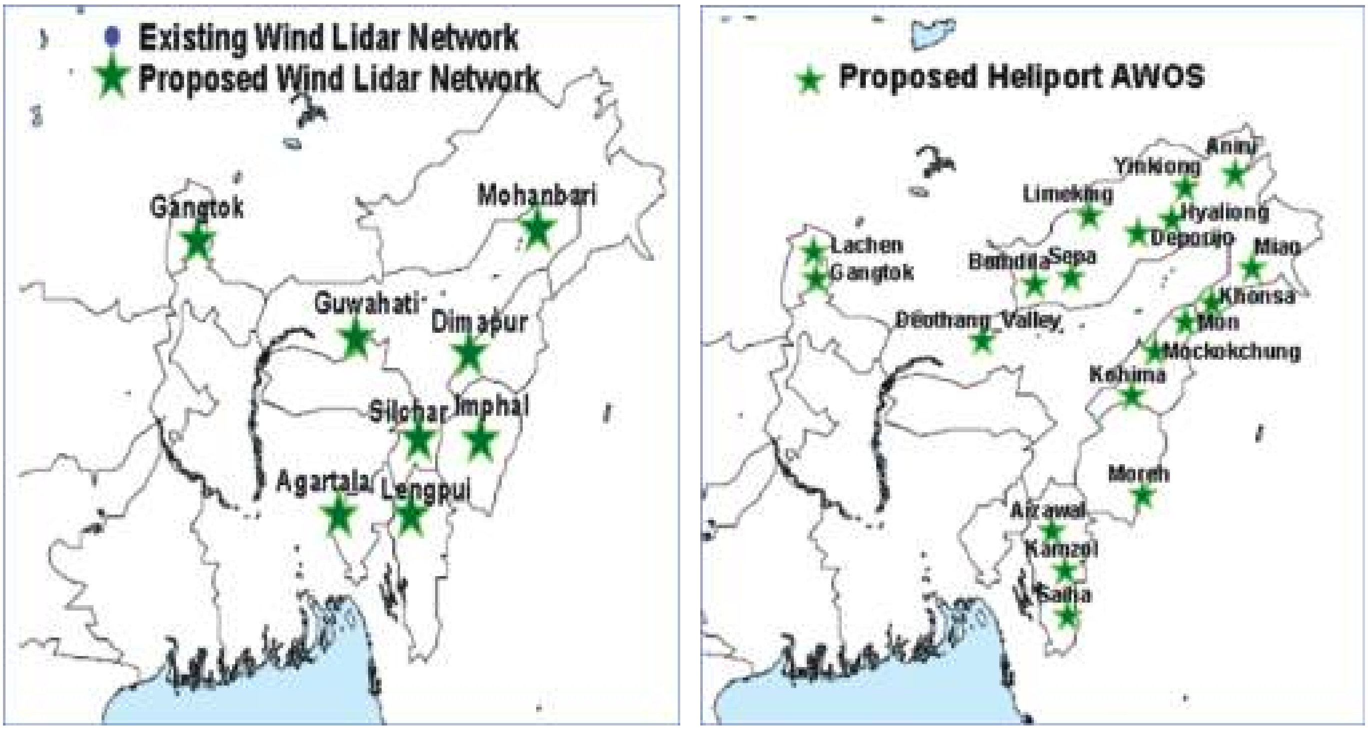


Existing and Proposed DWRs in North-east Region

Infrastructure facilities will be arranged for installation of systems, wherever required. Various locations in the northeastern region are subjected to the power cuts and fluctuations. Instruments to be installed are very sensitive to power fluctuations. Online UPS will be provided to these stations. To ensure the continuous operations of the Radars & Upper Air Observations, provision of Generator supply will also be kept. Test equipments will also be provided to stations for taking up the first level of maintenance. New Meteorological Centres (MCs) will also be established in the Northeast Region and some of existing MCs will be upgraded to provide meteorological services covering entire northeastern region. All MCs will be operated from the corresponding DWR building in the state capital, which will be headed by senior scientists.



Existing and Proposed AWS/ARG (left) and existing and proposed Radiometer Network (right)



Existing and Proposed Wind Lidar Network (left) and Proposed Heliport Aviation Weather Observing Systems (AWOS) network (right)

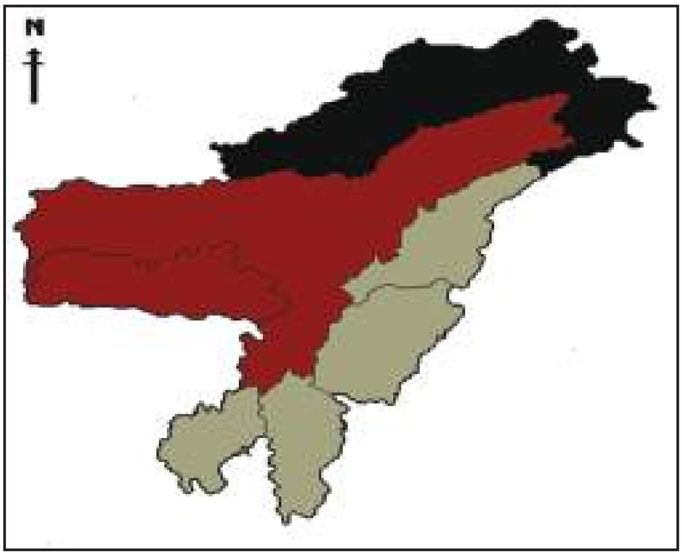
'Meteorological Sentinel of North East India' – Regional Meteorological Centre, Guwahati

Introduction

The Meteorological observatory Guwahati shifted to Borjhar Airfield, New ATC Building from Kahikuchi on 01-01-1953. Later It was upgraded to "Meteorological Centre" on 25-03-1974 and subsequently further upgraded to RMC on 01-04-1997. It renders the meteorological services to three meteorological sub divisions

1. Assam & Meghalaya
2. Arunachal Pradesh
3. Nagaland, Manipur, Mizoram & Tripura.

Which includes 7 states Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura. There are 17 field offices under administrative, technical and financial control of RMC Guwahati.



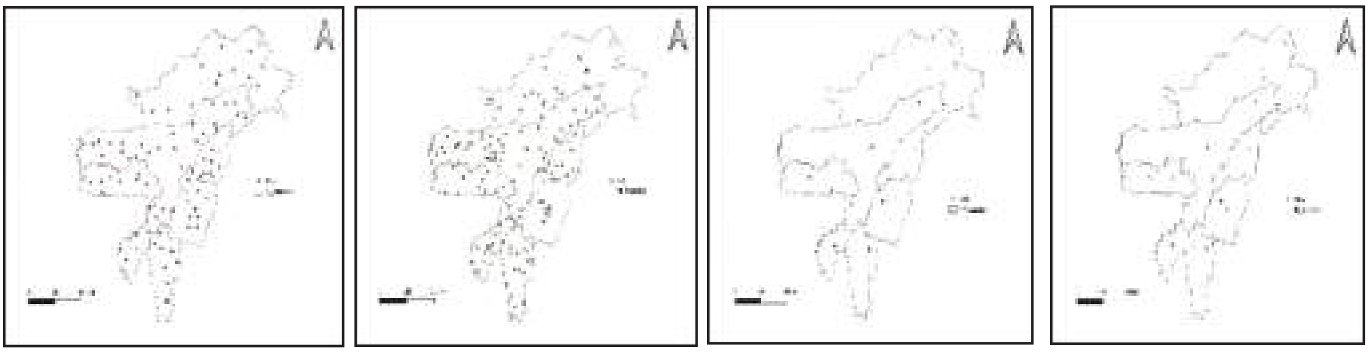
Meteorological Sub division of NE India 2

Observation Network in North East

Regional Meteorological Centre, Guwahati caters to the meteorological requirements of North Eastern part of India with extensive density of observation network three meteorological sub division which includes the states of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura which are as follows:

1. Surface Observatory – 16 nos.
2. Upper Air Observation Network
   a) GPS based RS/RW Network – 8 nos.
   b) PBO Network – 3 nos.
3. Doppler Radar – 3 nos.
4. Automatic Weather Station – 74 nos.
5. Automatic Rainguage - 124 nos.

Apart from this, meteorological Data are collected from several Part time observatories, AWS of different of departments, rainfall data from state government observatories and Central Water Commission.



Activities of Regional Meteorological Centre, Guwahati

Due to complex topography of North East India and pertaining weather variability and communication challenges, Regional Meteorological Centre, Guwahati caters to the meteorological requirements of the states of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura by supervising and coordinating the weather services in these states. Weather forecast (both aviation and non-aviation) for optimum operation of weather sensitive activities like Civil Aviation, Power, agriculture, irrigation, aviation, tourism etc. and warnings against severe weather phenomena like heavy rains, thunderstorm, strong winds etc., which cause destruction to life and property are rendered by this centre. Necessary Meteorological services for air navigation, towards the safety of aircraft operation in these states, is provided by 3 nos. of Airport Meteorological Office and 5 nos. of Aviation Meteorological station of this office. The following activities are carried by RMC, Guwahati which are as follows: -

Weather Forecast

i) Regional Forecast: Forecasts are issued for three meteorological sub-division in Northeast region viz. Arunachal Pradesh, Assam& Meghalaya and Nagaland, Manipur, Mizoram & Tripura validity for 5 days with 2 days outlook.

ii) District level forecast.

iii) Location specific local forecast.

iv) Location specific forecast for tourist places.

Heavy Rainfall Warning

Heavy rainfall warnings are issued in color code (Green/Yellow/Orange/Red) in district wise to SDMA and District Collectors, and so that the disaster management machinery can be kept in readiness.

QPF for Flood Forecast

From 1st March to 31st October every year Flood Meteorological office of RMC, Guwahati issues Bulletin with Quantitative precipitation forecast for 3 days of 3 basin and 17 sub-basins to Central Water Commission which act input for Hydrological model for Riverine flood forecasting.

Nowcast Warning

Issues 3 hourly nowcast warning during thunderstorm in English, Hindi and local language. Warning contains information about issue time, Validity (3 Hours), occurrence of Thunderstorm, associated with lightning, hail, squally wind and heavy rainfall over districts of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura. Warnings are issued to SDMA, District Collectors.

Ferry forecast

Nowcast for seven ferry routes along the River Brahmaputra and one along the river Barak of Assam to Inland Water Transport Department, Govt. of Assam.

Agriculture Bulletin

Agromet Advisory services Bulletin for farmers of North east India through AMFU and SAU.

Aviation Weather Forecast

Warning & Current Weather products are issued to 8 Airport of North East India from three AMO and five AMS offices.

Weather Reports

Daily weather report & Weekly weather report of realized weather in seven state of North East India is prepared by RMC, Guwahati for records, decision making and future planning by state government based on weather reports

Future Plans

India Meteorological Department under MoES has prepared roadmap for enhancement of meteorological observations in North-eastern part of India. A large number of AWS, DWR, agro-AWS, disdrometers, snow gauges, AWOS, HAWOS, microwave radiometers, wind lidars etc. are being installed. After installation of such instruments, a good networks of different types of observations will be available for both aviation and non-aviation weather forecasting as well as for research purposes.

About NESAC

The North Eastern Space Applications Centre (NESAC), an autonomous organisation under Department of Space (DOS), Government of India was set up at Umiam, Shillong, Meghalaya on September 5, 2000 as joint initiative of DOS and the North Eastern Council (NEC). Since its inception, the centre has provided dedicated service to the North Eastern Region (NER) of India comprising of eight states viz. Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura. The centre was set up with a vision to play the catalytic role in holistic development of NER of India by providing Space Science and Technology support on natural resource management, infrastructure planning, healthcare, education, emergency communication, disaster management support, and space and atmospheric science research. The major objectives of the Centre are: 1) To provide an operational remote sensing and geographic information system aided natural resource information base to support activities on development / management of natural resources and infrastructure planning in the region. 2) To provide operational satellite communication applications services in the region in education, health care, disaster management support, and developmental communication. 3) To take up research in space and atmospheric science area and establish an instrumentation hub and networking with various academic institutions of NER. 4) To enable single window delivery of all possible space based support for disaster management. 5) To set up a regional level infrastructure for capacity building in the field of geospatial technology.

NESAC is equipped with geospatial technology Lab and required equipment for supporting satellite communication activities for societal applications, including emergency communication facility like VPN under ISRO-DMS network, Satellite Mobile Radio (SMR) etc. The center is equipped with, a Micro Rain Radar, Disdrometer, a large network of Automatic Weather Stations (AWS), Aethalometer, a Multi-Wavelength Radiometer (MWR), a SODAR, balloon launch facility, a Mini Boundary Layer Mast, online trace gas analyzer, 32 m tower with Sonic Anemometer at four levels, etc. under Space and Atmospheric science programme. A dual polarimetric Doppler Weather Radar in S-band is also operated by the centre. The Centre is having a few of Unmanned Vehicles (UAVs - rotary and fixed wing types) for undertaking very high resolution aerial surveys. The Centre has been certified as ISO 9001:2015 standard institution.

During 2 decades of its existence, with a small team of scientific human resources, NESAC has evolved as a unique centre by creating infrastructure and taking up projects for applications of space science and technology in all possible sectors. It has made its presence felt very strongly in the region by providing critical space based inputs in planning and developmental process of all NE states. Today, through several web-portals and standalone kiosks at state and district level, NESAC ensures that the entire space based database generated at NESAC and in other centres are available to the decision and policy makers. The centre also makes special effort on capacity building and space science popularization in NER.

Remote Sensing (RS) & Geographic Information System (GIS) Applications

The core activity of the centre is RS & GIS applications in Agriculture, Soil sciences, Forestry, Water resources, Geology, Infrastructure planning, Urban studies, IT, health GIS, etc. and it has completed more than 100 projects in this area. While most of the projects focused on creation of thematic maps & database, development of new techniques, etc. a few projects were taken up exclusively to disseminate the database to the end user. The most significant among the projects are, early warning of outbreak of Japanese Encephalitis, RS and GIS inputs for forest working plan preparation for NE states, North Eastern District Resources Plan programme, database preparation for NRDB & SIS-DP projects, North East Spatial Data Repository (NeSDR), etc. A national project on applications of RS and GIS in Sericulture development has also been completed for 178 districts covering 26 states in India. Sericulture Information Linkages and Knowledge System (SILKS) web portal developed under the project was awarded the National E-Governance award 2014-15 in the category of innovative use of GIS in e-governance. Another project, North Eastern District Resources Plan (NEDRP), which is one of the unique initiatives of NESAC sponsored by the North Eastern Council (NEC), Ministry of DoNER (MDONER). NEDRP was awarded with the National Award for e-Governance for the year 2017-18 for outstanding contribution using Spatial Technology and GIS in e-Governance by the Department of Administrative Reforms & Public Grievances (DARPG), Government of India The centre coordinates with the State RS Applications Centres of NER and acts as a nodal centre for implementation of major national and regional programmes. NESAC has recently demonstrated the strengths of Unmanned Aerial Vehicle (UAV) for different thematic application projects covering studies on vegetation, forestry, agriculture, soil health and forest biomass, geosciences, urban management, etc.

Improving Satellite Communication Infrastructure

Another very important area of activity is Satellite Communication applications and it is more significant because the NER of India is conventionally known to have poor connectivity. NESAC is implementing all key application projects of ISRO like Telemedicine, Tele-education, Village Resource Centre, communication support in disaster management etc. in NER. To bring all major space based communication services under one umbrella, ISRO has planned to demonstrate a single window delivery capability of several services like Telemedicine, Tele-education, E-governance, remote banking, extended mobile coverage, etc., as an integrated package catering to most of the needs of rural India. An Integrated Service Pilot Network is being set up by connecting a remote village named Umsaw in Meghalaya with the Prime Minister's Office (PMO).

Research on Space and Atmospheric Science

The centre has set up a regional facility to conduct research on improving short and medium range weather forecast, characterization of aerosol and greenhouse gases, atmospheric boundary layer dynamics and to study their impact on regional weather and climate. The first ever land campaign along the east-west and north-south corridor of NER was conducted to understand the spatial distribution and consequent impact of aerosol on radiation budget over the region. The centre is also engaged in research to improve the accuracy of numerical weather forecast up to 48 hours to support forecasting flood and thunderstorm with actionable lead time. To improve the surface observations, ISRO, through NESAC has established a network of 118 Automatic Weather Stations across NER and one S-band Doppler Weather Radar (DWR) at Cherrapunjee, Meghalaya. The data from the DWR has been extensively used to improve flood early warning, thunderstorm and hailstorm nowcasting and several other applications. Various new ground based lightning detection sensors have been installed over NER with the initiative of NESAC and in collaboration with Indian Institute of Tropical Meteorology (IITM), Pune and National Remote Sensing Centre (NRSC), Hyderabad for detection of lightning.

Supporting Disaster Management

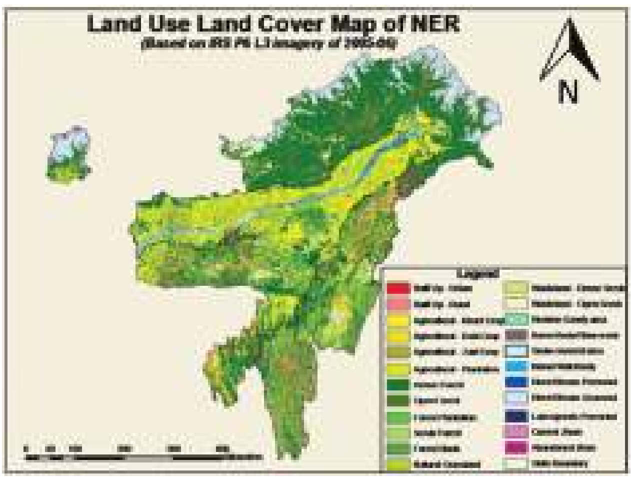
NER is one of the most disaster prone regions in India and of late, more attention has been given on efficient use of space technology for management of disasters. Flood Early Warning System (FLEWS) developed for forecasting flood in Brahmaputra and Barak valley in Assam covering 42 river basins, has been very effective with mean success rate of about 75% during 2009-2019 periods. With an objective to provide more coordinated service and single window delivery of all space based disaster management support, DOS took a new initiative and set up the North Eastern Regional node for Disaster Risk Reduction (NER-DRR) at NESAC. NER-DRR is mandated to support management of disasters like Floods, Forest Fire, Thunderstorms, Landslides, Drought, Earthquakes, and Health disaster. In addition to providing support during and post phases of disaster management, NER-DRR is focusing more on pre-disaster preparedness and early warning. Thunderstorm early warning has been done experimentally since 2014 and efforts are on for early warning of landslide, forest fire, and agricultural drought.

Capacity building in geospatial technilogy

Capacity Building is one of the important mandates of the center and hence various training courses on different space technology based topics are being carried out. Participants and students, not only from regional and national level but from International level have undergone such courses. One such training course specially designed for participants from BIMSTEC countries, is being carried out to augment the use of space based technology in our neighboring countries is worth mentioning here. Apart from this, NESAC also provides beginners and advanced courses on UAV remote sensing and applications.

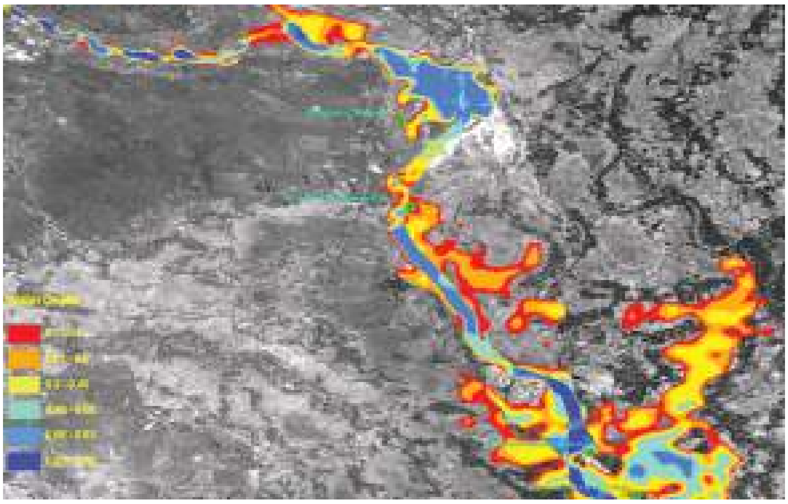
In its 2 decades of dedicated service to the North Eastern Region of India and to the Nation as a whole, the center has grown up remarkably. The region has its unique geography, which on the one hand have provided a vast opportunity to study and explore the unexplored and on the other

NESAC office campus



Land use land cover map of NER

hand posed major challenges with its complex terrain and meteorological conditions. NESAC has been taking up these challenges quite fervently and using space based technology for the betterment and development of this region. By providing different space based services and inputs, the center has emerged out as an asset for the state departments in this region.



Riverine flood inundation simulation under FLEWS project

DWR at Cherrapunjee

TROPMET 2020

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THEME 1

Dynamics and Physics of Orographic Clouds and Precipitation

Radar monitored Cloud vertical structure measurements over a complex terrain

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The cloud vertical structure (CVS) and associated dynamical information are mainly utilized to decipherer the wet, and dry Indian Summer Monsoon (ISM) spells. The first Indian ground-based 35-GHz millimetre-wavelength cloud radar measurements of equivalent radar reflectivity (dBZe) and spectral width profiles over complex terrain in the Western Ghats region during the two ISM spells clearly show contrasting cloud vertical structure differences. The observed CVS changes are closely associated with the large-scale circulation associated with the monsoon intra-seasonal oscillation signature over the observational site. Moreover, a conspicuous characteristic role associated with the low-level warm cloud and the pertinent onset of rain processes is explored with the three lower-order moments of cloud radar spectra. Further, the role of convection and the dynamical process can be explained with the CVS that inherently connects both the macro- and micro-physical aspects of cloud profile and large scale dynamics from the reanalysis data. The mid-level mixed-phase clouds play a vital role in understanding the change of ISM vigor. The high-level ice-phase cloud's principal function is during ISM wet spell that becomes one third or less during ISM dry spell, which is the main reason for surface rainfall yield differences during the wet and dry spell. We aim to cross-check this observed CVS or cloud profiling using cloud parameterization schemes used in the models, for mainly unravel the macrophysical compose and dynamically controlled microphysical process. This study can be a scientific observational basis for testing the ISM cloud parameterization schemes for a better atmospheric circulation model.

Keywords: Cloud Vertical Structure, Active and Break ISM phases, Onset of rain, cloud turbulence, vertical profiling of cloud using Cloud radar

Diurnal evolution of the vertical structure of precipitating clouds over the southernmost part of the Western Ghats of India during summer and winter monsoons

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In the present communication, diurnal evolution of the vertical structure of precipitating clouds over the southernmost part (7o-11o N) of the Western Ghats (WG) of Indian region during summer and winter monsoon periods is discussed using 17 years (1998-2014) precipitation radar measurements on-board Tropical Rainfall Measuring Mission (TRMM) and 5 years (2014-2018) of Global Precipitation Measurement (GPM) Satellites. This part of the WG experiences both summer and winter monsoons

and provides a unique opportunity to study the orographical processes involved in the formation of precipitating clouds at diurnal scales during two contrasting background environments. During the summer monsoon, the lower tropospheric winds are dominated by the presence of strong low level westerly jets, which interact with steep slopes of the WG whereas, during the winter monsoon, winds are very weak easterlies and encounter relatively lower peaks of the WG (from eastern side). The climatology of precipitation over the study region shows a relatively narrow distribution with a peak over the upslope of the WG during summer monsoon whereas, during the winter monsoon, it shows a broader distribution with a peak over the secondary crest of the WG. Besides discussing the precipitation climatology over the study region during both the monsoons, the composite longitudinal distribution of vertical structure of precipitating clouds in terms of frequency of occurrence of radar reflectivities ≥ 23dBZ is constructed at four local time intervals. The diurnal evolution of precipitating clouds with respect to the WG during both the monsoon is discussed. The results show a systematic and contrasting longitudinal distribution during summer and winter monsoons. The potential orographical processes involved in the formation of precipitating clouds are also discussed. The significance of the present study lies in bringing out the diurnal evolution of the vertical structure of precipitating clouds over the southernmost part of WG during two contrasting monsoon environments for the first time.

Keywords: Precipitating clouds, rainfall, orography, monsoon, TRMM, GPM

Extremely heavy rainfall episodes over North-East India during South West Monsoon 2020 - A Case Study

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Southwest monsoon season (June to September) is the major rainfall season for the country and the country receives about 80% of its annual rainfall during this season. If the rainfall activity over the four broad homogenous regions of India during the season is considered for the year 2020, it had been 106% of Long Period Average (LPA) over East and North-East (NE) India. As per the India Meteorological Department (IMD) classification, North East India consists of three meteorological sub-divisions viz. Arunachal Pradesh, Assam & Meghalaya and Nagaland, Manipur, Mizoram & Tripura (NMMT). There had been large variation in the observed rainfall activity during South-West Monsoon 2020 among these subdivisions and Arunachal Pradesh, Assam & Meghalaya and NMMT received normal, excess and deficient rainfall respectively during the season.

However, during South West (SW) Monsoon 2020, northeastern region (except NMMT) witnessed extremely heavy rainfall (EHR) episodes on several occasions causing riverine as well as urban flooding and landslides over the regions. The highest number of EHRepisodes reported had been in Assam and Meghalaya, whereas NMMT reported NIL episodes.

The main goal of this study is to identify those EHRepisodes which had been disastrous for the NE States and to identify the associated synoptic features. In this paper, only those EHR episodes which had been reported for consecutive two days or more are considered. It is observed that there had been a total number of seven occasions during the season when such EHR episodes were reported over at least one sub-division of the region.

Keywords: North-East India, South West Monsoon 2020, Extremely Heavy Rainfall

Thermodynamic and dynamic structure of the atmosphere associated with Kerala flood during 2018

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Indian summer monsoon was vigorous in southwest peninsular India during the first half of August 2018. This continuous monsoon rainfall for more than two weeks with two heavy rainfall events led to a flood in most parts of Kerala. In this study, an attempt is made to examine the thermodynamic and dynamic structure of the atmosphere to understand the factors responsible for the heavy rainfall event. The study is carried out utilising NCMRWF high-resolution reanalysis products such as temperature, humidity and wind profiles and precipitation data (IMDAA). In addition, NCEP reanalysis data, IMD gridded rainfall data and NOAA OLR data sets are also utilised. A comparison of basic parameters (temperature and humidity profiles) is made with radiosonde data at Thiruvanandapuram station and found that the reanalysis products are closely matching with the in situ observation. The thermodynamic parameters evaluated from 12 km resolution IMDAA reanalysis data are LCL, LFC, LoC, CAPE, CINE, MSE, Theta-E and TPW. The Level of Free Convection is relatively lower (around 900 hPa) during most of these days indicating that the stable layer near the surface is very shallow. As the Lifting Condensation Level is close to the surface (below 900 hPa) due to high relative humidity associated with the continuous rainfall, the rising surface air parcel attains saturation easily and subsequent condensation takes place quickly. Thus a favourable situation for conditional instability was prevailed over the region. It is found that CAPE was relatively high (more than 3000 Jkg-1), even though small CAPE value (less than 2000 Jkg-1) is observed during normal monsoon days. Equivalent potential temperature profiles confirmed that the presence of conditional instability prevailed in the atmosphere even though cloudy or rainy situation prevailed most of these days. In other words, the thermodynamic structure of the atmosphere was conducive for the rising of air parcel. Further, we examined low level divergence and vorticity pattern over the region. The low level vorticity pattern was cyclonic most of the time leading to the occurrence of ascending motion. The NCEP omega values at 850 hPa / 500 h Pa confirmed the presence of the vertical motion associated with the heavy rainfall events. Features of Walker and Hadley circulations are also studied. Strong moisture transport of humid air by westerly wind from the Arabian Sea, cyclonic vorticity prevailed near the surface and orographic lifting by the Western Ghats supported ascending motion of humid air most of these days. Further, the ascending motion became strong on 8 and 15 August to produce heavy rainfall events over the two locations in the Kerala state. It is found that the ascending limb of the Walker circulation was shifted to peninsular India most of the period with strong ascending limb over the locations of heavy rainfall during these two days. Even though a ridge prevailed in the Arabian Sea almost parallel to the Kerala coast, the strong moisture transport and subsequent ascending motion in the conducive thermodynamic structure of the atmosphere made the continuous rainfall with two heavy rainfall events.

A study of regional variation of electrical properties of precipitating systems and associated rainfall during the premonsoon and monsoon seasons

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The northeastern and eastern regions of India have a different climatic regime. These two regions have different land and orographic formations. The previous studies have reported that the morphological and microphysical properties of the precipitating systems over these two regions have different characteristics. In the present study, the electrical properties of precipitating system and associated rainfall at Kohima (Nagaland) in the northeastern region of India and Rampurhat (West Bengal), in the eastern region of India is investigated during the pre-monsoon (March-May) and monsoon (June-September) season of 2017-18. For this purpose, simultaneous observation of electric field and rainfall are considered from the Electric Field Mill (EFM-100) and a tipping bucket rain gauge of 1 minute integration time respectively. The rain event is designated as an electrified rain when the absolute value of the electric field is > 500 V/m, with at least one lightning discharge; otherwise, it is designated as a non-electrified rain event.

In term of percentage occurrence, during both the seasons, over each station electrified rain events are more than the non-electrified rain events. Kohima received total 68% (pre-monsoon: 27%; monsoon: 41%) of electrified rain events and 32% (pre-monsoon: 25%; monsoon: 7%) non-electrified rain events. Similarly Rampurhat received total 65% (pre-monsoon: 24%; monsoon: 41%) of electrified rain events and 35% (pre-monsoon: 12 %; monsoon: 23%) non-electrified rain events. The result further suggests that season-wise, over both the stations, the occurrence of electrified rain event is more during monsoon season compared to the pre-monsoon. It is further observed that, over both the stations, even though the occurrence of electrified rain event is more during monsoon season compared to the pre-monsoon, yet these rain events are stronger during the pre-monsoon compared to monsoon. During the pre-monsoon, and monsoon the average count of flash/event over Kohima is80 flash/event and 32 flash/event respectively, whereas over Rampurhat, it is 162 flash/event and 72 flash/event respectively. It is to be mention that, over each season, by virtue of higher flash count, the electrified rain events are stronger over Rampurhat compared to Kohima, suggesting the strong mixed phase process in the precipitating systems over Rampurhat.

In order to associate the rain intensity with the electrified and non-electrified rain events, the maximum rain intensity for each event is found and then the average value of maximum rain intensity is calculated by taking into account all the rain events in the respective category. For the electrified rain, during the pre-monsoon and monsoon, the averaged maximum rain intensity over Kohima is 62 mm/hrand 49 mm/hr respectively, whereas over Rampurhat, it is 82 mm/hrand 69 mm/hr respectively. The result shows that, for the electrified rain event, the higher rain intensity is associated with relatively stronger electrified rain event (particularly over Rampurhat). It is also observed that non-electrified rain events have relatively less rain intensity compared to electrified rain. For non-electrified rain events during the pre-monsoon and monsoon, the average maximum rain intensity over Kohima is 32 mm/hr and 56 mm/hr respectively, whereas over Rampurhat it is 29 mm/hr and 41 mm/hr respectively. Overall it is observed that, for electrified rain event, the rain intensity is higher during the pre-monsoon whereas on the contrary, for non-electrified rain events it is higher during the monsoon season. Overall, predominantly higher rain intensity events are associated with the precipitating systems having strong mixed phase process during the electrified rain event. Further analysis is in progress.

A mathematical model for parameterizing the precipitation enhancement and momentum flux associated with airflow over mountainous region

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Dynamical parameterization of the effect of a mesoscale orographic barrier on airflow, like enhancement of precipitation on the windward side, the vertical flux of momentum and energy, etc., has been a challenge to mesoscale Numerical Weather Prediction. To meet it, in earlier studies separate dynamical model used to be proposed to diagnose orographic rainfall.

In this study, a mathematical model is proposed for dynamical parameterization of the effect of a mesoscale orographic barrier on airflow, viz., enhancement of precipitation on the windward side and vertical flux of momentum and energy.

Actual topography has been approximated with an elliptical barrier the contour of which is analytically expressed as $Z(x,y) = \frac{H}{1+\left(\frac{x}{a}\right)^2+\left(\frac{y}{b}\right)^2}$ and an undisturbed moist basic airflow is considered to flow over and around it. The basic flow is assumed to have both the components, U and V, normal and parallel to the major ridge of the elliptical mountain respectively. The temperature, specific humidity, density and the two wind components U, V of the basic flow are allowed to vary realistically in the vertical. Here, 'H' is the maximum height of the mountain and 'a', 'b' are respectively the half widths along the normal and parallel to the major ridge of the elliptical mountain. Orographic enhancement of precipitation on the windward side and vertical fluxes of momentum and energy are due to the perturbations caused to the basic flow by the mountain.

To develop the model for perturbation wind field (u', v', w') and perturbation pressure field (p') the governing equations in z co-ordinate are used. These equations have been linearized using perturbation technique. The linearized governing equations are again subjected to double Fourier transformation (DFT). After simplification, a single second order ordinary differential equation (ODE) is obtained. This equation is integrated numerically from the top using the boundary conditions imposed at the ground and at the top of the model. At the lower boundary, the airflow is supposed to follow the terrain and, at and above the upper boundary, vertical velocity decays exponentially. Using the vertical velocity so obtained, along with conservation of moisture and mass, orographic rainfall intensity is estimated. Also using u', v', w' and p' obtained from the model the vertical profiles of eddy momentum and energy flux have been computed.

The above model has been applied to the Western Ghats, Khasi-Jaintia hills, India, Assam-Burma hills and for mountain corner. In the rainfall pattern, we obtain one primary maxima and three secondary maxima. The primary maxima is located just behind the peak on the windward side. Two secondary maxima are located on the lee side, beyond the two ends of the barrier along the major ridge, and the third secondary maxima is located on the lee side of the major ridge. In the absence of 'V' the rainfall intensity distribution is symmetrical about the central plane, whereas the presence of 'V' rotates the plane of symmetry about the central plane. In the vertical fluxes, different levels for flux convergence or divergence has been found. This model, although has been applied to an analytical form of the mountain, however it can be applied to any regular or irregular shaped mountain, provided height at different grids (at 5km grid length) are available. It is proposed to append this diagnostic model in a forecasting model as a sub-routine.

Keywords: Orographic precipitation, momentum flux

Orographic effect on the heavy to very heavy rainfall over Kerala in 2018

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An attempt has been made to understand the dynamical role played by the orographic barrier, if any, in the recent heavy to very heavy rainfall episodes during August 2018 in Kerala. For that, a 3-dimensional mesoscale linear dynamical model has been developed. This model has two parts, viz., a dynamical part and a thermodynamical part. In the dynamical part, a steady-state non-viscous, adiabatic, non-rotational and Boussinesq far upstream undisturbed basic flow is perturbed by constraining it to flow around and above a 3-dimensional mesoscale, orographic barrier and the vertical perturbation velocity is computed. In the thermodynamic part, using this computed perturbation vertical velocity along with mass and moisture continuity equation and also incorporating the wind drift effect, rainfall intensity (mm/hr) has been computed over a 600km x 600km (~ 6° X 6°) region, centred at Anamudi (10.16° N, 77.06°E) the locally highest peak. In the present study, the orography in that region has been approximated analytically as a 3-dimensional elliptical barrier, centred at Anamudi, with height 2.7 km, half-width 27km in the west-east direction and 18 km in the south-north direction. Maps of computed RFI over the above-mentioned region has been prepared daily during 15-20 August 2018 and same has been compared with that of observed rainfall intensity.

Computed RFI overestimated the observed RFI for the stations to the southwest and underestimated the observed RFI for the stations to the northwest of the peak of model orography.

Keywords: Orographic rainfall, Kerala heavy rainfall

Seasonal precipitation projections using CORDEX-South Asia experiments in Northeastern Climatic Region of India (Eastern Himalaya)

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Seasonal precipitation (SP) in the Northeastern Climate Region of India (NECRI), home to the world's highest rainfall receiving zone, varies widely in spatio-temporal dimensions. Information at a regional scale and the likely changes in precipitation under future climate scenarios is inadequate. We analyze the changing scenarios of SPs for immediate (2020-2049) and distant (2070-2099) futures using two Regional Climate Model (RCM) simulations (namely RCA4 and REMO) from the South Asia-CORDEX framework. Changes in SP under each emission scenarios (RCP's 2.6, 4.5 and 8.5) were compared with the corresponding reference past climate (1970-2005). Both models projected an increasing trend of pre-monsoon (March-May) precipitation (+1.5 to 25%) during distant future, while a deficit trend (-3 to -11%) for immediate future under low emission scenarios (RCP 2.6 and 4.5). Gauge observation and model simulation (1970-2005) revealed a significant (p<0.05) decreasing trend (@ 0.02-0.06 mm day-1) of Southwest Monsoon (SWM) precipitation in different parts of the region. However, for future scenarios, the RCA4 simulation projected a significant (p<0.05) increasing trend (@ 0.004-0.060 mm day-1) of SWM precipitation across RCPs during the immediate future, while the trend in REMO projection was quite inconsistent. In the distant future, both RCA4 and REMO models, however, projected a decrease in SWM precipitation by 24-30%. Winter precipitation in the region will increase by 3-17% in the immediate future and will increase further to 51-145% in the distant future with a likely shift in SWM pattern over the region. The RCA4 found to be more sensitive in simulating pre-monsoon (MAM) and monsoon (JJAS) precipitation, while REMO is more reliable in assessing post-monsoon (ON) and winter (DJF) precipitation behaviour across the NECR of India.

Keywords: Regional Climate Model, CORDEX-South-Asia, Seasonal precipitation, Precipitation projections; Northeastern Climatic Region of India.

Raindrop Size Distribution Features of Pre-Monsoon and Monsoon Season over the Western Ghats

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Four years (2015-2018), Joss-Waldvogel disdrometer data are utilized for analyzing Raindrop size distribution (RSD) of pre-monsoon and monsoon season over the Western Ghats. Tropical Rainfall Measuring Mission (TRMM) and ERA-Interim data sets are also integrated with disdrometer data to establish microphysical and dynamical features of pre-monsoon and monsoon season rain. Long-term trends in rain spectra are not studied until now over the Western Ghats. Rain spectra of pre-monsoon and monsoon season show notable differences. Rain spectra of monsoon display considerably higher divergence compared to pre-monsoon rainfall. Monsoon rainfall has a higher concentration of smaller drops, while pre-monsoon rainfall contains a significantly higher concentration of large droplets. RSD classified on the rain rate demonstrates a higher mass-weighted mean diameter (D_m) and a lower normalized intercept parameter ($\log_{10}N_w$) in monsoon than winter. Similarly, the Diurnal variation of RSD reveals higher D_m with a lower value of $\log_{10}N_w$ in pre-monsoon season. Also, in both seasons, the higher value of mean D_m in convective precipitation than stratiform. Convective activities with increased ground temperature alter RSD in pre-monsoon season rather than monsoon season through droplet classification, evaporation, and collision-coalescence processes.

Isotopic composition of daily precipitation from Kashmir Valley, NW Himalaya: Insights on the role of meteorological parameters and dual moisture transport pathways

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Understanding the temporal processes controlling water stocks in the Himalayan region becomes fundamental in the current greenhouse world. The recent reports on the isotopic composition of monthly and seasonal variability in high Himalayan precipitation have highlighted and identified the control of dual atmospheric circulation patterns associated with Western Disturbances (WDs) and Indian Summer Monsoon (ISM) derived precipitation. However, being the monthly composites, these studies were not capable of resolving the short-term processes that govern the individual rainfall events corresponding to the WD and SWM moisture sources. Additionally, the role of several meteorological parameters (temperature, relative humidity, and surface pressure) which are known to significantly affect the Himalayan hydrology have not been addressed so far. We provide daily-scale precipitation isotope record from the Kashmir Valley, northwestern Himalaya with an aim to better quantify the relationship between the precipitation isotopes and the meteorological variables separately for WD and SWM seasons. The records indicate that precipitation isotopic composition in this region is strongly modulated by temperature and relative humidity during the periods of WDs while as a weak dependency was observed for the SWM season. Moisture transport pathways calculated from HYSPLIT back trajectory analysis suggest moisture sources restricted to Mediterranean region during the WD period, but a wide spatial variability was seen during the SWM period. The present isotope record will help operational meteorologists to observe the role of regional synoptic-scale processes for a better understanding of the regional hydrology.

Impact of Western Disturbances (WDs) during January to April, 2020: A Case Study

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It is well known that Western Disturbances (WDs) are major synoptic systems affecting the weather of north India and causing intense weather, especially over the Western Himalayan Regions (WHR). Occasionally these systems cause severe weather over the adjoining plains of North-West India also. The year 2020, mainly from January to April, witnessed severe weather due to Western Disturbances. Hence the main goal of this study is to identify those WDs which resulted in intense spells of disastrous weather over Western Himalayan Region (WHR) and adjoining plains of northwest India, other supporting

synoptic features and realized weather and its intensity due to these WDs. In order to classify the WDs as active or otherwise, the following conditions are considered.

Condition 1: At least two subdivisions out of three from WHR (Jammu & Kashmir, Himachal Pradesh and Uttarakhand) reported widespread/fairly widespread rainfall and one sub-division from plains of North-West India reported fairly widespread/scattered rainfall.

Condition 2: At least two subdivisions out of three from WHR (Jammu & Kashmir, Himachal Pradesh and Uttarakhand) and one sub-division from plains of North-West India reported hailstorms.

Condition 3: At least two subdivisions out of three from WHR (Jammu & Kashmir, Himachal Pradesh and Uttarakhand) and one sub-division from plains of North-West India reported heavy rainfall (24 hour accumulated rainfall more than 64.5 mm).

If at least one condition among the three given above is satisfied, during the passage of WD, it is considered as an active WD.

Vertically integrated moisture transport and role of monsoon dynamics associated with the 2018 flood over Kerala

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Kerala, a state in South India, experienced a severe flood event which was considered as a flood situation after 1924 and hence treated as flood situation once in a century. It is reported in the literature that global warming and subsequent climate change lead to the occurrence of extreme weather events. The change in land use pattern, deforestation, urbanization of small towns, etc. made further havoc to the natural equilibrium of the ecosystem and hydrological cycle. The compound events which make the scenario worse to become the extreme event more vulnerable. The flood event in Kerala was during the period 7-18 August 2018. The extremely heavy rainfall events observed at different parts of the state were exceeding more than 400 mm/day. The flood occurred during two spells, which were during 7-10 August and 14-18 August. Here, we investigate the mechanism responsible for the heavy spells of rainfall leading to the flood situation, employing vertically integrated moisture transport, moisture budget, heat source and heat sink. The analysis is carried out using the high-resolution IMDAA Reanalysis data with 12 km resolution provided by NCMRWF, India. We observed that a large amount of moisture from the Arabian Sea is transported to southwest peninsular India during a short period of time and this moisture transport played a vital role for the heavy rainfall over the region. We analysed the vertically integrated moisture transport from the surface to 300 hPa of the atmosphere. It is found that the moisture transport was maximum during the period of occurrence of the flood with a value of 800-900 $kgm^{-1}s^{-1}$ over the Kerala region. A comparison was made for moisture transport during the period of heavy rainfall and in the absence of heavy rainfall. It was found that the VIMT values are 200-300 $kgm^{-1}s^{-1}$ prior to the occurrence of the flood (1-5 August) and after the flood (20-25 Aug). The heat source Q1 and moisture sink Q2 was

derived for different layers from the temperature and humidity data. The examination of the heat source and moisture sink during flood revealed that there was more heating rate during flood period compared to clear sky days. It reveals that there is a significant increase in the net enthalpy, Latent Heat Energy and the moisture and heat budget terms in association with the occurrence of flood over the Arabian Sea and adjoining area. The moisture budget for the period was evaluated over the selected domain. The area integrated moisture budget was obtained from line integrated values over the boundaries of the study area. It was found that the moisture budget was very high during the flood period indicating high precipitation compared to evaporation so that the integrated values of (P - E) in the box covering the entire domain is very high.

Intriguing aspects of Indian Summer Monsoon through cloud vertical structure over a complex and flat terrain of monsoon region

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Mountains and hills have direct and indirect effects on precipitation within clouds. The Western Ghats located in peninsular India is an ideal testbed for understanding the cloud and rain microphysics modulated by complex topography. Another aspect of the Western Ghats is being one of the two most heavily rainfall regions during the summer monsoon. The south-westerly monsoon precipitation systems first pass over the selected site and then to the Indian mainland. This complex and another homogeneous plain terrain located in the core monsoon system in central India, Bhopal, are selected for comparison. This observational research work uses high-resolution Ka-band scanning polarimetric radar (KaSPR) measurements over a high altitude region in the Indian Western Ghats and radiosonde data. Vertical pointing data and range height indicator (RHI) plots are used to study the dynamics and cloud features. The cloud vertical structure (CVS) depends on the cloud genesis, the processes involved, and evolution; these factors need to be explored and well understood for the better predictability of Indian Summer Monsoon (ISM). The active and break spells during the Indian Summer Monsoon can put forward contrasting features in CVS in these terrains. The study also inspects the effect of orography on the CVS using RHI plots, which can provide information on both windward and leeward sides of the mountain region. Due to a lack of cloud radar, CVS at Bhopal can be calculated using GPS-Radiosonde. It is one of the easiest means for finding CVS by identifying saturated levels in the atmosphere. Radiosonde at a nearby site of radar can be used for comparison to cloud radar. From these, the main differences between two different terrains in CVS during active and break spells can be brought out. The two selected areas are both dynamically different, one being near the coastal region and another continental. The moisture influx in the former being more than later. Turbulent characteristics can be studied by using vertical measurements of the refractivity index structure parameter (Cn2). Large scale features and dynamics in these areas can be brought out by the Indian Monsoon Data Assimilation and Analysis (IMDAA) data for the Indian region. The study provides a detailed view of the effect of terrain on the atmospheric features mainly clouds during the Indian Summer Monsoon.

Evolution of tropical clouds over Western Ghat using ground based Ka-band radar

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Indian summer monsoon (ISM) is one of the most dominant tropical circulation systems in the general circulation of the atmosphere. One of the outstanding features of ISM is the two coastally oriented narrow rainfall maxima, one along the Western Ghats (WG) and the other along the Myanmar Coast resulted out of the interaction between the northward propagating intra-seasonal oscillations and the shallow orography in the two regions. Hence, WGs has a great impact on the circulation dynamics and rainfall features during the ISM period due to its orographic features. Most research efforts over the WGs were mainly confined to the investigation of orographic rainfall and their inter-annual variability. However, a detailed and systematic study on clouds that ultimately produce rain is lacking due to the lack of high-resolution cloud sensitive observations. Thus, there are several gap areas in the understanding of cloud processes. To fill the gaps, high-resolution observations from Ka-band radar, Mandhardev (18.04° N, 73.86° E), over the Western Ghats has been utilized. Three years (2013-2015) of quality-controlled data of vertical profile of reflectivity factor (VPR) from Ka-band radar were used to study the inter- and intra-seasonal variation of cloud vertical structure during the Indian summer monsoon. Ka-band radars are very sensitive to the detection of small targets such as cloud droplets, insects and other biological particulates (biota) present in great numbers in the lower atmosphere. Algorithm 'TEST' has been developed indigenously to extract the pure cloud metrological information. The differences in genesis and evolution of three different types of tropical convective clouds, i.e., shallow cumulus, moderate cumulus congests and very deep cumulonimbus cloud have been explored through their vertical structure as cloud vertical structure provides complete information of cloud systems associated with altitude and hence change of temperature. Besides, vertical looking observation, volume scan and RHI scan from Ka-band radar have also been utilised to show the cloud evolution over orographic region of WG. To understand the characteristic differences of clouds resulted from the complex terrain of this region, contrast in the VSC in the leeward side and windward side is carried out separately in the diurnal and seasonal time frame. Shallow to deep cloud transition is well evident in the analysis of hourly average VPR data spanning over 60 days of the two consecutive ISM months. Both moisture advection and horizontal wind component are found responsible for this transition. The mid-level moistening is observed to be necessary for the growth and sustenance of the deep clouds. Frequency of occurrence of VPR is helpful to distinguish between a normal and a below normal monsoon year. In addition to that, annual variability of mean VPR can explain the change in rainfall signature based on the respective large scale background monsoon conditions of that year. Cloud classification shows there is a subsequent increase of shallow cloud occurrence with the below normal performance of ISM from 2013-2015. For 2013 and 2015 (2014), max rain accumulation occurs for longer durations of deep cloud (cumulus congests) whereas, minimum rain accumulation occurs when there is sustained dominance of "no cloud" regime. It is also evident from this study that Synchronous linkage between ice phase, mixed phase and warm phase cloud regime in the total VSC plays an important role in making high rain accumulation at the surface.

Diurnal variability in rainfall events and associated vertical structure of precipitation over a high altitude site in the Western Ghats during the summer monsoon season

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Using ground based scanning X-band radar, the vertical structure of rainfall events with different durations have been studied over a High Altitude Cloud Physics Laboratory (HACPL) situated in the complex terrain of Western Ghats (WG). The cascaded topography of the WG is known for the orographic lifting of monsoon winds which lead to copious rainfall at high altitudes in the WG. The vertical structure of the precipitating systems, their macro and microphysical properties and the diurnal features are still poorly understood. The HACPL is established by the Indian Institute of Tropical Meteorology at Mahabaleshwar (17.92°N, 73.66°E) is 1.35 km amsl in the WG. This high altitude laboratory where clouds touch the surface makes a unique location to investigate the cloud and precipitation properties of orographic rain. The radar is stationed at Mandhardev, another remote hilly location in the WG which is ~25 km away radially from HACPL and has been utilized to examine the vertical structure of precipitation over HACPL. The radar observations collected during summer monsoon campaign of 2017 and 2018 have been used. The observed rainfall events have been categorized into short, medium, long and extended-duration events and the associated diurnal variation of precipitation intensity, frequency and echo top heights have been analysed for each category of a rain event. Initial results show more than 60% of total rainfall comes from extended-duration rainfall events. The rainfall analysis shows different diurnal features for different duration rain events and is associated with different mechanisms of rain formation. Further, the vertical structure of precipitation is investigated for various categories which would be greatly helpful in understanding the variability of rain events in detail and may be useful for physical parameterizations in weather models.

THEME 2

Lightning Physics and Forecasting

Lightning characteristics in various phases of thunderstorm over northeastern India associated with Dual-Polarization Radar - A preliminary case study

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Lightning is one of the challenging issues in northeastern region (NER) of India and risk reduction is in demand. However, knowledge of lightning and associated phenomena over this vicinity is limited. Recently, two different remote sensing tools employed that are radar and lightning location network over NER. An indigenous dual polarization Radar has installed in Cherrapunjee (Sohra), that covers 240 km circular area, to enhance the understanding of thunderstorms which is also used for operational purpose. In addition, Earth network total lightning network (ENTLN) provides the lightning location data both the Intra cloud (IC) and Cloud to ground (CG). In consideration of the likelihood of several disasters associated with thunderstorm and lightning this work deal with characteristics of lightning in different phases (cumulus, mature and dissipating) of various (single cell, multi cell and squall line) category thunderstorms in association with radar reflectivity.

In this study, nine thunderstorms in which three squall line, three-multi cell and three single cells have analyzed that reported from 2018 to 2020. The electrical nature of these thunderstorms to discussed in detail. Figure 1 shows, a single cell thunderstorm that passed over the study region, radar reflectivity superimposed with the lightning within 10 min. In our initial investigations, we noticed CG strokes commonly associated above 20 dBz radar reflectivity in all cases. Further, we also observe in most of the cases IC flashes were dominating in cumulus and dissipating stages and surprisingly CG flashes in the mature stage of squall line and multi cell. Additionally, Positive cloud to ground (PCG) lightning were below 20% of total CG in single cell and multi cell thunderstorm. Nevertheless, in squall line PCG/CG was crossed 40% in monsoon season.

Study of lightning activity over Bengaluru

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Lightning activity plays an important role nowadays due to its frequent occurrence due to several unknown reasons. Lightning and thunderstorm are the manifestations of the electrical nature of the Earth's atmosphere. The observations were made by the World Wide lightning location network (WWLLN) of the USA, which includes a station at Bangalore University, Bengaluru, India. Electric field receivers in WWLLN are sensitive between 1 kHz to 24 kHz, detect lightning generated sferics, and the local computer determines the time of group arrival (TOGA) of wave packets. Using GPS lock, TOGA is determined for sferics within a microsecond. The central processors calculate lightning locations using this continuous flow of TOGAs. Lightning locations are determined to spatial accuracy of 10 km and time accuracy better than 30 microseconds. The continuous measurements show pronounced lightning activity and exhibit distinct diurnal and seasonal variability. Lightning is most frequent during afternoon hours and continues till night-time. The statistical variability of lightning stroke density over Bengaluru confirms the enhancement of activity from the recent past. Preliminary study shows that in addition to the observations of WWLLN over Bengaluru requires similar ground-based and satellite data from/over other low latitude stations and also integrates it with visual and other observations reported in the media. The study has revealed that sensors are most sensitive to lightning strokes with a peak current exceeding 50kA for annual mean values.

Meteorological Studies of two very severe lightning strike cases on 25th February 2020 and 25th June 2020 over the State of Bihar, India

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A lightning strike has now emerged as one of the major causes of human causality due to natural phenomena. This has prompted the policymakers to include it as one of the listed natural disasters. Indo-Gangetic plain is most venerable for lightning strikes, particularly during Pre-monsoon and Monsoon season. The present paper is a case study of two such incidents occurring on 25th February and 25th June 2020 in which a total of 107 persons had died in the state of Bihar due to a strike of lightning. The days selected are representative of the winter season and early period of the Monsoon season respectively.

The study is primarily based on the classical theory of charge separation arising due to the collision and coalesce process inside an active thunderstorm. Lightning strike data maintained or subscribed by central and state government agencies has been used to identify the location, time, and duration of thunderstorm cells generating the lightning and the same has been corroborated with the Doppler Weather Radar data to analyze the structure of the cell including the vertical extent and up-draft and downdraft characteristic. The OLR & CTBT data of the corresponding period has been used to profile the environmental condition most favourable for cloud to ground discharge which is the predominant cause and also the predominant cause of lightning-related causality.

The study brings out some interesting features of a typical thunderstorm both during the winter period when the environment is rather stable and pre early monsoon period when the environment is still very unstable and favourable for convection and hence lightning activities. Out of a total of 35364 lightning strikes on 25th February 2020, out of a total of 35364 strikes, 11398 (32%) were Cloud to Ground(C-G) while 23966 (67%) were Cloud to Cloud(CC). In the case of the 25th June episode, out of 56863 lightning strikes, 27977 (49.20 %) were Cloud to Ground(C-G) while 28886(50.79%) were Cloud to Cloud(C-C). Therefore, apart from the increase in the number of strikes itself, the CC and CG cases seem to even out during the early monsoon phase. This finding is in variance with the current understanding wherein cloud to cloud (CC) lightning is supposed to be five to ten times higher than the cloud to ground lightning.

The level at which CG lightning starts has been correlated with the corresponding temperature level and it is found that most of the lightning is occurring between -20^{0}C and -60^{0}C. Similarly, Max Z which is the maximum reflectivity occurring in any particular direction, is found to be between 40 and 55dBz.

The finding of the case study helps in improving our understanding of the complex process of cloud electricity which in turn can be utilized to give a better prediction of time, location, and potential of a lightning strike.

Keywords: Lightning, Thunderstorm, CC, C-G, Reflectivity

Regional variation of electrical properties of deep convective systems during pre-monsoon and monsoon season over Eastern and North-Eastern region of India

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The electrical properties of Deep Convective Systems (DCSs) is analyzed during the pre-monsoon (March-May) and monsoon (June-September) seasons of 2017 over Rampurhat (Eastern India) and Kohima (North-Eastern India). The DCSs are identified with the help of minimum brightness temperature of 11 µm channel ($Tb_{11(min)}$) of INSAT-3D with $Tb_{11(min)} \leq 235$ K. The electrical properties correspond to DCSs are measured by using Electric Field Mills (EFM-100). The electrical properties of DCSs are studied in terms of the ambient electric field (E), step change in electric field (ΔE), peak flash rate (FR) and average duration of all the detected events over both the regions.

During the pre-monsoon (monsoon), over Rampurhat and Kohima a total number of DCSs are found to be 35 (96) and 42 (120) respectively. For the overhead DCSs, during both the seasons, over Rampurhat higher average electric field is found compared to Kohima. During the pre-monsoon (monsoon) season over Rampur hat and Kohima, the average value of E corresponds to DCSs are found to be 3.6 kVm^{-1} (1.6 kVm^{-1}) and 1.7 kVm^{-1} (1.1 kVm^{-1}) respectively. Further, during the pre-monsoon (monsoon) season, over Rampurhat and Kohima, the average value of ΔE is in the ranges of -1.8 to 2.7 kVm^{-1} (-1.7 to 2.2 kVm^{-1}) and -1.4 to 2.3 kVm^{-1} (-1.5 to 1.9 kVm^{-1}) respectively.

During the pre-monsoon (monsoon), over Rampurhat and Kohima, the average peak FR is found to be 61 flash/minute (33 flash/minute) and 43 (28 flash/minute) respectively. Longer durations of the events are found over Rampurhat than over Kohima during both the seasons. Overall, over both the regions, the pre-monsoon events are of shorter duration than the monsoon season. Although, pre-monsoon events are shorter in duration, more intense systems are observed in this season than the monsoon season as evident from the higher flash rate in the pre-monsoon. In addition, a number of events were observed where lightning jump (flash rate reaches more than 70 flash/minute) was observed over Rampurhat during pre-monsoon associated with the severe weather at the ground.

Study of Lightning Activity during Different Stages of Life Cycle of Tropical Cyclones 'Vayu' And 'Fani'

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Tropical cyclones pose a serious threat to human lives and assets, especially over coastal regions. Early detection and timely warning of intensity and location of these systems are utmost important for decision-makers. Satellites and RADARs have proved to be the most reliable observational tools as regards to early warning of tropical cyclones. However, the prediction of the location of landfall and intensity still remains a challenging task for forecasters. Tropical cyclones being high energy systems are supposed to be associated with deep and intense convection, therefore evaluation of lightning activity during various stages of the life cycle of tropical cyclones can also be considered to infer and forecast the intensity of tropical cyclones. This study attempts to analyse lightning activity associated with two tropical cyclones 'Vayu' and 'Fani' formed over Arabian Sea and Bay of Bengal respectively. The lightning activity in terms of the lightning flash count is studied with respect to the intensity change from a depression to a cyclonic storm (or maximum intensity attained) and again weakening to a depression. For the present work, the lightning data of Indian Air Force (IAF) Lightning Detection System (LDS) network has been used. The evolution of lightning flash count with the intensity of system has been studied so as to use time lightning activity as a proxy to probe the temporal evolution of cyclonic activity and use this as an indicator to forecast intensity of tropical cyclones. Evident changes in number of flash counts occurred in both the cases when intensity change from depression to tropical cyclone was observed. Further, the area and distance of highest flash count with respect to the Centre of the system was observed to be changing during various stages of evolution of the system.

Explicit lightning forecasting over North-Eastern India: Preliminary results

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This work is an attempt to demonstrate the utility of an explicit electrification module coupled with the weather research and forecasting model (WRF) to forecast lightning activity over north-eastern India. In the lightning forecast model, both inductive and non-inductive charging scheme of hydrometeors is considered along with polarization of cloud water, and the exchange of charge during collisional mass transfer. This module calculates explicitly the three components of the ambient electric field through a computationally efficient multigrid elliptic solver. A bulk discharge scheme is also included, wherein charge within a volume is reduced whenever the magnitude of

the electric field exceeds the local breakdown threshold. Several case studies have been evaluated over the study region. An extensive analysis has been carried out for thunderstorms events on 3 April and additional days over north-eastern India. The simulated flash origin densities (FOD) are evaluated against observed total lightning from the Earth Networks ground based sensors. Together with the electrification module, a lightning assimilation technique has also been employed in EWRF to better represent the observed lightning on the innermost convection-allowing grid (3 km) during the analysis. This study further focuses on the sensitivity analysis of EWRF and its validation for the complete pre-monsoon season of 2019. The different statistical score has been calculated for the whole season to assess the model performance over north eastern part of India.

Keywords: WRF, FOD, WWLLN, Earth Networks, Assimilation

Seasonality in power law scaling of convective and stratiform rainfall with lightning intensity over Indian monsoon regions

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The power law relationship between the total rain (R_T) and lightning flash (LF) is useful for estimating rainfall over poorly gauged catchment areas of rivers over north-east India (NEI). Moreover, the relation between the LF and storm parameter like storm top height (STH) is key to lightning parametrization in models. However, they are poorly constrained over the Indian monsoon region where the potential for significant changes exists with large spatial variability of rainfall, strong land-ocean contrast, seasonality and contribution of stratiform to total rainfall. Using 16 years of TRMM-PR data and TRMM-LIS data, here we examine the R_T and LF relationship and between LF and STH during pre-monsoon and monsoon seasons over four regions, NEI, Central India (CI), Bay of Bengal (BoB) and Indian Ocean (IO). A stronger power law (exponent b = 0.71) during pre-monsoon than that during the monsoon season (b = 0.58) apply for convective rain over land (including BoB) while a weaker relationship is applicable for stratiform rain with b = 0.60, and b = 0.47 respectively. Over IO, the relationship is nearly identical for convective and stratiform rain with no seasonality (b ~ 0.4). A power law poorly represents the LF-STH relationship over land and fails over IO. A fifth power law is applicable only for pre-monsoon convective rain over land weakening to half in monsoon seasons (b = 2.48). Whereas, for stratiform rain, it is weaker with (b = 3.27) and (b = 1.67) for pre-monsoon and monsoon seasons respectively. Our findings suggest that one threshold based lightning parameterizations are inadequate and need to be generalized to include regional and seasonal differences which are unravelled here.

Keywords: Lightning Flash, Rainfall, Power law relation, Storm Top Height

Sensitivity of physical schemes in WRF model on simulation of mesoscale convective system over South-east India

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Role of various parameterization schemes in simulating the evolution of the mesoscale convective system (MCS) occurred over southeast India. Using the Weather Research and Forecasting (WRF) model, numerical experiments are conducted by considering various planetary boundary layer, microphysics, and cumulus parameterization schemes. Performances of different schemes are evaluated by examining boundary layer, reflectivity, and precipitation features of MCS using ground-based and satellite observations. Among various physical parameterization schemes, Mellor-Yamada-Janjic (MYJ) boundary layer scheme is able to produce deep boundary layer height by simulating warm temperatures necessary for storm initiation; Thompson (THM) microphysics scheme is capable to simulate the reflectivity by the reasonable distribution of different hydrometeors during various stages of the system; Betts-Miller-Janjic (BMJ) cumulus scheme is able to capture the precipitation by the proper representation of convective instability associated with MCS. The present analysis suggests that MYJ, a local turbulent kinetic energy boundary layer scheme, which accounts strong vertical mixing; THM, a six-class hybrid moment microphysics scheme, which considers number concentration along with mixing ratio of rain hydrometeors; and BMJ, a closure cumulus scheme, which adjusts thermodynamic profiles based on climatological profiles might have contributed for better performance of respective model simulations. Numerical simulation carried out using the above combination of schemes is able to capture storm initiation, propagation, surface variations, thermodynamic structure, and precipitation features reasonably well. This study clearly demonstrates that the simulation of MCS characteristics is sensitive to the choice of parameterization schemes.

Physical Mechanisms of Mesoscale Convective Systems over Southeast India using collocated multi Observations

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To enhance the knowledge of various physical mechanisms related to the evolution of Tropical Mesoscale Convective Systems (MCSs), detailed analysis has been performed using a suite of observations (weather radar, electric field mill, surface weather station, flux tower, microwave radiometer and wind profilers) available at Gadanki (13.5N/79.2E), located over southeast India. Analysis suggests that these systems developed in a warm, moist environment associated with large-scale low-level convergence. Significant variations in cloud to ground (CG) lightning activity indicate the storm electrification. Deep (shallow) vertical extents with high (low) reflectivity and

cloud liquid water; dominant upward (downward) motion reveals variant distribution in convective (stratiform) portions. Existence of both +CG and –CG Cashes in convective regions, dominant –CG in stratiform regions explains the relation between lightning polarity and rain and cloud type. Sharp changes in surface meteorological variables and variations in surface fluxes are noticed in connection to a cold pool of the system. Increase (decrease) in temperature, moisture, and equivalent potential temperature within the boundary layer in convective (stratiform) regions associated with latent heat warming (cooling) of air parcel is apparent. Presence of updrafts and downdrafts in convective region and dominant downdrafts in stratiform regions are evident from vertical velocity measurements. Isentropic upgliding (downgliding) illustrate the existence of isentropic ascents (descent) of air parcels in the storm vicinity. Veering (backing) of wind due to warm (cold) and moist (dry) air advections demonstrated the formation of thetae ridge in storm environment. Blend of observations provided considerable insight of electrical, microphysical, thermodynamic, dynamic and kinematic features of MCS.

Prediction of thunderstorms over southeast India using empirical methods

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Thunderstorms, associated with lightning and heavy rain, are a weather hazard causing human deaths, urban floods and damage to crops. Current work attempted to study the thunderstorms over Andhra Pradesh, coastal state in Southeast India, using multiple satellite datasets, gridded rainfall, Doppler Radar Images and Advanced Research Weather Research and Forecasting (ARW) model simulations during the pre-monsoon seasons of 2017 and 2018. Thermodynamic stability indices computed using INSAT-3D/3DR satellite data were used to identify precursors and lead time of prediction, IMD daily gridded rainfall data were used to identify the thunderstorm occurrence days, Doppler Radar Images and INSAT imagery were used to fix the location. Eight severe thunderstorm cases were analyzed to assess the precursors and the predictability. Further, ARW model predictions for two thunderstorm cases were performed and stability indices computed using model output were compared with satellite based indices for evaluation. Statistical metrics had shown good agreement of ARW model based stability indices with satellite based stability indices. The results illustrated the predictability of the location and intensity of thunderstorm with 3-4 hours lead time. These results would find usefulness in the real time prediction of thunderstorms.

Keywords: Forecasting, INSAT-3D/3DR satellite, Thunderstorms, stability indices

Evaluate WRF-based Lightning Potential Index (LPI) Lightning Parameterization over Sri Lanka during Second Inter-Monsoon in 2018

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Lightning is a most grievous and oppressive weather phenomenon and is often accompanied by a severe thunderstorm, which under the circumstances with potentially lethal consequences for human life, and significant damage to critical infrastructure sectors. The impact of lightning normally depends on our understanding of the characteristics of lightning, forecasting capabilities, and also the validity of the precautionary steps that can be launched. However, quantitative analysis of natural hazards, such as the amount of death, resulted in a weather system reveals that lightning accidents come to a considerable place. Predicting a thunderstorm is one of the most difficult, demanding and grievous weather phenomena in the meteorology. It is important to develop accurate and reliable lightning prediction system that can be contributed towards the safety of life, both concerning forecasting for the public safety and safety of aviation and electrical power. This study aims to evaluate WRF-based Lightning Potential Index(LPI) lightning parameterization and its applicability for predicting lightning over Sri Lanka during the second inter-monsoon. The WRF-ARW model 3.9.1 was used to produce predictions for three lightning events with various physical parameterization schemes with two nested domains with a resolution of 12km and 4km respectively. In this study, four different microphysics schemes (WSM6, WDM6, Thompson and Morrison 2-Moment) were used, which have six types of hydrometeors to investigate the sensitivity of the microphysics process to the model. Two cumulus parameterizations schemes (Betts-Miller-Janjic and Grell-3) were selected in this study. The model simulated LPI values were evaluated using the Earth Networks Global Lightning (ENGLN) dataset. Results show corresponding lightning simulations were produced with spatial distribution aligned with ground-based lightning data. Results consistently show a high correlation of the LPI index with an hourly CG flash rate over the three cases. The WDM6 is the best microphysics, among these selected microphysics and cumulus physics schemes are not much affected to the fine domain. Moreover, the WRF model was able to capture the lightning using LPI in Sri Lanka, suggesting that it can be used operationally to predict potential lightning region.

Keywords: Lightning prediction, LPI, Sri Lanka, WRF model

Dynamic Implications of Jump in 'Rate of Lightning' Prior to Tornadogenesis

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Implications of jump in the rate of lightning, 15 – 20 minutes before tornado has been analysed. The occurrence of high EF($\geq$ 2) tornadoes, mostly with positive lightning, has been mathematically hypothesised and role of the geomagnetic field is noted. The jump before tornado formation causes repeated triggering to accentuate prevailing environmental rotational convergence, buoyancy and levitation support at a low level. It also explains the cause of tilting of Streamwise Vorticity

Current (SVC) vector to abruptly orient upwards as has been noted in recent 3-D numerical modelling of tornadogenesis.

Rate of heating per unit surface area is directly proportional to B0 2 ,$\sqrt{\omega}$ and inversely proportional to $\sqrt{\sigma}$; where B_0 is maximum of the in-situ horizontal magnetic field, σ is electrical conductivity in Siemens per meter(S/m) and $\omega = n/(2\pi.T)$ where n is number of return strokes of Cloud to Ground lightning and T is the total duration of strokes in seconds. As positive lightning induces stronger B0 hence it is more effective in helping tornadogenesis.

If J is the current due to lightning and B is the magnetic field then for channel of radius 0.8 cm, the Lorentz force ($\overline{JxB}$) at 50m radial distance induced buoyancy force of approximately $0.08g < F < 8g$, where g is the acceleration due to gravity. If by any chance lightning is repeating in close proximity then cumulatively the vertical column would receive repeated flash heating, enhancing the skin-depth temperature by ≈ 2 K(after ≈ 100 close flashes). Over dry vegetation region sometime, therefore, high voltage supercell may spawn tornado fire under high-density lightning region.

Cloud voltage drastically drops due to repeated Cloud to Ground (CG) lightning hence its frequency either immediately reduces or sometimes permanently stops after the formation of a tornado.

It is hypothesized that probable location of quasi-linearly placed tornadoes formation is at right angle to the horizontal component of the in-situ geomagnetic field.

Preliminary evaluation of Indian Lightning Location Network (ILLN) performance across Lucknow using ordinary camera

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Lightning safety is highly demanded in India as more than 2000 deaths reported every year. Uttar Pradesh is one of the highest deaths reporting state due to lightning and forecasting with awareness is in demand. Recently, a lightning location network is deploying and expending over India that has more than 83 sensors across the country. Currently, these sensors procured and operated by Indian Institute of Tropical Meteorology (IITM), Pune and data had directly transferred to IITM server. Until now, there is not any validation of these data using optical ground truth, which is one of the reliable validation methods. In consideration of this, the present work showing the validation of this network using the lightning observed by an ordinary camera

The camera mounted on the rooftop of a residential complex in Lucknow when the thunderstorm has noticed on 20 April 2020 and reached closer to the observation location. Seventeen CG flashes recorded from the camera within 10 minutes interval and most of them were identified multi-stroke CGs. In the validation with Indian Lightning Location Network (ILLN), we found ILLN were capable to locate 13 flashes in which one stroke was positive CG and two misclassified as IC. The peak current range of negative CG was -12 to -35 kA and the single positive CG peak current was 39 kA. It is revealed that the flash detection efficiency was around 76.5%. Authors believe that this is a good detection accuracy as the experiment was conducted during the nation wise lockdown due to Covid-19 and many sensors maintenance were worse and some were non-operational. Further, these validations were within the 50 km area from the mounted camera and it may be possible some of the flashes were located outside of the range due to poor location accuracy and needs a further investigation. In this preliminary study, the observed cases are shedding a light on the ILLN performance. These validations encouraging enhance the density of the network and validation, which will support to improve the ILLN over India and could utilize by meteorologist and forecasters.

Lightning and electrical properties of severe thunderstorm on 25th June, 2020 over the Eastern part of India: A case study

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The study of thunderstorms is of special interest because of their socio-economic impact. A study of lightning and electrical properties of a thunderstorm along with thermodynamical parameters facilitate the better understanding of the cloud mixed phase process and dynamical structure of the thunderstorms. A case study is carried out for a severe thunderstorm occurred on 25th July 2020 over the Eastern part of India. According to National Crime Investigation Bureau (NCIB) report, about 116 people lost their lives by the lightning strikes that occurred during the life cycle of the thunderstorm over different parts in Eastern India.

In order to understand the characteristic of the thunderstorms, the life cycle of the thunderstorm was studied by using INSAT 3D observed cloud top temperature (CTT). The simultaneous ground observations are considered from the lightning detector (LD-350) and Electric Field Mill (FM-100) stationed at Rampurhat in West Bengal. The thunderstorm is analyzed in terms of lightning strike rate for + cloud-to ground (+CG), - cloud-to ground (-CG), + intra-cloud (+IC) and + intra- cloud (+IC) along with the surface electric field (E) and its step change during lightning discharge, These observations are supported by Convective Available Potential Energy (CAPE) and Lifting Index (LI), considered from the ERA 5 reanalysis datasets.

It is observed that the thunderstorm was initiated in the northern part of Uttar Pradesh and crossed over Bihar, Jharkhand and West Bengal to dissipate at the Bay of Bengal. During the later part of the active stage of the thunderstorm, it crossed Rampurhat (24.17 °N; 87.78 °E; West Bengal) where the ground observatory is situated. The duration of the initial, active and dissipation stage of the thunderstorm is found to be 2.8 hours, 4.3 hours and 3 hours respectively. The minimum CTT (Tbmin) of the thunderstorm during initial, active and dissipation stages is 210 K, 191 K and 209 K respectively. The IC-CG ratio shows the maximum value of 12 during the initial part of the active stage, followed by an initial stage (7) and the dissipation stage (4). However, the ±CG strike rate was maximum during the later part of the active stage (133 strikes/minute) followed by initial (78 strike/minute) and dissipation stage (45 strike/minute). In addition, it is also observed that, out of total lightning discharge, +CG% (-CG %) contributes in the range of 8% to 18% (16% to 31%) during the whole life cycle of the thunderstorms.

The step change in the electric field shows mostly - CG lightning during the active and dissipation stage. This suggests that thunderstorm is associated with a positive dipole structure. The lightning strike distributions with both the polarity support this result. The maximum IC-CG ratio, minimum CTT and maximum CAPE values are observed to occur nearly 1 to 2 hours prior to the occurrence of the maximum ±CG strikes.

A study using three years of Lightning Data over the PAN India during 2017, 2018 and 2019

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Lightning strikes were the worst killer among all the natural disasters in India as per the data of the National crime records bureau of India (ncrb.gov.in). Lightning strikes major impacts is human deaths and many people who survived after lightning strikes showed symptoms of "memory loss, dizziness, weakness, numbness, and other life-altering elements". Lightning strikes impact trees by vaporizing water present in the tree into steam and may blow the tree apart (nationalgeographic.com). The present study aims to analyse lightning strokes across India for the three consecutive years, i.e., 2017, 2018 and 2019 respectively. Observance of lightning events determined using the installation of lightning sensors and data preparation and analysis done using earth network. Lightning sensors installation increased from 2017 to 2019 and thus accuracy in reporting of the forecast for lightning events also got improved effectively. 10 and 8 Lightning sensors installed in states like Karnataka, West Bengal in 2018 respectively, while 6 and 2 more lightning sensors installed in Odisha, Assam and 1 each in Nagaland and Mizoram respectively in 2019. Increase in installation of lightning sensors in West Bengal region improved in reporting of lightning events in West Bengal, Odisha, Jharkhand states mainly in 2018 and as a result, we observed increase in a number of lightning strikes in Eastern region of India in 2018. Similarly, lightning events were more accurately reported in north-eastern states and Odisha in 2019. Considering such increase of lightning sensors yearly, we have incorporated detection efficiency calculation for the cloud to ground (CG) lightning strokes. Major parameters like lightning strokes density, CG and Inter as well as Intra cloud (IC) lightning densities, positive CG and negative CG lightning density, CG by IC lightning events ratios, Average IC lightning heights and total lightning events recorded in each state and union territories of India from 2017 to 2019 were reported in this study respectively.

Keywords: Lightning, Cloud to ground, Earth Networks

Comparative Study of Severe Thunderstorm Events of 25th/26th June 2020 and that of 3rd May 2009

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High Impact severe weather events like thunderstorms are associated with strong winds, dust, thunder, lighting, heavy rainfall, hail etc. Such event has devastating consequences particularly as aviation hazards, loss of life and damage to property, vegetable crops and food. A fusillade of lightning strikes associated with intense thunderstorm spread across the two states of Bihar and Uttar Pradesh on

25th/26th June killed more than 100 people. Similarly, a severe thunderstorm had also caused large scale damage to life and property over the West Bengal region on 3rd May 2009. In the present study, a comparative study has been carried out by investigating synoptic, thermodynamic and dynamical features leading to these two intense systems. Further, the mesoscale model viz., the Weather Research Forecasting (WRF) Model are also used in the present case to see the fidelity of the model in simulating such events.

The low level convergence associated with an increase in Convective Available Potential Energy (CAPE) and the moisture supply from the Bay of Bengal regions were responsible for the severe thunderstorm of May 3 2009. Similarly, the event of 25th/26th June 2020 during the monsoon period is also associated with low level convergence over Bihar and Uttar Pradesh, which continued for two days causing severe casualties and loss of lives.

Weather Research and Forecasting model version 3.6.1 at 3 km resolution has been used for simulation and investigation of the present case of 25th/26th June, whereas the earlier version of WRF model (with nesting at 18, 6, 2 km) was used for the simulation study of the event of 3rd Mat 2009.

The results show that the WRF model with nesting has the capability to forecast extreme weather event (Thunderstorm). The genesis of the thunderstorm events is well predicted in WRF models almost 12 to 18hr before the genesis of the system. The results are further analyzed in the present study.

THEME 3

Numerical Weather Prediction, Data Assimilation and Forecasting

An Ensemble-based Forecast Sensitivity Approach to Estimate the Impact of Satellite-derived Atmospheric Motion Vectors in a Limited Area Model

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The availability of satellite observation over data sparse regions such as oceans is understood to be one of the major reasons for the improvements in the tropical cyclone forecast in the recent decade. The observations from *in situ* and satellite are assimilated into the initial conditions of Numerical Weather Prediction models using data assimilation systems such as Ensemble Kalman Filter (EnKF) to enhance the performance of weather models. However, recent studies show that more than 50% of observations that are assimilated into the model degrade the forecast than improving it. Hence it is important to identify and remove the observations that degrade the forecast to improve the efficiency of weather forecast models. In this study, we utilized the Ensemble Forecast Sensitivity (EFSO) method to estimate the impact of satellite wind observations under the pretext of two tropical cyclones formed over the Bay of Bengal. The initial results are encouraging and our results concur with the previous studies that 52% of satellite wind observations improved the forecast while the rest of the observation degrades it. The mathematical formulation and other details of the experiments will be presented at the conference.

Sensitivity Analysis of Two Extreme Rainfall Events over Southwestern Coast of India using Ensemble Statistics

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The role of synoptic-scale features and its uncertainties on ensemble forecasts of two heavy rainfall events over Kerala, the southwestern Indian state, in the years 2018 and 2019 are evaluated by using European Centre for Medium Range Weather Forecasting (ECMWF) THORPEX Interactive Grand Global Ensemble (TIGGE) dataset. Kerala witnessed intense rainfall episodes in the years 2018 and 2019 associated with the formation of a low pressure system over the Bay of Bengal (BoB). Most of the numerical models had difficulty in predicting the intensity of precipitation of these two events. The uncertainty in the atmospheric features and predictability of these two rainfall events are addressed in this work using Ensemble-based Sensitivity Analysis (ESA). This sensitivity analysis establishes a linear relationship between the key synoptic-scale features and area-averaged precipitation and uses ensemble statistics to reveal uncertainties in the dynamics. The results showed that the low predictability in the two rainfall events is associated with uncertainties in the strength and position of the mid-tropospheric trough and westerly monsoon winds. Further, the 2018 precipitation forecasts are sensitive to the position of the remotely aligned circulations over the South China Sea (SCS) and Western North Pacific (WNP) and this sensitivity feature was not seen in 2019 even though circulations were present in those regions. The large spread in the August 2019 precipitation

forecasts was mainly due to the strength of the depression over the Bay of Bengal and its northwestward progression. These results are further confirmed by comparing composites of good and bad ensemble members. It appears that ensembles with a more eastward shifted circulation over SCS are associated with better forecast skill and more precipitation in August 2018.

Numerical Simulation of a massive Biomass Burning Event over South Asia: Impact on meteorology and Air Quality

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Atmospheric aerosols are capable of modifying the regional weather pattern by altering Earth's radiation budget. Black Carbon (BC) is considered one of the major absorbing aerosols that can create significant atmospheric warming. Both anthropogenic and natural biomass burning events emit a large amount of BC aerosols into the atmosphere. A massive biomass burning event was detected over the south Asian region from 19th to 23rd March 2012. Using a fully coupled chemical transport model (WRF-Chem), multiple numerical simulations were performed to understand the impact of BC aerosols on meteorology and air quality (focused on surface ozone) during the aforesaid biomass burning event. The simulated BC pattern during the study period matches the observation (by MODIS Aqua) well qualitatively. It is observed that the elevated BC concentration reduces the surface temperature up to 2 K in the source region. The radiative impact of black carbon reduces the incoming short wave flux at the surface and the boundary layer (PBL) height by 70%. The reduction in PBL height further increases the BC concentration in the source region. Thus the enhanced BC originated due to biomass burning initiates a feedback mechanism.

Besides aerosols, the ozone concentration is also well simulated and validated against the observations. It is crucial to notice that the ozone concentration is well captured using a global emission inventory (HTAP) rather than an area-specific emission inventory. The results show that surface ozone concentration can increase significantly during a biomass burning event. However, elevated BC can drastically reduce the surface ozone concentration (~30%) at the source region by altering the incoming radiation and changing the photolysis frequencies. The study provides practical evidence regarding the impact of elevated BC on meteorology and air quality.

Understanding the 2016 Delhi Diwali Pollution Episode: A numerical modelling perspective

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Delhi, the National Capital Territory (NCT) region of India, is considered among the most polluted cities in the world. The city has experienced several post-monsoonal pollution episodes in recent years as the peak in air pollution occurs typically during the post-monsoon and winter period depending on several factors. However, the 2016 Diwali pollution episode was considered the most significant one. Diwali or the festival of lights is one of the major festival associated with firecrackers burning celebrated throughout the Indian subcontinent. The 2016 pollution episode persisted for more than a week and had created massive discomfort for the local inhabitants which led the judiciary to ban the selling of firecrackers in Delhi. Several numerical simulations using a fully coupled atmospheric chemistry model (WRF-Chem) were performed to understand the origin of the pollutants during that period.

Both the concentration of the pollutants and the meteorology is well simulated and shows a close association with observed data. Results show that the aerosols produced from crop residue open burning in the north-western states of Punjab and Haryana contributed to more than 60% of the total pollutant concentration during the 2016 episode. The contribution from the local pollutant sources inside the NCT was negligible compared to the transported pollutants. The impact of local emissions due to Diwali festival does not last beyond 48 hours. Low surface temperature, boundary layer height, and weak north-westerly winds also provided a favourable condition for the stagnation of the air mass over Delhi during the study period. The study provides insight into a less common instance where regional air pollution significantly affects megacity pollution.

Investigation of Air-Sea Interaction Processes in Tropical Cyclones over the Bay of Bengal Basin

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The eastern coast of India is prone to the landfalls of intense tropical cyclones (TC). These TCs are associated with massive storm surges and incredibly high wind speed, which result in immense destruction of properties, inundation of coastal estuarine deltas, and loss of lives. The extremely severe cyclonic storm Fani made landfall over the coastal state of Odisha in May 2019. The following year, a Super Cyclone Amphan made landfall over West Bengal. The ocean surface and sub-surface conditions strongly modulate these cyclones, and accurate understanding of these ocean processes, which in turn provide feedback to the atmospheric conditions, will improve the accuracy of cyclone

intensity and track forecasts. In the current study, the TC Fani and Amphan are simulated using the Coupled Ocean-Atmosphere Wave and Sediment Transport (COAWST) Model. The atmospheric component of the model, i.e., Weather Analysis and Forecasting (WRF), is simulated using the Global Data Assimilation System (GDAS) $0.25^{o}\times0.25^{o}$ tropospheric analyses initial and boundary conditions. The ocean component, i.e., Regional Ocean Modeling System (ROMS), is simulated using the National Centre for Medium-Range Weather Forecast (NCMRWF) ocean analysis datasets. The Wave component, i.e., Simulating Waves Near-shore (SWAN), is simulated using the European Centre for Medium-Range Weather Forecast (ECMWF) 5th Generation Reanalysis (ERA5) forcings. Incorporation of the ocean processes resulted in considerable improvement in intensity and mean sea level pressure forecasting compared to the stand-alone WRF simulations. The ocean coupling is quantified in terms of the ocean surface fluxes. The moist static energy (MSE) budget analysis is employed to investigate the energy conversion processes. Furthermore, the sub-surface processes are validated using buoy observations over the Bay of Bengal basin and are thoroughly investigated for a better understanding of the feedback processes.

A Technique to Forecast Visibility over Hindon Airport with WRF-ARW and Analyzing the Impact of Air Quality over Reduction in Visibility

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Visibility forecasting for aviation during post-monsoon and winter season has always been the most challenging task for aviation forecaster, especially for visibility range of operational significance (visibility less than 3 Km). Decadal analysis of visibility over Hindon (Ghaziabad) airport was carried for a period of three decades (1990-2019). Poor visibility (less than 2 Km) episodes have increased from 39% to 74% in the last three decades. In the absence of any Meteorological evidence of significance, this increase in the frequency of poor visibility is assumed to be due to the degradation of air quality because of urbanization, industrialization and anthropogenic contribution. In this study, an attempt has been made to develop a forecasting technique using WRF ARW V4.0 NWP model with air quality indices as additional predictors. The air quality indices selected are Particulate Matter (PM10 and PM2.5), SO_2, NO_2 and CO. The Meteorological parameters used along with these parameters are Dew Point Depression (at surface, 925hPa and 850hPA), wind speed (at surface, 925hPa and 850hPA), cloud fraction (low, medium and high), lapse rate between surface and 925hPa and lapse rate between surface and 850hPa. The technique developed using air quality indices as a predictor was able to address limitations of existing techniques which uses only Meteorological parameters as predictors.

Convective Scale Data Assimilation of thunderstorm events over a complex terrain

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With the development of high-resolution models, the efficient use of observations at high density in data assimilation is becoming significant. Convective-scale models explicitly represent convection and generally experience a rapid evolution of weather systems. Since many convective-scale phenomena are forced from the lower boundary condition, surface and soil data assimilation are essential components of any convective-scale data assimilation system. We have developed the framework for convective scale data assimilation using satellite and radar reflectivity data. The direct method of assimilating reflectivity in the initial conditions involves an empirical reflectivity observation operator to link reflectivity with rainwater. Total liquid water is used as a microphysics control variable. The model initial and boundary conditions are prepared at 6-km and 2-km over the south Indian domain, and the Weather Research and Forecast model (ARW-WRF ver 4.2) is used for model simulation. The assimilation experiments were designed using the observation operator and microphysics parameterization. The impacts of assimilation are being studied for convective events over Gadanki, Trivandrum using X-Band Radar and DWR, respectively. The assimilation of X-band radar data shows the improvement in the precipitation in the neighbourhood of the location of RADAR. The simulated rainfall has been compared with the GPM measurements as well as in-situ measurements. The bias and RMSE are calculated with respect to the observed data set. It is observed that the spatial correlation of the rainfall has been increased with the assimilation of RADAR data in hourly rapid update cycle mode. The results of the case studies will be presented at the conference.

Object-Based Diagnostics Evaluation of Super Cyclone Amphan

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There are various methods available for verification of cyclones. The Object-based diagnostic evaluation is one of the techniques. This is an object-based technique of spatial verification methods which provides information which is not possible to obtain using general traditional grid-point based verification methods. It objectively identifies simple objects in rainfall fields at different thresholds, which would mimic what humans call as "regions of interest". This process is a multistep one which is called the convolution thresholding technique. It basically involves the application of a simple circular filter which in terms is a function of convolution radius (CR), here we have used 2 grid squares (1 grid size ~10 km). Once the filter is applied, the convolved field is thresholded using a convolution threshold (CT) to generate a mask field. Finally, the actual data is restored inside the masked regions of object interiors to obtain the object field. Thus the objects are the function of convolution radius and convolution thresholds. From the object-based evaluations of Amphan's high intensity rainfall in the cluster pair table which shows the overall performance of the NCUM modelling system. The Object-based Evaluation analysis shows the minimum centroid distance

which is a quantitative measure of the forecast spatial displacement (2.35 grid-squares) and area ratio is 0.94 (128/136) which shows a very good areal extent of forecast 5 days in advance, which is supported by the total interest.

Keywords: Object-based Diagnostics, Convolution threshold, convolution radius, centroid distance, angle difference, Interest

Development of a high-resolution (400 m) operational air quality early warning system for Delhi, India through integrated chemical data assimilation

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Managing air quality levels in the National Capital Region (NCR), especially Delhi, India has emerged as a complicated task. It is now a matter of top priority to develop meaningful policy options. Short-term air quality forecasts can provide timely information about forthcoming air pollution episodes that the decision-makers can use to implement temporary emission control measures and reduce public exposure to extreme air pollution events. Although India has developed air quality forecasting systems for NCR, it was challenging to predict acute air pollution episodes during which hourly PM2.5 concentrations exceed 300 μg/m^3. In this perspective, a very high-resolution (400 m) operational air quality prediction system has been developed to predict extreme air pollution events in Delhi and issue timely warnings. This modeling framework consists of a high-resolution fully coupled state-of-the-science Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) and three-dimensional Variational (3DVAR) framework of the community Gridpoint Statistical Interpolation (GSI) system. The system assimilates satellite aerosol optical depth (AOD) retrievals at 10 km resolution, real-time crop residue burring at 1km resolution, surface PM2.5 data from 260 air quality monitoring stations, and uses high-resolution dynamical emissions (400 m) from various anthropogenic sources. The chemical data assimilation is further integrated with dynamical downscaling to obtain improved chemical conditions for the 400 m resolution domain. This paper summarizes the performance of the model forecasts for the winter season 2019-2020 and the evaluation of the model against the observations. Here, we demonstrate that the assimilation of chemical data in a coupled weather-air quality model improved the overall accuracy of PM2.5 forecasts in New Delhi by 70-86% during the winter season 2019-2020. Results show that the skill score for the poor (AQI 200-300), very-poor (AQI 300-400) and sever pollution (AQI 400-500) days is relatively promising for the hit rate with a value of 0.74 for (very-poor). This indicates that the model has reasonable predictive accuracy for air quality events. False Alarm rate (0.19), missing rate (0.32) are low, and the probability of detection is relatively high (0.67), indicating that the performance of the real-time forecast is better for both very poor events and no-very poor events.

UM Regional coupled Suite over India: Status and Future plans

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In recent years high-resolution regional models are extensively used for short range weather forecast (up to 3-days) by both research and operational purposes. These forecasts become very useful, especially in case of severe weather events such as tropical cyclone, monsoon depressions. Forecast products from high-resolution regional models can provide better insight for both researchers and end-users. Many research groups and operational weather forecast agencies are using limited area models (also referred to as regional models) to fulfil their respective requirements. Like their global counterparts, these regional models are also going through a phase of continuous development, most of these models have, therefore shown improved skills over different parts of the world. However, providing short range high-resolution forecast with very high skills over the monsoon region remains a challenging task. Ocean-atmosphere coupled processes over the Bay of Bengal requires a high-resolution coupled model for a proper understanding of air-sea interactions and oceanic mixing. Regional atmospheric models coupled with regional ocean model can be used to improve the skills of the forecast over monsoon domain. An attempt is underway for the development of a regional coupled prediction prototype by U. K. Met office. This model uses NEMO as the regional ocean and Met Office's UM model as a regional atmospheric component of the regional coupled system, with provision to include wave model. Few case studies of recent severe weather incidents are carried out using UM regional coupled suite over Indian domain. Initial results are looking promising. Additional research is ongoing for further improvement of this suite. This work is in the early stages and many more sensitivity tests and fine tuning of the model is still ongoing. Initial results from a regional suite's set-up will be presented during the conference.

Performance of ensemble forecasts as compared to deterministic prediction for extreme rainfall events over complex terrains

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A high spatial resolution enables a better representation of topography with a more accurate description of horizontal and vertical structures and assimilation of observations. The global Ensemble Prediction System at the National Centre for Medium Range Weather Forecasting (NEPS-G) features one control and 22 perturbed members with 12 km horizontal resolution and 70 vertical levels. The initial condition (IC) perturbations are generated by Ensemble Transform Kalman Filter (ETKF). Physics perturbations are obtained from Stochastic Kinetic Energy Backscatter (SKEB) and Random Parameters schemes. For the medium-range prediction of extreme weather events particularly, instead of over-interpreting a single high-resolution deterministic forecast, it is better to

combine the probabilistic forecasts as well, in order to facilitate risk assessments of varying magnitude. The performance of deterministic and consensus forecasts are investigated in this study for a few extreme rainfall events. The ensemble mean precipitation forecasts between 15.6-65.5, 65.5-115 and 115-195 mm/day rainfall are verified against Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG GPM) fine-scale observations. It has been found that both NEPS-G mean and CNTL have a systematic tendency to over-predict precipitation over complex terrains like the Western Ghats, Himalayan ranges, Assam, Meghalaya, Arunachal Pradesh and Myanmar during June-September. The consensus or ensemble mean forecast is associated with relatively lower systematic errors and RMSE as compared to that of CNTL forecast. NEPS-G mean is found to perform reasonably better than the single CNTL forecast in terms of proportion correct, Peirce's skill score, Heidke skill score and Gerrity score for the extreme rainfall events.

Contribution of Lagged Members to the Performance of a Global Ensemble Prediction System

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The ensemble size of the 12-km global ensemble prediction system of NCMRWF (NEPS-G) is 23 (22 perturbed + 1 control). Out of these 23 members, the control and 11 perturbed members run from 00 UTC of the current day and another set of 11 perturbed members run from previous day 12 UTC to provide next 10 days forecast. Ideally, the start time of all the ensemble members should be the same because the slightly different initial conditions of all the ensemble members are supposed to represent the initial condition uncertainty of the initial model state. The focus of the present study is to investigate how much degradation of the forecast quality does the lagged ensemble cause and whether we are getting any benefit from the contribution of lagged ensemble members over the set of 11 members that starts from 00 UTC every day. For this, we have carried out an inter-comparison of the relative skills of (i) 11-member ensemble starting from 00 UTC i.e. E00_11, (ii) 11 member ensemble starting from 12 UTC i.e. E00_12 and the (iii) operational 23-member ensemble i.e. E23 based on the verification of probabilistic geopotential height, temperature and zonal wind forecasts for 7-day forecast lead times over the period of 15th April 2019 to 15th June 2019. The verification of geopotential height at 500 hPa and temperature at 850 hPa has been carried out over the northern hemisphere and zonal wind at 850 hPa has been carried out over a smaller tropical region which includes India. The metrics used for verification are ensemble-spread, ensemble root-mean-square error, brier score, brier skill score, relative operating characteristics, reliability, rank histogram and continuous ranked probability score. The results show that although RMSE of E12_11 is larger than E00_11 at all forecast lead times, it is still always smaller than that of the control member. Another striking feature is that spread of E23 for all three variables is always larger and hence RMSE-spread ratio is smaller than E00_11 and E12_11 at all forecast lead-times. Although E12_11 skill is always less than that of E00_11 when it combines with E00_11 to form E23 the skill of E23 becomes better than both of them at all forecast lead times. BSS is positive and ROC skill score is greater than 0.5 beyond 7 days forecast times for all the variables for all three ensembles. CRPS for E00_11 and E23 are almost same for all forecast lead times and are better than E12_11. Overall, the contribution of 11 lagged ensemble members helps in improving the skill of the global ensemble prediction system.

Improved Track and Intensity Prediction skill of up-graded NCUMG model: A case study of Super Cyclone Amphan

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National Centre for Medium Range weather Forecasting (NCMRWF) provides Numerical Weather Prediction (NWP) model guidance in terms of cyclogenesis, track, intensity and landfall forecast of all the tropical cyclones (TCs) develops over North Indian Ocean (NIO). NCMRWF NWP modelling system undergoes a periodic update to integrate the new scientific and technological advancements under "UM Partnership". During June 2020, the NCUM global system (NCUMG) has been upgraded with the latest UM components (based on Parallel Suite 43 of Met Office, PS43). The new version of the model (Unified Model Version 11.2) has improved model physics and latest land-surface science configurations. Major improvements in the data assimilation (DA) system include the capability to assimilate cloud-affected microwave observations from ATOVS. Observation pre-processing system is enhanced with the capability to process the latest satellite observations.

The present study investigates the skill of up-graded NCUM global model in predicting the Super Cyclonic Storm (SuCS) "Amphan" with respect to its predecessor in terms of track errors. Based on the different model initial conditions, it was noticed that NCUMG has excellent prediction skill with average initial position error less than 50 km whereas the average track errors in 120-h is 239 km. Results further suggest that NCUMG shows early prediction of cyclogenesis and reduced track errors. Although there is no improvement noticed in model initial position error, direct position error (DPE) is reduced by 12%, 44%, 54%, 62% and 39% in 24-, 48-, 72- and 96-h forecast lead time. This improvement is attributed to the reduction in errors in both the along (ATE) and cross track errors (CTE).

Keywords: NWP model, NCUM, Tropical Cyclone, Track Error

Numerical modelling of Super Cyclonic Storm AMPHAN using WRF-ARW model

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Tropical cyclones (TCs) are one of the most feared and deadly meteorological phenomena which hit the coastal regions on landfall causing huge devastation to life and property. The devastation is mainly due to the strong wind, heavy rainfall and associated storm surges. In the present paper we simulate the Super Cyclonic Storm (SuCS) "AMPHAN" which was the first SuCS over the BoB, after the Odisha Super Cyclonic Storm of 1999. The widely used time-tested WRF-ARW model has been employed to test the impact of real time Sea Surface Temperature (SST) on the life cycle of the storm. The model is designed to have two domains one an outer domain with 27km horizontal

resolution and the other is an inner domain with 9 km resolution. The initial and the lateral boundary conditions have been taken from the National Center for Environmental Prediction (NCEP)-GFS at 0.50x0.50 resolution and the SST data is obtained from NCEP. The results showed that the track of the cyclone is estimated better when a real time SST is used. Also, the evolution of the vortex is presented with and without an updated SST at various stages of the life cycle of the storm.

Keywords: Super Cyclonic Storm, WRF-ARW, Sea Surface Temperature.

Characteristics of Daily Sea Surface Temperature Analyses over the North Indian Ocean

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Sea surface temperature (SST) is the most important physical variable in weather analysis as it helps in quantifying, predicting and analysing the complex ocean-atmosphere interaction. The daily SST products are required to determine how heat is distributed over the global ocean which directly impacts the regional and global weather pattern. The SST is also very crucial parameter used in Ocean-Atmosphere coupled model particularly used for extended range (up to 4 weeks) and seasonal forecasting of precipitation and temperature. At present, the daily SST analyses used by IMD in the operational coupled model used for extended range forecasting is obtained from the Global Ocean Data Assimilation System (GODAS) carried out at Indian National Centre for Ocean Information System (INCOIS). The INCOIS GODAS SST product is used to provide ocean-state information as input to extended range forecast operational at Indian Meteorological Department (IMD) for the weekly to seasonal forecast. In the present study evaluation of INCOIS-GODAS SST field against the OISST (Optimal interpolated Data) is carried out to understand its characteristics by taking the daily SST analysis for 6 years from 2014 to 2019 during the monsoon season from June to September (JJAS). The comparison of SST is carried out in the 12 sea areas of North Indian Ocean (NIO) classified by IMD, particularly for the marine forecasts. The skill scores like Correlation coefficient (CC), Mean Bias and Root Mean Square Error (RMSE) is calculated for each region of NIO. As the El Nino and La Nina is an important atmosphere-ocean coupled phenomenon particularly the modulation of monsoon activity over the Indian region, the study also addresses the ability of INCOIS-GODAS in accurately representing the SST anomalies in the tropical Pacific Ocean associated with El-Nino event of 2015 and La Nina event of 2016. The results obtained from the present analysis shows a significant correlation existing between the SST values for the two datasets. The El-Nino and La Nina event of 2015 and 2016 are also well captured in INCOIS-GODAS SST analysis like that is seen with the OISST analysis. The outcome of this study can address the utility of INCOIS GODAS SST data for providing initial condition for the Numerical Weather Prediction models used at IMD.

A Geostatistical Approach to generate weather information over the Northwest Himalayas at fine spatial grids

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Western Himalayas, along with the adjoining Tibetan Plateau, are one of the most complex regions in terms of topography and weather. Strong orographic influence, erratic terrain and local climate physics intensify the spatiotemporal variability of weather variables in the region. Due to these peculiar characteristics, accurate estimation of weather information for such a complicated terrain is difficult. Rain gauges are sparse due to topographic constraints and harsh weather leading to unavailability of sufficient observation data. Moreover, due to computational limitations, meteorologists usually generate data at coarse spatial resolution covering a larger area and fine resolution data for smaller areas. Considering the significance of the region in influencing the weather patterns along the surrounding mainland, we in this study, set up a geostatistical model based on Multiple-Point Statistics (MPS) to generate fine gridded precipitation and temperature data in future utilizing the available hindcast data (coarse and fine scale data). High Asia Re-analysis (HAR), a product of Weather Research and Forecasting (WRF), provides both coarse and fine scale precipitation and temperature data at 30 and 10 km respectively over the Northwest Himalayan region from October 2000 to September 2014. The dataset is accessible online at http://www.klima.tu-berlin.de/HAR. MPS uses a multivariate training image which includes the spatial information of variables over several years. In our case, the training image consists of HAR data of daily precipitation and temperature at both 30 and 10 km from 2001-2012 for the four monsoon months: June, July, August and September (JJAS). The training image is used to predict precipitation and temperature data for the year 2013 at 10 km resolution, assuming no information is available for this year. Along with the training image, another dataset known as Conditioning data is used. Conditioning data is a set of pre-informed pixels consisting of information only at 30 km resolution for the target year, i.e. the year 2013. It helps in the identification of patterns in variables. Locational variables such as latitude and longitude, and topographical variables such as elevation, slope and aspect are also employed to identify correct patterns and features among variables. The final output is a daily time-series of precipitation and temperature data for the months of JJAS of the year 2013 at 10 km resolution. The estimated data for both variables are then compared against the reference dataset to evaluate the accuracy of the model to predict correct data. Our study signifies three major advantages: 1) provision of continuous fine scale weather data for a highly complex region such as the Northwest Himalayas, 2) the simulation takes reduced CPU run-time hour in comparison to dynamical downscaling, for generating the same data, 3) the generated fine scale data can be used as an input to hydrological and glaciological models to study future hydroclimatic scenarios in the Himalayan region.

GNSSRO Platforms Operational at NCMRWF – Present Status & Quality Assessment

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NCMRWF (National Centre for Medium Range Weather Forecasting), MoES (Ministry of Earth Sciences) assimilates GNSSRO (Global Navigation Satellite System (GNSS) Radio Occultation (RO) Data from various platforms for their operational model runs. One of the assimilation systems operational at NCMRWF is GDAS (Global Data Assimilation System). Bending Angle from the RO dataset is assimilated by GDAS using GSI (Gridpoint Statistical Interpolation) 4D-EnVar assimilation scheme. RO observation from new missions' COSMIC-2, KOMPSAT-5, METOP-C, FY-3C & FY-3D have been incorporated recently into the NCMRWF GDAS. Proper quality assessment of both the existing and new datasets is necessary to filter out the data of non-acceptable quality. This presentation will focus on the evaluation & quality assessment of all the RO dataset operational at NCMRWF.

Simulation of thunderstorm over NER of India by WRF model with direct and indirect assimilation of DWR data

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The DWR reflectivity data that gives information about the intensity of a cloud system whereas radial velocity provides information on vertical atmospheric motions were assimilated in WRF model for the simulations. Experiments were also conducted by indirect assimilation of DWR data in the WRF model. A case study on simulation of thunderstorm over the southern part of NER of India is discussed here and the experiments are named as CNTL for the control simulation without data assimilation, DWR_RF for direct DWR reflectivity assimilation with radial velocity and DWR_Q for indirect reflectivity assimilation with radial velocity. In the indirect method, instead of directly assimilating radar reflectivity, the retrieved rainwater and water vapor derived from radar reflectivity are assimilated. The thunderstorm considered here initiated at 12 UTC of 30th March 2018. The simulated thermodynamic indices and the meteorological field such as equivalent potential temperature, reflectivity, and vertical velocity are compared between CNTL, DWR_RF, and DWR_Q experiments. Vertical cross sections are taken through the thunderstorm core area at 24° N and 93° E for the analysis. It is observed that DWR experiment reveals the presence of moist warm core corresponding to strong updraft that further enhances the instability to build up the thunderstorm. The results depict tall cloud favorable for severe thunderstorm which is missing in the CTRL experiment. However, the severity of the thunderstorm is better simulated by DWR_Q, where reflectivity is assimilated indirectly. One of the problems with the direct reflectivity data assimilation is that reflectivity data from DWR gives information about the existence of precipitation only, but no information about water vapor, temperature and other fields. Therefore, warm-rain processes cannot be activated in the minimization of the cost function by DWR data only, until and unless prior instability exists required for convection. However, in the indirect method, the assimilation of the estimated water vapor is expected to provide a favorable environment that supports convection.

The skill of maximum temperature forecasts for major cities of North-East region of India during summer 2020

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India Meteorological Department issues maximum temperature (Tmax) forecasts for 36 locations of the northeast region of India (NER) for 7 days on daily basis. The forecasts are prepared based on various NWP models- temperature forecast field with value addition by the forecasters. In this paper, Tmax forecasts during summer 2020 for 14 major cities of NER have been evaluated using absolute error (AE), root-mean-square error (RMSE) and percentage of forecasts with an absolute error of less than or equals to 1.0°C. The forecast skill varies in the plain stations and also for stations located in higher altitudes. The results show that day 1 forecast are better than day2 and day3 in all the three summer months (March, April & May). For all the stations RMSE varies from 1.60 to 2.80 for day1 in the plain stations, however for hill stations it varies from 1.0 to 3.0 for day2 and day3, RMSE values are comparatively higher in all the stations. A similar pattern is observed in AE values also. The scores are compared with that of the scores of 2019 at an individual station to evaluate the relative performance.

Keywords: Maximum Temperatures, absolute error, root-mean-square error

Mesoscale Simulation of Helicity Evolution in Tropical Cyclone over North Indian Ocean

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Helicity is the fluid's tendency to helical (rotating updraft) flow measured by the spin component in the wind component direction. Helicity evolution during the pre-cyclogenesis environment until its dissipation has been investigated in this study. The high resolution (6km) analysis of tropical cyclone (TC) Fani, Titli, Mekunu, Luban, and Ockhi originated over the North Indian Ocean is generated by using the WRF mesoscale model and En3DVar assimilation techniques. We have examined the thermodynamic profiles and deep-layer shear to understand the favorable conditions for helical flow development. Evolution of vorticity, upper (lower) tropospheric divergence (convergence), and vertical velocity have been analyzed to realize the linkage between tangential (primary) and vertical (secondary) circulations. The dominance of developed convection over shear deformation has been analyzed by Okubo-Wiess (OW) parameter. Characteristic of turbulence cascade is explained from enstrophy variation of TC. The evolution of helicity and kinetic energy with TC intensification is analyzed to diagnose tropical cyclogenesis from helicity aspects.

It is found that helicity develops when convective available potential energy is greater than

1800 J kg^{-1}, and deep layer shear is above 2.5×10^{-3} s^{-1}. The helicity evolution profile reflects the tendency of bulk shear, which indicates that a minimum value of bulk shear is required to overshoot the prevention of suppression of updraft by precipitation. OW parameter crossing 10 $\times 10^{-8}$ s^{-1} represents the vortex at the cyclonic stage. The more intense stages correspond to a further increase in the values of the OW parameter. The increase in the helical feature is observed when TC intensifies from a lower scale to higher scales. Analysis indicates that 1 - 1.5×10^3 is the vortex's threshold helicity value to become at the cyclonic stage. The detailed results will be presented at the conference.

Numerical simulation of Sea breeze induced convective thunderstorms over southeast coast of India with different Microphysical parameterization

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Thunderstorms are severe mesoscale weather systems that develop during the warm season under strong heating and moist convection. In this work, observational analysis and numerical simulations are performed to study the thunderstorm characteristics over the southeast Chennai- Pondicherry coastal region. Detailed analysis of thermodynamical stability indices from Radiosonde observations at Chennai over five years (2016-2019) indicated that the Convective Available Potential Energy (CAPE) and Convective Inhibition (CIN) values are maximum during summer, southwest monsoon and minimum during northeast monsoon/ winter which correlated well with actual observed thunderstorm events. It has been found that most of these thunderstorms are associated with moisture advection by sea breeze during the summer season. Prediction of thunderstorms is highly challenging and requires cloud resolving simulations. Here the sensitivity of high resolution (2 km) WRF numerical simulations for thunderstorms to the cloud microphysics is examined for a few thunderstorm cases (24 April 2015, 27 May 2015 and 26 June 2019). Four different microphysical schemes (Thompson, Goddard, Morrison and Lin) are tested to evaluate the model performance in simulating the thunderstorm characteristics, location and distribution of rainfall amounts. Comparison of model results with data from Automated weather stations, Radiosonde and DWR observations indicated that while Thompson, Morrison and Goddard microphysical schemes predicted the thunderstorm characteristics well, the rainfall is slightly under predicted by Thompson and Lin simulated a weak storm. Among the four tested microphysics, Morrison simulated both area and intensity of rainfall for all three cases.

Observational Aspects and Numerical Modelling of Fog over the Indo-Gangetic Plain

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Fog is a visible mass consisting of cloud water droplets suspended in the air or near the Earth's surface. It affects various socio-economical activities like aviation, public transport, shipping, agriculture, etc. In India, fog is predominantly observed during the winter months (December- February), especially over the northern parts of the country. During the past 10-15 years, there has been an increase in frequency and the intensity of fog occurrence over northern parts of the country. Land-use changes and increasing pollution in the region are responsible for growing fog occurrence. This introduces formidable challenges for fog forecasting over the region. Since fog has large impacts on various sectors, especially in aviation, it is necessary to understand the physical characteristics, factors responsible for genesis and intensity and ultimately develop reliable models for predicting different characteristics of fog. For the aviation sector, it is necessary to know whether a fog event will occur during next 24 hours, if so what could be its intensity when it will start and dissipate, or duration of the fog event. Therefore, understanding different physical features of fog formation, and factors responsible for its genesis, intensity and duration are important to develop suitable forecasting model. It is also important to evaluate the performance of the numerical model to simulate the fog life cycle based on various model configurations such as initial and boundary conditions, vertical and horizontal resolutions, Planetary boundary layer (PBL) and microphysical schemes. This study particularly deals with the detailed investigation of the fog formation, development and dissipation over the IGP region of India using the data collected from the ground-based field campaigns viz. Winter Fog Experiment (WiFEX), and numerical weather prediction model. Evaluation of model forecast against the observations during WiFEX field campaign and the performance of the model forecasts for forty-three (43) very dense fog episodes (Visibility < 200 m) has been studied. Further, it also provides insight into the strengths (ability) and weaknesses of the WRF model to predict the fog events. Open issues in model predictions for fog have also been discussed.

Effect of Assimilation of Conventional and Satellite Radiance GTS Observations on Simulation of Mesoscale Convective System over Southeast India Using WRF-3DVar

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The impact of assimilation of conventional and satellite radiance observations in simulating the mesoscale convective system (MCS) formed over south-east India was investigated. An assimilation

methodology based on Weather Research and Forecasting model three-dimensional variational data assimilation is considered. Few numerical experiments are carried out to examine the individual and combined impact of conventional and non-conventional (satellite radiance) observations. After the successful inclusion of additional observations, strong analysis increments of temperature and moisture fields are noticed and contributed to significant improvement in model's initial fields. The resulting model simulations are able to successfully reproduce the prominent synoptic features responsible for the initiation of MCS. Among all the experiments, the final experiment in which both conventional and satellite radiance observations assimilated has shown a considerable impact on the prediction of MCS. The location, genesis, intensity, propagation and development of rain bands associated with the MCS are simulated reasonably well. The biases of simulated temperature, moisture and wind fields at surface and different pressure levels are reduced. Thermodynamic, dynamic and vertical structure of convective cells associated with the passage of MCS are well captured. Spatial distribution of rainfall is fairly reproduced and comparable to TRMM observations. It is demonstrated that incorporation of conventional and satellite radiance observations improved the local and synoptic representation of temperature, moisture fields from the surface to different levels of the atmosphere. This study highlights the importance of assimilation of conventional and satellite radiances in improving the models initial conditions and simulation of MCS.

A study of Retrieval and Assimilation of AMV from Polar Satellites

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Atmospheric motion vectors (AMVs) are crucial source of tropospheric wind over tropics and poles where wind information is in scarcity from conventional data sources. AMVs being extremely important in Numerical weather prediction (NWP), have many errors Mainly due to height assignment to the target. Modification in the retrieval algorithms has been done from time to time to minimize the errors in AMV. This study provides details of current Retrieval algorithm viz., tracking, height assignment, and quality control procedures for the retrieval of AMVs for polar satellites. Further, the impact of Polar AMV has been estimated by conducting Observational System Experiments (OSE). The results from this study will be presented in the workshop.

Study of TAF verification parameters for different MWO stations in India

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In this paper, verification has been carried out for TAF data (Terminal Aerodrome Forecast) as per ICAO (International Civil Aviation Organization) guidelines for four MWO (Meteorological Watch Office) stations viz. Delhi, Chennai, Mumbai, and Kolkata. The verification has been carried out for six meteorological parameters like wind direction, wind speed, visibility, precipitation, cloud amount and cloud height for the year 2019. TAF data has been verified with corresponding METAR data and it was found that wind

speed, precipitation, cloud amount, and cloud height provide better results than ICAO guidelines whereas wind direction, and visibility provide little less as visibility variability in Delhi is more due to fog in the winter season.

A Case Study: WindSat winds impact in Global Forecast System

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The US Naval Research Laboratories (NRL) WindSat is the first spaceborne polarimetric microwave radiometer to measure the partial polarized emission from the ocean surface to derive the ocean surface winds. The WindSat radiometer operates in discrete bands at 6.8, 10.7, 18.7, 23.8, and 37.0 GHz. The 10.7, 18.7, and 37.0 GHz channels are fully polarimetric, while the 6.8 and 23.8 GHz channels are dual polarized only (vertical and horizontal). WindSat onboard Coriolis provide information related to surface wind vectors as well as sea surface temperature, atmospheric water vapor, integrated cloud liquid water and rain rate over the ocean. A two-scale model of the ocean surface emission and scattering is implemented to derive wind speed and wind direction. The accuracy of wind speed has a ± ve bias of 2 m/s and the valid range is 3 – 25 m/s. And the wind direction has a ± ve bias of 20o with valid range 0 – 360o with a spatial resolution of ~30 km. The presentation contains the accuracy of WindSat winds with the buoy observation. Impact of WindSat winds in 3d-var Global Forecast System over a cyclone period Amphan. A detailed improvement in track prediction, errors in mean sea level pressure, maximum winds will be discussed in the presentation.

Keywords: WindSat, Data Assimilation, GSI, Amphan

A study on the surface temperature and winds over India using IMDAA reanalysis

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NCMRWF runs data-assimilation-forecast systems and generates numerical weather forecasts daily in real-time for the next 10 days. NCMRWF receives global observations both from conventional sources and remote sensing platforms. NCMRWF recently engendered a regional reanalysis dataset called IMDAA (Indian Monsoon Data Assimilation and Analysis). IMDAA is the regional reanalysis over the Indian region developed for the period from 1979 to 2018, jointly with UK Met Office. IMDAA data has a spatial resolution of 12km and temporal resolution of 1-hour, having many regional applications.

In the present study, the surface observations from the Automatic Weather Stations (AWS)

and SYNOP over the Indian region, available at NCMRWF are used for verifying the IMDAA surface temperature (2m) and wind (10m) during the last five years period (2014-2018). The statistical metrics of the correlation coefficient, index of agreement, mean absolute error, root mean square error etc. are computed between the observations and IMDAA variables. This evaluation is performed at the annual, seasonal and monthly time scales, and different spatial domain regions. These results are compared with that for ERA-5 reanalysis data sets. The present study further discusses the frequencies in temperatures and winds for different threshold values over different regions and at different time scales along with observations.

Tropical Cyclone Track Prediction skill of GFS Model

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The tropical cyclone (TC) track prediction using different NWP models and its verification are the important tasks to provide a prior knowledge about the model errors which in turn beneficial to use the model forecast guidance during real time issue of cyclone warning advisories. In this study, an attempt has been made to predict and verify the tropical cyclone track over North Indian Ocean using the Global forecast system (GFS) model. GFS is one of the operational models in India Meteorological Department (IMD), which provides the medium range weather forecast up to 10 days. The forecast tracks predicted by the model have been obtained using a vortex tracker developed by Geophysical Fluid Dynamics Laboratory (GFDL). A total of 10 tropical cyclones formed over the North Indian Ocean, eight during 2019 and two in 2020 has been considered for this study. The accuracy of the model predicted tracks have been verified up to 4 days with 12 hours interval in terms of direct position error (DPE) in track and cross track error. The weighted average DPE (Wt-DPE) during 2019 increased from 67 km at 12 hours to 207 km at 108 hours of forecasts, whereas in 2020 similar error trend has been found with lower values i.e. 58 to 168 km from 12 to 108 hours. But, there is a large variance from the cyclone to cyclone and Bay of Bengal basin to Arabian Sea basin.

Keywords: Tropical cyclone, track prediction, GFS, NWP, global model, direct position error, weighted average, GFDL

Identification of important rain gauges in Ganga river basin and their influence on the streamflow prediction

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Rainfall information is effectively and efficiently collected with the help of the rain gauge network. For several decades, rain gauge networks have been studied from a range of hydrological perspectives, where rain gauges with unique or non-repeating data are perceived as important. However, there is less literature on the quantification of node importance of the important nodes in rain gauge network. For this study, we have selected the rain gauge network of the Ganga river basin. The total number of rain gauges monitored by Indian Metrological Department (IMD) in this basin is 692. Degree Centrality (DC), Clustering Coefficient (CC) and Mutual Information (MI) are considered to be parameters for quantifying the variability of rainfall associated with all network rain gauges. Four different rain gauge sets (i.e. Network Size (NS) = 173, 344, 519, and 692) with different rain gauge density with daily temporal resolution are used to study the node importance quantification. Soil and Water Assessment Tool (SWAT), a semi-distributed hydrological model is used for proxy validation to validate this theory. SWAT delineate the sub-basins based on the topography that is connected by the stream network and further these sub-basins is divided in Hydrologic Response Units (HRUs) based on the similar land-use, soil and slope type.Ganga river basin is subdivided in to 14 subbasins by SWAT model. Initial three year data from 1998 to 2000 is used as warm-up period by SWAT and data from 2001 to 2018 data is used for calculating the stream flow. For reading the input data in SWAT, we apply spatial interpolation (using the Inverse Distance Weighing (IDW) method) method on rainfall data and evaluate the rainfall value at the centroid of each sub-basin. Because by default, SWAT rainfall input information is processed by a very basic, Nearest Neighbour-based system, in which data from the closest rain gauges is allocated to the centroid of the subbasin of each sub-basin. The results of the simulations are based on a few rain gauges in this default system and the data from all rain gauges is not used. Our results indicate node's importance in rain gauge network is extremely affected by the rain gauge density. We also conclude that for the quantification of the node's importance, the degree centrality and clustering coefficient is the preferred parameter over the mutual information parameter. We also found that, regardless of the network size, the rain gauges located in high elevated areas are extremely significant. In the ground-based observation network architecture of a wide range of meteorological parameters with spatial correlation, the technique may be further useful.

Sensitivity of physics schemes on tropical cyclone simulations over Bay of Bengal using WRF-ARW model

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Gauging a set of appropriate physical parameterization schemes for any numerical weather prediction model is essential for obtaining high accuracy in tropical cyclone forecasting. In this study, combinations of five Microphysics, three Cumulus Convection and two Planetary Boundary Layer (PBL) schemes are investigated with respect to track and intensity to determine an optimal combination of physical schemes of the Weather Research and Forecasting (WRF) model (version 4.0) with ARW core. The initial and boundary conditions for sensitivity experiments are drawn from the National Center for Environmental Prediction (NCEP-GFS) data. All the model simulated track and intensity are compared with the Indian Meteorological Department (IMD) observations.

The results represent that the KF cumulus is performing better with YSU PBL along with WSM6, Ferrier (new eta) and Thompson microphysics for track (position and time), and intensity with least errors. Further, the model performance is examined with the above combination of schemes on another four landfalling cyclones (Bulbul, Hudhud, Aila and Sidr). The average Root Mean Square Error (RMSE) for lowest Central Pressure gives least value at 2.2 hPa and 2.04 ms-1 for Maximum Surface Wind (MSW) for the entire simulation period with YSU-KF-Ferrier combination. The equivalent potential temperature shows strong vertical mixing up to 500 hPa in case of YSU-KF-Ferrier, which enhances the formation of warm core which further explains the intensity of cyclones. Overall, the study signifies that the track and intensity forecast for intense tropical cyclones using YSU PBL, KF cumulus schemes and Ferrier microphysics performs relatively better than other combination of physical schemes and thereby can be suggested as an optimal scheme for forecasting of Tropical cyclones in WRF-ARW model.

Keywords: WRF-ARW core, Bay of Bengal, tropical cyclones, physical parameterization schemes

Spatial Verification of Rainfall from Ensemble Prediction System at NCMRWF

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Verification of rainfall forecasts is challenging due to the fact that traditional methods which use grid-to-grid matching usually give poor scores. Therefore, spatial verification methods which verify the rainfall in an area rather than individual grids have become more popular in recent times. Contiguous Rainfall Area (CRA) method is a spatial verification tool which identifies rainfall contours with a specific value (40, 80 mm/day etc) in both observations and forecasts within the area of interest. These are then compared for their maximum and volume of rainfall, shape and distance between the two and the errors are reported based on these values. In case of an ensemble prediction system (EPS) the contours are obtained from each ensemble member and the probability of maximum rainfall exceeding a threshold is calculated which is then compared with the observed frequency to obtain verification metrics based on this comparison. The EPS running operationally at NCMRWF is the NEPS which is a 23 member ensemble (22 perturbed members+1 control). The horizontal resolution of NEPS is 12 km with 70 vertical levels. In the current study we have tried to verify the rainfall forecast over Mumbai on 29th June 2019 obtained from NEPS. On this day the observed rainfall was approximately 45 mm/d. However, the maximum rainfall from the NEPS mean and the control were under-predicting this rainfall amount at all lead times. However, several ensemble members were showing higher rainfall than both the mean and control. On verifying the maximum forecast rainfall exceeding 120, 150, 180 and 200 mm/d it was seen that the Brier Score was the lowest for 120 mm/d rainfall threshold followed by 150 mm/d thresholds. This implies that the model shows better skill in forecasting lower rainfall amounts. This is also seen from the Relative Operating Curves (ROC) plots where the curve for the 120 mm/d forecasts is further away from the diagonal line of no skill as compared to higher thresholds at all forecast lead times.

Keywords: Spatial Verification, Ensemble Prediction System, Contiguous Rainfall Area, Probabilistic Verification

THEME 4

Monsoon Prediction and Dynamics

Swapping of the Pacific and Atlantic Niño influences on North Central India summer monsoon

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The highly populated north central India receives 90% of annual rainfall during June to September. The interannual variation of summer monsoon rainfall is less studied compared to central and western India, due to its weak signal with the El-Niño-Southern Oscillation (ENSO). Previous studies have reported a marked decadal variation in the ENSO influences on north India rainfall, but the teleconnections of this variation are not satisfactorily understood. A pathway of the changing ENSO influences on north central India rainfall is revealed from observational data analysis and numerical experiments. While La Niña-like conditions produce anomalous northeasterly wind over India and reduce the tropospheric wind shear, the emergence of the Atlantic Niño appears to overtake this ENSO influence. The Atlantic Niño intensifies the meridional stationary wave affecting pressure anomaly over north-west Europe. This excites the Eurasian Rossby wave train along the mid-latitude producing upper-troposphere high pressure anomaly, subsequently affecting north India. Future work should examine the extent to which these teleconnections are represented in climate forecast models to aid the seasonal prediction of north central India rainfall.

Keywords: Indian summer monsoon, North India, ENSO, Atlantic Niño, Deep convection, Sea surface temperature, Pressure anomaly

Features of upper tropospheric temperature fluctuations during drought years of Indian summer monsoon: results inferred from COSMIC observations

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Sub-seasonal fluctuations in the Indian summer monsoon season generally show large variability on an interannual scale. Long intense breaks in the monsoon rainfall cause seasonal deficit rainfall that can lead to drought conditions in the country. The year 2009 was a major drought year with a seasonal deficit of rainfall by ~21%. Previous studies suggest that standard predictors such as El-Nino Southern Oscillation and Indian Ocean dipole are not consistent with the extended dry spells in 2009. In the present study, we focus on the upper tropospheric temperature anomalies during the dry spells of deficit years 2009, 2014 and 2015 to understand the characteristics of drought years. The availability of long-term (2007-2016) global temperature data from COSMIC radio occultation measurements, with the relatively high vertical resolution, provides a unique opportunity to explore the upper level temperature changes during the Indian summer monsoon. A strong consistent enhancement of 2-4 K

in the upper tropospheric (8-16km) temperature anomalies are noticed over north-west part and core monsoon region over central India during 2009 dry spell between 20 July and 10 August. The warm anomaly over north-west part of the Indian monsoon region is found to be unusually high compared to normal and excess monsoon years between 2007and 2016. Detailed analyses over different sectors of monsoon regions are carried out to understand the role of convective activity and associated circulation in creating the extended dry spell.

Investigation of Winter Precipitation Variability and Extreme Rainfall Events in North Indian Regions using multi-source climate datasets

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Extreme Rainfall Events (EREs) and associated hydro-meteorological hazards are a great threat to the society in terms of potential damage to life, infrastructure, environment and agricultural sustainability. The frequency and duration of such events is projected to be intensified in the context of global warming due to enhanced moisture content in the atmosphere. The North Indian region receives a significant amount of the annual precipitation during the winter season (December to March), in the form of snow and rainfall, associated with synoptic scale extra-tropical cyclonic systems, called Western Disturbances (WDs). This precipitation is an important irrigational source for Rabi crops and plays a critical role in recharging the water resources in the northern plains as well as maintaining the snow cover of the Western Himalayan glaciers which feed some major north Indian rivers. The region is thickly populated and highly vulnerable to EREs and associated hazards such as heavy rainfall, flash floods, cloudbursts, landslides, avalanches, etc. Our study focuses on the investigation of the dynamical and thermodynamical characteristics of mean precipitation as well as variability patterns of Indian winter monsoon and understanding the processes responsible for growth and sustenance of EREs in the North Indian region (73°E-80°E, 30°N-37°N) during the winter season (DJFM) using multi-climate datasets, including observation, satellite and model based datasets. Detailed results will be discussed.

Keywords: Indian Winter Monsoon; Extreme Rainfall Events; Spatio-temporal variability; Hydro-meteorological hazards

Changing teleconnection between Tropical South Atlantic and Indian Summer Monsoon Rainfall in a Warming Scenario

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The teleconnection between the Tropical South Atlantic (TSA) sea surface temperature anomalies (SSTA) and the Indian Summer Monsoon Rainfall (ISMR) on the inter-annual timescale provides a

source of predictability for the ISMR, especially during the non-ENSO years. The TSA-SSTA and ISMR teleconnection has been investigated in a global warming scenario by analysing the Coupled Model Intercomparison Project Phase Six (CMIP6) models under the Historical and Shared Socioeconomic Pathway (SSP5-8.5) scenario after removing the effect of ENSO. Out of a total of 34 CMIP6 models analysed, only 4 (8) models are able to correctly simulate the observed relationship between TSA index and ISMR index (Webster-Yang Monsoon Index). It is found that with an increase in greenhouse gas concentration, the inverse relationship between the TSA and the ISMR index shall weaken. It is argued that the change in the strength of velocity potential and increased atmospheric stability as a result of global warming is mainly responsible for the weakening relationship between the TSA and ISMR indices.

Keywords: Tropical South Atlantic; Indian Summer Monsoon Rainfall; Coupled Model Intercomparison Project Phase Six; Shared Socioeconomic Pathway

Indian Summer Monsoon - 2020 in NCEP Global and Forecasts System

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The summer monsoon season of 2020 receives 109% of rainfall during June to September over India. The wide spread rains during monsoon season in 2020 lead to floods in many parts of the country. An endeavor is made in this study to assess Indian summer monsoon 2020 features with the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS). The 1200 UTC operational analysis and forecasts (up to 5 days) archived with 0.5° horizontal resolution and 19 vertical levels from 15 May to 30 September. The summer monsoon 2020 features are investigated in terms of onset, advancement and withdrawal with NCEP analysis and also assess the forecast performance.

The manifestation of rainfall variation in the analysis and forecast are elucidated with of basic meteorological parameters and large-scale budget of kinetic energy, heat and moisture. The results reveal that the summer monsoon features over India are well represented in NCEP analysis, i.e. onset vertex, low level westerly flow, upper level tropical easterly jet, etc. The analysis realistically produced the heavy rainfall events that lead to floods over different parts of India during monsoon season. The model forecast fields from day 1 to day 5 are reasonable predicted the monsoon climate over India.

Keywords: Summer monsoon westerly jet, tropical easterly jet, NCEP analysis and forecast, kinetic energy, heat and moisture

Representation of process-based diagnostics in NCUM global and regional models

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The primary goal of this study is to assess the fidelity of National Center for Medium Range Weather

Forecasting Unified model's (NCUM) global (12km) and regional (4km) versions in representing the monsoon sub-seasonal variability over Indian region by applying process based diagnostics. Moisture budget analysis is performed on the model's forecast fields for a typical extended monsoon episode event occurred during boreal summer monsoon season 2019. The exercise is repeated using the ERA5 reanalysis and the relative roles of the budget terms are quantified.

We also tested the budget diagnostics onto the newly generated Indian Monsoon Data Assimilation and Analysis (IMDAA) product. Preliminary results obtained from the moisture budget analysis is encouraging. Analysis indicates that dry air advection from the north-west regions strongly dries the atmospheric column nearly 7-10 days before the peak dry phase over the Indian subcontinent. Dry air intrusion towards Indian subcontinent is consistent with the anomalous total precipitable water vapor from satellite observations. One of the main implications of this work is, the lead time obtained in the moisture advection term can be used to improve the model forecasts.

A Study on some dynamical aspects of Uttarakhand Heavy rainfall events

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Study Heavy rainfall events (HRE) over the Himalayan slopes are crucial as it often leads to flood situation which has a socio-economic impact. The rising number of such events during the recent decade is a major concern. Complex terrain, Orography and interactions of atmospheric systems at different synoptic scales make a prediction of HRE vulnerable. The primary objective of this study is to understand the moisture transport, atmospheric conditions and related dynamics which lead to HRE over the Uttarakhand region during the Indian summer monsoon season (JJAS).

The study region includes Indian subcontinent and surrounding ocean, 0 – 45°N and 30°E – 110°E. IMD 0.25° × 0.25° gridded high-resolution data set (Pai et al., 2014) and ECMWF ERA 5 reanalysis data are the main data sets used in the study. The HREs are identified using IMD rainfall data over the 10 years from 2010 to 2019. Uttarakhand region bounded by 29°N - 30°N and 78°E - 80°E is used to detect HRE. To understand the moisture transport and dynamics associated with ERE, ECMWF ERA 5 reanalysis data sets are used. Vertically integrated Water Vapor transport (IVT) is calculated from surface up to 300 hPa over the study domain to explore the moisture transport to the affected region. To understand the cause of moisture transport, divergence/convergence, wind fields at 200 hPa and 850 hPa are investigated.

Preliminary results from IVT analysis shows that continuous moisture supply from Arabian Sea and Bay of Bengal established for most of the HRE. 850 hPa wind analysis shows low level jet plays a crucial role in the moisture transport to the affected area from Arabian Sea and Bay of Bengal. 200 hPa wind analysis shows southward penetration of the mid-latitude westerly trough up to 30oN exists for most of the HRE over Uttarakhand. Upper level divergence caused by this southward penetration of westerlies, low level convergence caused due to it and its effect on moisture transport is the topic of detail investigation in this study.

Quantile Mapping Bias Correction Methods in Support of NCMRWF Unified Model Operational Forecast for i-FLOWS Mumbai and Chennai

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Integrated Flood Warning System(i-FLOWS) is an urban flood forecasting system which was developed with the active collaboration of various institutes in India and to name a few are, Ministry of Earth Sciences (MoES), Government of India (GoI) (India Meteorological Department (IMD), National Centre for Medium Range Weather Forecasting (NCMRWF). The i-FLOWS system involves various components, including the regional weather forecast model, tide forecast model, storm-water drainage model, etc. The precipitation is one of the primary inputs for flood forecasting, which is obtained from the NCMRWF unified model (NCUM). The NCUM model is operated both at the regional scale (4-km spatial resolution) and global (12-km spatial resolution) and regularly disseminates the medium-range weather forecasts for Chennai and Mumbai regions under i-FLOWS. While several improvements in past years with respect model physics, spatial resolution, satellite data assimilation, etc., the model precipitation outputs usually suffer from systematic biases that vary with space and time. Hence, in this study, we address such biases and assess the various quantile mapping bias correction methods to the NCUM precipitation forecasts over the coastal cities of Chennai and Mumbai in India that are regularly suffering from extreme rainfall events also extremely sensitive to climate change. This study will be useful in the future to apply the bias-corrected precipitation data for improving rainfall forecast and hence running the urban flood model with better predictability under i-FLOWS.

Verification of rainfall forecasts for MoES models during JJAS 2020

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The verification of forecasts for MoES models during summer monsoon season (JJAS) is an important task in every year. As a part, the verification is focused on the rainfall forecasts during JJAS 2020 since the India Meteorological Department (IMD) is using the NWP model rainfall forecast to issue daily operational weather forecast warnings in short to medium range. The present study is focused on verification of two high-resolution deterministic models namely (i) IMD's GFS and (ii) NCMRWF's NCUM generating real time NWP forecasts in the medium range time scale (up to 10 days) over Indian land regions. Various skills scores have been computed for both the deterministic models. The Mean Error is seen to be more than 10 mm. The RMSE >20mm is evident over the wet regions like the west coast, eastern Indian and NE India. The dry regions of eastern peninsula and NW India have low RMSE whereas the core monsoon region has the highest RMSE. The RMSE is found to increase from Day-1 to Day-5 in both models. For higher thresholds, i.e., moderate rain (>15.6mm/day) even though both models indicate reasonable agreement with observations, GFS has a higher account over western parts of India. For heavy Rain (>65.5 mm/day) NCUM indicate comparable frequency over west coast while GFS indicates underestimation. During June and July, both GFS and NCUM successfully predict the extended dry spell seen to the north of 20N. The Probability of detections (POD) suggests poor skills over the

north-west region of India. The Equitable Threat Score (ETS) values exceeding 0.3, are confined to a small region over NW India. NCUM Day-5 forecast has higher ETS than for GFS. ETS examined for different rainfall thresholds shows that both models have very similar forecast skill. GFS Day-1 forecast shows a higher PSS than NCUM for the rain/no rain case. NCUM exhibits a higher PSS for rainfall exceeding all the other thresholds.

Keywords: Monsoon, Forecast, Rainfall, Verification

Fidelity of Indian Summer Monsoon Circulation Indices in Representing Rainfall Variability and Teleconnections

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In the past years, a large number of circulation indices has been constructed to represent the Indian summer monsoon to aid diagnosis of teleconnections with Indian summer monsoon rainfall (ISMR), and simulations by climate models based on the assumption of strong coupling between rainfall and circulation. However, the correlations between the ISMR and circulation indices are poor raising question on the coupling between monsoon rainfall and circulation. In this study, we have tried to identify mechanistic reasons behind the poor correlations and attempt to provide insight into why that is so. By looking into the periods and variances explained by the oscillatory modes of circulation indices and ISMR, de-correlation between the two can be easily understood. This is also the reason that all circulation indices underestimate the negative correlation between JJAS SST over the Nino3.4 and ISMR and fail to simulate the lead-lag relationship between the two. The local response of winds to deep convection over the waters of the Indian Ocean and western Pacific warm pool leads to a strong increasing trend in some of the circulation indices and adds 'noise' modes resulting in de-correlation between circulation indices and ISMR.

Keywords: Indian summer monsoon rainfall (ISMR), Circulation Indices, Coupling between ISMR and circulation, Coupled modes of variability.

Do the Hydration and Dehydration depend on the phases of Indian Summer Monsoon?

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Seven years of high-resolution measurements of upper tropospheric humidity (UTH) from the Indian Geostationary satellite, Kalpana-1 are utilized to understand the hydration and dehydration process during the active and break phases of the Indian Summer Monsoon (ISM). Most significant and new observation is that the upper troposphere is dry during active and wet during break phase. Humidity from the Megha-Tropiques SAPHIR and water vapor mixing ratio from Aura-MLS also shows dry during the active and wet during the break phase in the upper troposphere. CALIOP data shows

cirrus (sub-categorized as sub-visible, thin and thick) occurrence is more during the active as compared to the break. The upper tropospheric winds show strong divergence (convergence) during the active (break). The analysis for the first time illustrates that dehydration (hydration) dominates during the active (break). The dehydration is due to the presence of cirrus caused by the strong convective outflow and updraft. The study provides the first evidence that the upper troposphere shows dehydration during the active and hydration during the break phase of the ISM thereby exhibiting intra-seasonal variability in the UTH over the ISM.

Meteorological Information System (MIS) for Monitoring Monsoon and Extreme Rain Events across Subtropical Asia

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Meteorological Information Systems (MIS) is a new area of weather research. From model outputs of analyzed and forecasted parameters from operational agencies, customized charts, limited numerical values and a brief write up are analyzed-organized keeping in view requirements of end-users. Customized global/regional charts are displayed on the proper projection system using advanced Geographical Information System (GIS). By applying MIS approach, Kedarnath disaster (16-17 June 2013) has been studied using 2.5°-gridded surface and upper air parameters (1000-100-hPa) (period: 1979-2013). Normal and departure-from-normal 3D structure of atmospheric temperature and general and monsoon circulations during the event have been compared by preparing equatorially/globally-conditioned (EC/GC) charts. Briefly, normal monsoon structure is as 1000-850-hPa layer- cross-equatorial flows over the Indian Ocean and Eurasian westerlies confluence over Indian domain, the two flows further confluence downstream with Indo-Pacific easterlies, and the accumulated airmasses blow northeastward; 700-500-hPa layer- Eurasian westerlies after sweeping entire Indian domain exit northeastward; and 400-100-hPa layer- upper tropospheric anticyclone well-developed over subtropical Asia and outflows are spread all around. On 16-17 June 2013, the troposphere (1000-250-hPa) was warmer-thicker over tropics. It was warmest-thickest over Tibet-China (+2.5°C/+119.8m), followed by warmer-thicker over Mediterranean-Middle East (+1.9°C/+93.4m), and cooler-thinner over central Asia-India (-1.3°C/-21.8m). However, departures in downward slopes of tropospheric temperature/thickness from Tibet-China outwards were significantly steeper. The monsoon was more intense, but the upper anticyclonic cell was located over Tibet-China. In the 1000-400-hPa layer, India-Indo-Pacific warm-low regime was stretched east/northeastward while mid-high cool-low regime had larger-than-normal equatorward spreading over Middle East–northwestern India. In upper levels (300-100-hPa), two intense, large-warm-high anticyclonic circulations developed, one over Tibet-China and another Middle East–Mediterranean. Combined wind system of Eurasian westerlies and Indo-Pacific easterlies over Indian domain was forced to blow westward and make an exit from western slopes of Tibet-Himalaya due to higher than the normal height of lower tropospheric height fields. Combined effects of five factors produced disastrous rains over Kedarnath range: regime contrast between extratropical cool-low-dry and monsoon warm-low-moist; squeezing of deep warm-moist monsoon flows exiting from western Tibet; forced orographic lifting of moist airs; upward pumping of excessively accumulated moist-airs due to intense low-level convergences; and intense suction of airs by upper tropospheric divergences. Voluminous airs exiting from western Tibet-Himalaya modulated northern westerlies into single wave structure with a huge

ridge over eastern Russia–Canada-Arctic, and a deep trough over central Asia–India. Besides rainfall, different circulations were also unprecedented since 1979. Different reported causal factors were located along the path of this huge wave, hence interrelated. Evolutions of the factors took about two weeks to evolve. Over major parts of the northern hemisphere, the troposphere was warmer-and-thicker along upstream of the ridge while cooler-and-thinner in the downstream. From upper tropospheric anticyclonic circulation, lesser outflows were directed southward and cooler-thinner troposphere occurred over major portions of the southern hemisphere (south of 45°S). In other words, the westward blowing wind was divided into two parts, one that entered into the vertical circulation of tropical nature and another into the horizontal meandering flow of extratropical nature. The approach has been applied for ten EREs along subtropical Asia and results reported.

Effect of cloud microphysical parameterizations in simulating Monsoon low pressure systems over the Indian region through composite analysis

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Numerical Weather Prediction (NWP) is one of the vital components of meteorology and has direct implications for society. However, the most significant contributions to the forecast errors have sources in the parameterization schemes of the NWP model. This study assesses the impact of five cloud microphysical parameterization schemes (MP) on simulations of fourteen monsoon depressions (MDs) using the Weather Research and Forecasting (WRF version 3.8.1) model, where the MDsare important rain-bearing synoptic disturbance which accounts for an ample amount of monsoonal rainfall over the Indian subcontinent. The simulations are carried out with a lead time up to 96 hours at 27, 9, and 3km horizontal resolution for fourteen MDs for composite study. The five MP schemes are WRF single moment 6 class (WSM6), WRF double moment 6 class (WDM6), Milbrandt (MIL), Thompson (THOM), and Aerosol Aware Thompson (AAT). These fourteen MDs formed over the Bay of Bengal and moved towards India and have different stages of the storm (developed as 'low' and attained maximum category of 'deep depression'), the composite data has been created over the overlapping time window (27 hours duration) only of each MD. It is found that the choice of MP significantly impacts the key characteristics of the MDs, such as rainfall, wind, temperature, and associated convective processes. MPs have underestimated the precipitation compared to Tropical Rainfall Measuring Mission (TRMM), and WDM6 has the least errors; WDM6 produced the lowest amount of wind underestimation in the south-western sector of the storm up to 96 hours of simulation. The lowest biases in moisture convergence and absolute vorticity are found in WDM6 at the surface, which leads to lower moisture flux from ground and thus better rainfall correlation. Further, inter-comparisons of simulations of MPs are carried out using WDM6 as the benchmark, and the detailed results will be discussed.

Microwave Application for Prediction of Monsoon

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There are different Parameters that are used in the Model for Prediction of Monsoon. One of the important Parameter is Soil Moisture. The Variation of the Soil Moisture with time is one indicator for this purpose. This is the reason that the Variation of Soil Moisture has to be monitored on regular basis. The monitoring of Soil Moisture on regular basis can be done from Space. The Sensors operating in Microwave frequency could be used for this purpose.

The Satellite SMOS- Soil Moisture and Ocean Salinity Satellite regularly monitors the Soil moisture and it gives as per the revisit cycle of the Satellite once in three days the Soil Moisture of a Particular location. If we want the information of Soil moisture on daily basis, then we need THREE Satellites that will provide information about Soil moisture of a particular location on daily basis. The Soil Moisture and Ocean Salinity Satellite (SMOS) of European Space agency (ESA) have a Microwave Sensor, a Radiometer operating at 1.4GHz. This frequency is very Sensitive to Soil Moisture and Salinity in the ocean.

In present Communication the Soil moisture monitored for Nine states of India namely (i) Gujrat (ii) Rajasthan (iii) West Bengal (iv) Assam, (v) Kerala, (vi) Andhra Pradesh (vii) Punjab/Haryana (viii) Tamil Nadu and (ix) Orissa /M.P. The Soil moisture maps for these Nine states have been generated every third day. These data of Soil Moisture are extremely useful for working of the model.

Winter Precipitation Variability over North Indian Region in a state-of-the-art Indian high-resolution reanalysis database

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The North Indian region receives a significant amount of the annual precipitation during the winter season (December to March), associated with synoptic scale extra-tropical cyclonic systems, called Western Disturbances. This precipitation is an important irrigational source for Rabi crops and plays a critical role in recharging the water resources in the northern plains as well as maintaining the snow cover of the Western Himalayan glaciers which feed some major north Indian rivers. The complex topographic heterogeneity over this region has resulted in a paucity of observational data available. This discontinuity and insufficiency of available data create hindrance in producing accurate precipitation estimates as well as carrying out prediction studies over the region. In this work, we used recently developed Indian Monsoon Data Assimilation and Analysis (IMDAA) high resolution (12 km, daily) reanalysis dataset to understand the variability of the Indian Winter Monsoon in the north Indian region for the period, 1980-2018. This state-of-the-art reanalysis has been generated by the National Centre for Medium Range Weather Forecasting in collaboration with the India Meteorological Department and UK Met Office under the National Monsoon Mission project, Government of India. Our study focuses on the evaluation of IMDAA precipitation dataset using different multi-source climate datasets, including in situ, remotely

sensed and reanalysis based datasets. IMDAA precipitation climatology is in well agreement with the different precipitation datasets. It is noticed that the observed decreasing rainfall trend is well captured by the IMDAA. Further, this dataset is capable in reproducing the year to year variability over the region. Detailed results will be discussed.

Keywords: Indian Winter Monsoon, IMDAA, precipitation, variability

Spatiotemporal indices in assessing impending Monsoon

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Based on the promising outcome of our earlier work on spatiotemporal indices of monsoon, we have made a detailed analysis of the monthly mean (JJAS) and four zonal (NW, CI, NE, SI) mean IMD gridded data of 120 years.

The seasonal anomalies of Poor monsoon years (26) are found to be in better sync with corresponding June, July rainfall compared to the other two months. The correlation coefficients are significant though small, in the range from 0.3 to 0.5. The zone wise signals are much better with cc in the range of 0.4 to 0.6.

Good Monsoon years (only around 16 – compared to 26 of Poor monsoon years) show less promise, only September and Northwest zone showing the significant correlation. Independent evaluation of Poor and Good Monsoon months and zones (criterion: Anomaly being greater than LPA ± 2 standard deviation)) show these are significantly different from a combined criterion. The significance of Poor monsoon years being nearly 1.5 times the number of Good monsoon years is discussed to explain the above.

Extreme events forecast study under the influence of Extratropical-Tropical interaction over the Himalayan region

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A bidirectional teleconnection process exists through interaction between the tropical to extratropical (T2E) and extratropical to tropical (E2T). Earlier studies have pointed out that the mean flow modulation due to eddy forcing is a significant part of the general circulation over

the extratropics and the tropics. The key elements of general circulations are the transport of total momentum and heat fluxes, which can be decomposed into three components viz. mean meridional circulation, stationary eddies, and transient eddies. The study observed that eddies exhibits north to south migration in different seasons and can cause anomalous weather features over the Indian region by inducing low-pressure dynamical systems, Rossby wave breaking, and potential vorticity advection. In the present study, the General quantification of E2T (T2E) interactions manifested through suitable eddy flux transport indices. The representation of Eddy forcing in a spectral space would provide the frequency domain representation of climatological transport. Eddy flux transport indices manifest the variability of the E2T in terms of amplitude and periodicity associated with the Indian region's weather patterns. Studies have noted that with varying strength of the E2T incursions are in systematic features and are episodic patterns. Several studies stated that extratropical circulation might influence on tropics through enhancing or diminishing the underlying monsoon phase. Here, the present study will glance at the reinforcement of the monsoon phase, especially extreme events. Extreme precipitation is an uncommon and infrequent event in the season. Extreme precipitation events lead to flash floods, landslides, causing loss of life and property damage. Monsoon prediction over the orographic region is a challenging problem due to its underlying complex terrain. There are several instances noted about the influence of the extratropical originated system over the Himalayan region. The E2T interaction over the Himalayan region is one of the significant influencers along with underlying complex terrain. Extreme events over the Himalayan region are driven by underlying complex terrain and interaction with extratropical originated response during monsoon seasons. During the break spell of the Indian summer monsoon, the monsoon trough is located over the foothills of the Himalayas, thus supplying abundant moisture persist. Whenever the moisture supply and extropical originated system are co-existed, then an extreme precipitation event is expected. A comparative study shows a diagnostic analysis of the forecast concerning observation as far as extreme rainfall is concerned. The study focuses, especially on orographic Indian terrain. The study also examines an Ensemble Prediction System (EPS) skill in predicting the observed extreme orographic precipitation under E2T influence.

Dusty Marine Aerosol variations over Indian Subcontinent during Indian Summer Monsoon

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Aerosol data from Callipso has been used to plot dusty marine aerosol over the Indian Ocean and adjoining region during the Indian Summer Monsoon period. During drought years the dusty marine type of aerosols dominates over Arabian sea and Bay of Bengal region. While during normal monsoon year the case is not so. There are changes in circulation known associated with year to year variability of Indian Summer Monsoon. Similar, variations are evident over ocean region in dusty marine aerosols. Marine aerosols also show changes within each season, indicating that intraseasonal and interannual variability in aerosols may have an impact on circulation changes during Indian Summer Monsoon.

THEME 5

Boundary Layers and Turbulence

Atmospheric Boundary Layers at Distinct Environments

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Atmospheric boundary layer (ABL), the lowest atmospheric layerthat is in contact with Earth's surface, is directly driven by the surface energetics and associated changes in them. Entire transfer of moisture, pollutants, momentum and energy between the surface and the atmosphere takes place through this layer. Thermodynamic state of the ABL determinesthe surface layer processes that modulate the development of weatherand pollutant dispersal. ABL characteristics are strongly influenced by the surface properties and energetics, surface moist static energy, atmospheric instability, and the prevailing meteorological conditions, in addition to terrain features. This makes the surface-air interactions and evolution of ABL as one of the classical examples of the complex feedback processes in the earth-atmosphere system. As transfer of mass, momentum and heat in the ABL takes place through turbulence, measurement of ABL turbulence spectra is of fundamental importance in ABL characterization. While the knowledge on the characteristics of ABL is important for improvements inthe numerical modelling of atmosphere and transfer of moisture and pollutants to the free-troposphere (and hence convective processes, hydrological cycle and long-range aerosol transport), its long-term monitoring is essential from the climate change perspective (especially in climate change assessment). One of the main features of ABL is its substantial diurnal evolution, with daytime time continental convective ABL over continents extending up to 1-3 km while the nocturnal stable ABL is generally limited to less than a few hundred meters.In contrast, the marine ABL does not undergo significant diurnal variation and is generally limited to < 1 km. Over coastal regions, due to the mesoscale sea breeze/land breeze circulation driven by land-sea thermal contrast, the ABL structure is characterized by the development of a thermal internal boundary layer. Over hills, the ABL development is more complex and is influenced by the mountain circulation. Interestingly, the ABL clouds that are generated by the daytime convective ABL (CABL) can inhibit further growth of CABL by cooling the surface and regulating the surface energetics. Thus, geographical and background meteorological conditions have a dominant role in regulating ABL characteristics and their diurnal evolution. Due to this reason, ABL characteristics and their role in regulating tropospheric dynamics and hydrological cycle have to be investigated primarily for typical geographical conditions and climate zones.The Indian subcontinent encompasses a variety of climate (e.g., arid, semi-arid, tropical wet) and geographicalzones (e.g., continental-plain, mountains, coastal, island). An overview of the ABL characteristics over different geographical environments will be presented, especially in the light of the findings made as part of the IGBP-NOBLE project.

Assessment of wind pattern and turbulence associated with the boundary layer during Monsoon season over the Central Himalayan site using ARIES ST Radar and GPS Radiosonde

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Mountainous terrain greatly affects the atmosphere by modulating the mean flow and thus causing momentum exchange between the surface and the atmosphere as well as by thermal and radiative energy exchanges. Over the complex terrains, the evolution of convective boundary layer is significantly different from plane surface due to wave induced mixing processes and thermally driven advective wind systems. Due to these terrain induced effects, it is known to generate its own LBL(Local Boundary Layer). Small scale turbulence processes are inherent for mixing within the boundary layer and then momentum transfer with lower atmosphere. These are important for dispersion of pollutants and trace species within the boundary layer.

Very High Frequency (VHF) radars with their unique capability to provide vertical variation of all three components of wind vectors at high temporal and vertical resolution in all weather conditions have now become an indispensable tool to study dynamical variation in the atmosphere. These radars tend to give maxima in refractive index profile (Cn2) due to sharp gradient in potential temperature and moisture, giving enhanced radar reflectivity at the mixing layer. Heat flux also linearly decreases from the surface layer to the mixing layer, causing minima in the spectral width of radar echoes. Using these signatures, they can be used to study the evolution of the mixing layer with the time.

Recently a Stratosphere Troposphere radar operating at 206.5 MHz has been made operational at ARIES, Nainital (29.4N,79.5E, 1800 m amsl), a high altitude subtropical site in the Central Himalayas. The radar system is indigenously designed as an active aperture phased array system having the capability to provide high resolution three dimensional wind information up to 20 km. Provision of the wide bandwidth of 5 MHz and implementation of pulse compression technique to transmit complementary coded pulses has enabled the system to have observations from 375 m with a high vertical resolution of 75 m. This radar was periodically operated continuously for 24 hours to study the evolution of the boundary layer from the active monsoon season to its withdrawal phase. Day to day variability of wind from easterly in the beginning to changing westerly nearing to withdrawal phase has been tracked. Diurnal and day to day variability of turbulence parameters viz. turbulent kinetic energy dissipation rate and Eddy diffusivity coefficient have been estimated. Efforts have been made to decipher the thermal and wind shear effects causing diurnal and nocturnal turbulence. Previously reported values of turbulence parameters carried out with limited one-hour radar profiles and coarser resolution in the lower troposphere over this region have shown values of energy dissipation rates as high as 10-2 m2s-3 and eddy diffusivity coefficient as 102 m2s-1 showing topographical effects on turbulence strength. Usually turbulence in the atmosphere expected to be less severe as compared to other seasons due to light winds and cloud coverage in the atmosphere. In this study, we will be presenting diurnal and day to day variability of turbulence parameters during complete monsoon season with finer vertical resolution.

Diurnal evolution of several strong radar echo layers in the lower atmosphere will also be discussed. Pre-existing atmospheric conditions leading to late afternoon convection which is specific for mountainous regions will also be explored. The results of this study hold significance as it is the first attempt towards utilisation of VHF radar to study boundary layer turbulence along with the wind variability and the background meteorological parameters provided by co-located GPS radiosonde observations over this Himalayan region. It is planned to continue such observations with radars for upcoming winter and summer season to reveal the seasonal variations in boundary layer dynamics over this complex Himalayan terrain.

On the Decreasing Trend in Atmospheric Boundary Layer Height over the West Coast of India

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The trend of Atmospheric Boundary Layer (ABL) height and surface parameters over the southern part of the west coast of India has been studied using MERRA2 datasets for 1980-2017. A significant decrease in the ABL height has been observed during the study period. The shallow ABL is expected to cause an amplified response in the atmosphere and enhance the formation of extreme events over the region. The weakening of surface zonal wind is found to be the factor responsible for the decreasing trend in the ABL height. The change in the ABL height has a significant influence on the surface parameters such as specific humidity, temperature, CAPE and sensible & latent heat fluxes at the surface. A significant increasing trend in specific humidity is obtained for pre-monsoon, monsoon and post-monsoon seasons. The convective instability and CAPE have a significant increasing trend in pre-monsoon season, which may lead to the formation of intense thunderstorms during the season. Surface sensible heat flux possesses a significant decreasing trend during pre-monsoon and post-monsoon seasons. Surface latent heat flux shows a decreasing trend during monsoon, which may be attributed to the combined effect of a decrease in ABL height and trapping moisture at lower levels together with an increase in surface temperature.

Influence of urbanization and aerodynamic roughness on the Atmospheric Boundary Layer Characteristics and Rainfall over Chennai - a case study for 1 December 2015 using WRF

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In this work, we explore the boundary layer characteristics over the Urban Chennai region during the Heavy rainfall event occurred on 01 December 2015 by conducting high-resolution numerical simulations using WRF. The impact of urbanization is studied on PBL characteristics and rainfall using different land

use /land cover (LULC) data sets, and aerodynamic roughness (Zo) factors. From the change detection analysis of land cover data between 1992 and 2015, it has found that the urban area is expanded by 23% and crop and forest lands reduced by nearly 40-50% from their level in 1993. A detailed analysis has shown that the boundary along with the increase in urbanization a gradual increment in the surface flux distribution, TKE and PBL layer structure is clearly seen during the period. Simulations with increased Zo (0.5 to 1.08 m) lead to enhancement of drag and shear, momentum transport, reduction of winds and increase of TKE leading to increase of convergence and convection which increased the rainfall over the city and further downwind region in comparison to the control run using USGS 1993 LULC data. A detailed analysis of boundary layer characteristics has shown slightly different trends of temperature, wind, surface fluxes, Convective Potential Available Energy (CAPE), Turbulent Kinetic Energy (TKE) and the height of the planetary boundary layer (PBLH) during the dry and wet (cloudy/ rainfall) phases. It has been found that although the trends of various PBL parameters except CAPE are similar in both wet and dry spells, the enhancements in the fluxes are small in wet spell and the CAPE is substantially high during the wet spell. These changes suggest that the local boundary layer is mainly influenced by the mechanical effects such as increased drag force, convergence and convection and stronger updraft leading to higher CAPE over the dry phase. The results show that the surface drag modification due to urbanization plays a crucial role in the simulated surface parameters and PBL structure which modified the characteristics of the low pressure trough and upper air cyclonic circulation affecting the rainfall.

Turbulence study over Cochin for consecutive three years

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Wind profiler radars are now used for studying turbulence in the atmosphere, which plays an essential role in the atmospheric dynamics. Turbulent kinetic energy dissipation rate (ϵ) and eddy diffusion coefficient (κm) are usually used as turbulence intensity measures. Various turbulence estimation methods have been practised, which by improvisations over the years, have helped to understand the atmospheric dynamics better. The different methods of turbulence estimation from radar observations are (i) the backscatter signal-power method, (ii) the Doppler spectral-width method, and (iii) the wind-variance method (Satheesan and Krishna Murthy [2002]).

This study uses the data from the world's first 205 MHz Stratosphere – Troposphere radar located at Kochi (10.04 N,76.33E), which provides high-resolution measurements in the tropical troposphere. The Doppler spectral-width method (Hocking [1983], Hocking [1985], Nastrom and Eaton [1997], Satheesan and Krishna Murthy [2002], Satheesan and Murthy Krishna [2004]) is used for the turbulence study during 2017-2019. The lower tropospheric column's turbulence pattern and its dependence on the background wind conditions during pre-monsoon, monsoon, post-monsoon, and winter seasons are studied. Turbulence is observed to be minimum during the winter season, and later it increases from pre-monsoon to monsoon season. The South-West monsoon's influence during the monsoon season is visible in the turbulence and wind shear pattern. The monthly variation of turbulence in the boundary layer is also studied.

Evolution of optically thin ground fog into optically thick fog on the basis of turbulent kinetic energy observed during Winter Fog Field Experiment, New Delhi

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Structural evolution of dense fog events was used to investigate using micrometeorological data from the Winter Fog Experiment (WiFEX) field campaign at Indira Gandhi International (IGI) Airport, New Delhi. Study of 4 fog events occurred in January 2016 in which visibility dropped below 75m selected for detail consideration. Sequential development of thermally stable optically thin fog into a weakly mature unstable deeper fog is analysed depending on the visibility and micrometeorological structure. Observation shows humidity profile over radiative cooling of land surface and associated vertical growth of saturated layer in nocturnal boundary layer plays a vital role in the sudden development and intensification of the initial thin ground level fog into deep dense fog. It was revealed in this study that the TKE < 0.1 m^2/s^2 in the early fog stage and can reach 0.5 m^2/s^2 in the mature stage. A dense fog was sustained for higher values of TKE during the mature stage of fog. A noticeable characteristic of the fog event that it sustained during the optically thin phase till the air at 20 m remained in the sub-saturated condition in the thermally stable boundary layer. Due to the cooling of the air inside the shallow fog, it transformed into the extremely dense fog prior to that advancement of saturated layer near the surface was noticed. Conversion of optically thin phase of the fog to dense phase of the fog appears at when the air at 20m reached to saturation (Rh 100%). Evident feature of all fog cases that saturated layer at least deeper than 20m, which can endure larger turbulence intensity (between 0.4 m^2/s^2 and 0.5 m^2/s^2). The salient features of the fog life cycle from ground based measurement have been discussed in detail.

Measurement of carbon dioxide in the atmospheric boundary layer over Pune and its Seasonal variation

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Increase in greenhouse gases, including carbon dioxide (CO_2) concentrations in the atmosphere, is responsible for global warming. This increase is caused by anthropogenic activities like the combustion of petroleum products, biomass burning etc. In recent years, the measurement network of greenhouse gases has been expanded globally. In this study, we measured the CO_2 and water vapor (H_2O) concentrations along with wind and air temperature over Pune in the year of 2018-2019 comprising the four seasons: pre-monsoon (MAM), summer monsoon (JJAS), post-monsoon (ON) and winter (DJF). To collect these observations, the instrumentations used were the sonic anemometer for wind and

temperature, and the open path H_2O/CO_2 infrared gas analyzer for CO_2 and H_2O concentrations. Using these observations, the diurnal and seasonal variations of CO_2 concentrations were analyzed. The monthly mean CO_2 concentration was observed in the range of 375-425 ppm. The seasonal mean of CO_2 concentration was 397.88, 406.00, 396.89 and 386.33 ppm in pre-monsoon (MAM), summer monsoon (JJAS), post-monsoon (ON) and winter (DJF) respectively over Pune. The CO_2 flux was positive during night-time and negative during the daytime and was in phase with convective instability. CO_2 uptake was observed to be more in monsoon and post-monsoon season compared to the winter season. The observational site of Pune appears to be source for CO_2 in April and May months of pre-monsoon season.

Keywords: Carbon dioxide, CO_2flux, Sensible heat flux, Latent heat flux

Intercomparison of Planetary Boundary Layer characteristics derived from micro pulse Lidar and Radiosonde with WRF simulations using different parameterization schemes over Kattankulathur (12.83° N, 80.04° E)

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In this study, we evaluated the performance of different Planetary boundary layer parameterization schemes available in Weather Research and Forecasting (WRF) model to simulate the observed characteristics of atmospheric boundary layer height over tropical coastal station Kattankulathur (12.83 N, 80.04 E), Chennai. High resolution (3km) numerical experiments were conducted during different seasons with five different PBL parameterization schemes. The selected PBL schemes include two first order closure schemes Asymmetrical Convective Model version 2(ACM2), Yonsei University scheme (YSU) and three Turbulent kinetic energy closure schemes Mellor-Yamada-Janjic(MYJ) Mellor-Yamada Nakanishi and Nino level 2.5 (MYNN2) and Bougeault–Lacarrere (Boulac). The wavelet covariance transform method was utilised for obtaining boundary height from mini micro pulse Lidar (MPL) observational data. The obtained PBL height from mini MPL observation showing the strong diurnal variability in all seasons. The performance of each scheme is validated with radiosonde meteorological parameter vertical profiles (potential temperature, relative humidity etc.) and PBL height to radiosonde and Lidar observational data obtained BLHs. We also compared the WRF model output surface level meteorological parameters to surface AWS observations. It is revealed that during the night time, except MYNN2 scheme all the PBL schemes are simulating the very shallow PBL heights compare to the observations and the local TKE closure scheme MYNN2 able to capture the diurnal variability of PBL height well during all seasons. In the case of surface parameters, the WRF model underestimating the 2m temperature about 2-3k and the local MYJ and non-local ACM2 schemes are able to capture the model simulations well in most of the times.

An approach to study the Planetary Boundary Layer Characteristics over North Eastern Region of India

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Planetary Boundary Layer Height (PBLH) is a fundamental parameter that characterizes the extent of vertical mixing of pollutants in the atmosphere. Understanding the PBL process and its effect on the climate system remains a key uncertainty in climate modelling. The Modern-Era Retrospective analysis for Research and Applications-2 (MERRA-2) PBL height product has been used in this study to investigate the PBLH over North Eastern Region (NER) of India during January 2010 to September 2020. PBLH has been investigated over 13 sites of NER. For different seasons, different PBLH has been observed. PBLH is maximum during Pre-monsoon season and minimum during Monsoon. Maximum PBLH (1923.91 m) has been recorded over Dhubri and minimum (1268.82 m) over Tawang. The list of PBLH variation has been shown in table 1. PBL over a hilly station Umiam, Meghalaya has also been studied with the data obtained from Dr. Pisharoty Radiosonde and Vaisala Ceilometer. Seasonal average of Mixing Layer Height (MLH) obtained from radiosonde exhibits highest MLH of 472.50 meters during winter, followed by Pre Monsoon with 441.25 meters, Monsoon with 260.83 meters and minimum during Post Monsoon with 177.78 meters. A comparison analysis has also been made between the Mixing Layer Height (MLH) obtained from the Radiosonde and Ceilometer data during the time of balloon Launch over the study site which shows a correlation coefficient of 0.88855. From this study, it is observed that different PBLH definitions contributed to significant differences of PBL height values between the model and in situ data. Moreover, disagreements between the ceilometer and radiosonde derived MLH might also be caused by the drifting radiosonde, as the fixed active sensor might not be observing the same vertical extent as that of the radiosonde.

Keywords: Planetary Boundary Layer Height, Mixing Layer Height

Prediction of rainfall through measurements of radon activity near to the surface of earth during Nilam cyclone

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A cyclone is a large scale air mass that rotates around an intense centre of low atmospheric pressure. The cyclone creates instability in the atmosphere due to high winds and clouds. Nilam cyclone was a typical tropical cyclone which originated from an area of low pressured over the Bay of Bengal with wind speeds as high as 100 km/h. During the cyclonic activity, Andhra Pradesh was enormously affected, and specifically, Chittoor district where National Atmospheric Research Laboratory (NARL) is situated had received heavy rainfall.

The variation in the activity of Radon during the precipitation period is of considerable interest due to utilization of Radon in studying the stability of lower atmosphere. The radon measurements were made during Nilam cyclone from 28 October to 01 November 2012 at NARL. Before the precipitation, strong winds reduced the activity of Radon significantly due to advection. During the rainfall, water fill-up the pores and voids of soil, which are the source of exhalation of Radon from the soil and significantly washout the suspended particles in the atmosphere. After the precipitation, the meteorological parameters have regained its diurnal trend, but radon takes few days to attain diurnal trend and the evolution has a linear growth. During this stage, water from the pores and voids of soil and its surface might have evaporated and enhanced the concentration of Radon. A significant effect of precipitation on the gamma dose levels are observed, and the variations in gamma dose levels during precipitation period. The increase in ambient gamma dose during precipitation is because of accumulation of aerosols attached Radon progeny particles on the surface of the Earth due to washout from the atmosphere during precipitation. The reduction in gamma dose may be attributed to lesser contribution from Radon gas towards gamma dose due to reduced exhalation from the soil after the precipitation event. It is observed that a strong influence of the cyclone on the meteorological parameters, Radon activity and stability of the atmosphere.

Planetary boundary layer characteristics over Odisha and its neighbourhood regions for contrasting monsoon years

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This study evaluates the characteristics and role of various planetary boundary layer (PBL) parameters over the state of Odisha and neighbourhood regions for two contrasting monsoon seasons of 2013 and 2014 using the Weather Research Forecasting (WRF) model. Based on the previous research findings over the region, a total of 244 numerical experiments are carried out from May 30 to September 29 using the Asymmetric Convective Model Version 2 (ACM2) PBL scheme. The numerical experiments are carried out with horizontal resolutions of 27 and 9 km with a lead time up to 96 h. All the simulations are made up to day-4 forecast duration. This study aims to examine to validate the model results using the typical planetary boundary layer parameters for the season as a whole, onset, and active/break phases of the two contrasting monsoon seasons. Further, the study targets to critically examine certain convective indices and its relation with various boundary layer parameters and processes influencing rainfall and associated convection over the region. The model forecast for the whole seasons will be validated with available observational and reanalysis datasets over the domain on a daily basis. Further, we would like to validate the forecast results for few low-pressure monsoon systems over the region at temporal higher resolution, i.e., 6hourly. In general preliminary results suggest a strong influence of PBL parameterization on precipitation and stability indices over the region. Further, it is revealed that the model about simulating the realistic features of monsoon over the study domain and a robust influence of Turbulent Kinetic Energy (TKE) on the precipitation characteristics are clearly evident. Currently, more investigation is in progress and relevant results in terms of precipitation forecast skills score and associated boundary layer convective processes will be presented over the region.

Study of wind pattern and dynamics of atmospheric boundary layer

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The earth's atmosphere is an ocean of air that has a thickness of hundreds of kilometers that protect life from the Sun's intense heat and harmful radiation. The behavior of the atmosphere is quite complex. Observations from Mini Boundary Layer Mast (MBLM) deployed at Bangalore University, Bengaluru and radiosonde balloon observations were used to measure the wind vectors. The directional wind turning across the boundary layer in short-range forecasts made as part of our studies is compared with radiosonde data. Significant errors are identified, particularly in cases of warm advection in which it is found that the observed wind turning is systematically observed. Similar results are found in the higher-resolution operational forecasts. The transition from summer to monsoon season is clearly seen. Also studied the diurnal, monthly and seasonal variations of wind vectors. The results will be an input for forecast models and are presented in detail.

Effect of depression on 14th October 2020 on the surface layer meteorological parameters over Atigre (Kolhapur)

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The Compact Weather Station (CWS) is a compact weather meteorological sensing device used to measure the air temperature, relative humidity, wind speed and direction and precipitation and also atmospheric pressure as well. The CWS is installed by the Indian Institute of Tropical Meteorology (IITM), Pune at the experimental site at Center for Space and Atmospheric Science (CSAS). The present work is based on the case study, that is the signature of rain depression over Atigre village in Kolhapur region. Aigre village (16.74° N, 74.37° E, 604 meters above sea level, masl) is located on the south-eastern slope of Indian western Ghats. It is found that the drastic change in wind speed and its direction with reference to a normal pattern. Normally, air temperature is minimum in the night time while it is high in the day time. However, during the event on 14th October, 2020, the temperature pattern shows in reversed nature. The temperature was around 28^{0}C before and after the event. It is also found that humidity pattern also changed on the event date only, however the regular pattern of pressure variation has not changed. Herein, we mainly focused on temperature variation, humidity variation, wind speed and wind direction. This paper also presents the initial results of the same CWS and hence the analysis method and technical information are also described in detail.

Keywords: Compact Weather Station (CWS), Temperature, Pressure, Wind and Humidity

Trend and the Seasonal Variation of Thermodynamic Parameters at Different Pressure Levels over Cochi

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The atmospheric boundary layer is the lowest part of the troposphere that interacts with earth's surface with a time scale of less than one hour. Mechanisms within the planetary boundary layer control vertical exchange of heat, moisture and air pollutants between the earth's surface and free atmosphere. It has an important role in prediction and understanding of weather, climate and air quality. Planetary boundary layer height can be obtained from the vertical structure of temperature, moisture and wind profiles. The boundary layer parameters at different pressure levels have been studied using Radiosonde data over Cochi for the period 1989 to 2018 during different seasons incorporating the marine and continental influences. To obtain the effect of sea breeze-land breeze circulation both 00GMT and 12 GMT data was analyzed. It was found that temperature, mixing ratio, potential temperature and virtual potential temperature were decreased with altitude. The trend of temperature at the lower level was found to be increasing in all season except day time of pre-monsoon season. The regression of lower tropospheric stability, convective available potential energy and convective inhibition energy with thermodynamic parameters over Cochi during different seasons indicates the correlation is stronger for lower tropospheric stability. Lower tropospheric stability has an increasing trend during the day time of winter season only. It may be attributed to the increase (decrease) in the trend of temperature, potential temperature and virtual potential temperature (mixing ratio) at a higher level during the winter season. The decrease in the trend of lower tropospheric stability may be attributed to the increasing trend of trapping of temperature and moisture at a lower level. CAPE has an increasing trend during the day time of southwest monsoon season only, causes a higher trend in the decrease in lower tropospheric stability during monsoon. Therefore, it can be concluded that the marine and continental influence on the thermodynamic parameters affect the structure and stability of the atmospheric boundary layer.

Influence of Solar Eclipse on meteorological parameters over Northwestern India

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This study was conducted during the solar eclipse at Jaipur (26.7796° N, 75.8771° E), Rajasthan. The Solar eclipse was occurred on 21st June 2020. This study reported the variation of meteorological

parameters during the solar eclipse. The solar radiation (SDR) varies between 706 W/m2 to 79 W/m2 during the eclipse. SDR reduced to 79 W/m2 at the maximum peak of the solar eclipse at 11:55 AM. The variation was also found in temperature. The ambient temperature also decreases about 2 °C during the solar eclipse. The wind speed and relative humidity also showed the variation during the solar eclipse.

Keywords: Solar Eclipse, Solar Radiation, Temperature

THEME 6

The Mountain Cryosphere (Snowpack, Glaciers, Avalanches, etc.)

Monitoring of Extent and depth of Snow Packs and Glaciers and Prediction of Avalanches using Microwave Passive Sensors – onboard spacecraft

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The extent of Snow Pack on the mountain gives an indication and the measure of Melt and freeze cycle. Along with the extent, the other parameter is the depth of snow. The depth of snow will also provide information with respect to Melt and freeze cycle. These parameters also will give inputs with regard to the movement of Glaciers as well as Melting of Glaciers. The occurring of Avalanches also has relation to the melting of snow and the extent of the snow that will be seen through the images of Mountainous Terrain.

Thus for these three very important applications that are namely the monitoring of the extent of snow along with the depth of snow, the dynamics of glaciers that will include Melt and freeze cycle that is the function of extent and depth of snow and lastly avalanches that also depend on melting of snow which has relation to extent and depth of snow.

These parameters like the extent of snow and depth of snow can be monitored by Passive Microwave Sensor. The frequency 37GHz can be used for mapping of snow on Mountains that will give the extent of snow. The Microwave Temperature T_B of the terrain at 37GHz will give the extent of snow and will also indicate Melting and Freezing of snow. For monitoring the depth of snow, the data of the same location at one more frequency is required. One can use 18GHz as another frequency. The Microwave Temperature T_B monitored at 37GHz that is T_{B37} and Microwave Temperature T_B monitored at 18GHz that is T_{B18} can be used by using the following equation

$$S\ depth = 1.59\ (T_{B18} - T_{B37})\ \text{in mm.}$$

This equation can be generalised as

$$S\ depth = 1.59\ (\underset{LT}{T_{B\,Low}} - \underset{HT}{T_{B\,High}})\ \text{in mm.}$$

Thus the Radiometers operating in Two Frequencies Preferably 18 GHz and 37 GHz one can estimate the depth of snow and by using only 37GHz data one can estimate and monitor the extent of snow. So the Radiometers onboard spacecraft operating at 18GHz and 37GHz will be used for monitoring of extent and depth of snow on mountains. That will help in providing information about the extent and depth of snow PACKS, of Glaciers and likely occurrence of avalanches.

High-Resolution Satellite Study of Multiple Stressors in Arctic Marine Systems & Correlation of Ocean-Atmosphere-Cryosphere Interactions With Climate Variability to develop Arctic-Ocean Climate Predicting Models (Aocpm)

Virendra Goswami

President: Environment & Peace Foundation & Former Vice Chancellor

The understanding of impacts of multiple stressors on the ocean and the associated risks of abrupt state shifts can be explored through the comprehensive studies of Ocean Systems Interactions, Risks, Instabilities and Synergies (OSIRIS) & Arctic-Ocean Climate Predicting Models (AOCPM). Lately (Feb'17), Researchers found that the pools underneath the glacier, Thwaites, are draining out at an unprecedented rate and emptying themselves. This unstoppably melting of the glacier into the ocean mainly happens because of warmer seawater lapping at its underside.

Prof. Peter Clark, OSU attributed that the Glacier retreat was due to rising levels of Carbon Dioxide and other Green House Gases, as opposed to other types of forces.

Hence, efforts art on Co-evolution of climate and marine life in the Arctic-Sea through the Correlation of Ocean-atmosphere-cryosphere interactions with Climate Variability, i.e. to evaluate the correlation between the impacts of multiple stressors on the ocean and the associated risks of abrupt state shift, rising of sea level, melting of the glaciers, vis-à-vis climate variability.

The kinematic features of the mesoscale convective systems over the Arctic Ocean regions would be correlated with ocean-atmosphere-cryosphere variability on time & Space Scales; at the local, regional and global levels through the extracted Sea Surface Temperature (SSTs) over the grid box, attributing the regional change to natural and anthropogenic radiative forcing agents & to bring out a few optimum values of these to develop Ocean Systems Interactions, Risks, Instabilities and Synergies & Arctic-Ocean Climate Predicting Models by using high-resolution Satellite imageries, data access, assimilation; HPC and cloud computing for real-time analysis.

Spatial and Temporal Distribution of Snowfall over Western Himalayan Region

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The Himalayan region contains the most extensive and rugged high altitudes areas on the earth and snow is the dynamic natural element. Mountain ecosystem is often referred to as "hot spot of biodiversity" The distribution of snow is largely controlled by latitude and altitude. In a tropical country like India, snow distribution is mainly controlled by altitude. An attempt has been made in the present study to identify the relationship between the temporal distribution of snowfall with an elevation over the western Himalayan region. The climatic data of the past 30 years (1991-2020) for different stations of the Himalayan range, particularly Himachal Pradesh and J&K were analysed to see the impact of climate variability in precipitation as snowfall. The stations were selected with elevation ranging from 900 to 2900 meter above mean sea level.

Keywords: Temporal distribution, Snowfall, Climate variability

Glacier Mass Changes observed over the Upper Indus Basin during 2000-2012

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Decadal glacier thickness changes over the Upper Indus Basin in the Jammu and Kashmir Himalaya were estimated using the TanDEM-X and SRTM-C Digital Elevation Models (DEM) from 2000-2012. In the study area, 12243 glaciers covering 19727 ±1054 km2 have thinned on an average of -0.35 ±0.33 m a-1 during the observation period. The highest thinning of -1.69 ±0.60 m a-1 was observed in the PirPanjal while as the marginal thinning of -0.11 ±0.32 m a-1 was observed for the glaciers in the Karakoram. The observed glacier thickness changes indicated a strong influence of the topographic parameters. Higher thickness reduction was observed on the glaciers situated at lower altitudes (-1.40 ±0.53 m a-1) and with shallower slopes (-1.52 ±0.40 m a-1). Significantly higher negative thickness changes were observed from the glaciers situated on the southern slopes (-0.55 ±0.37 m a-1). The thickness loss was higher on the debris-covered glaciers (-0.50 ±0.38 m a-1) than on the clean glaciers (-0.32 ±0.33 m a-1). The cumulative glacier mass loss of -70.32 ±66.69 Gt was observed during the observation period, which, if continued, would significantly affect the sustainability of water resources in the basin.

Keywords: Upper Indus, Glacier mass changes, TanDEM-X, SRTM

Variations of Snow Cover Area of Dokriani Glacier Catchment, Garhwal Himalayas

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Himalayan glaciers are shrinking at an alarming rate as a response to global climate change. Global warming is melting Glaciers in every part of the world, thereby affecting the availability of potable water resources, and putting millions of people at risk. Therefore, mapping the snow cover in the Himalayan glaciers is important to understand the changes, and also for understanding the impacts on Himalayan rivers. However, it is challenging to review changes in Glaciers extent using ground observations only. Satellites images have proven useful in the study of such changes in remote and hostile terrains with limited field measurements. We have studied the variability and seasonal trends in Snow cover area of Dokriani catchment between 2017-2019 using images obtained from Sentinel 2. Snow Covered Area (SCA) was calculated using the Normalized Difference Snow Index (NDSI) with a threshold of ≥0.45, and its seasonal variation over time was studied. Our analysis has shown that the onset of melt season initiated from April and lasted till October before the accumulation started again. A subtle increase in the SCA was observed from October until March during 2017-2019. The study is useful for estimating the amount of water stored in the catchment, which is vital for the management of water resources downstream.

THEME 7

Climate Change and Climate Variability

Retrieval of the Hadley Cell Boundaries and Associated Dynamics at Regional Scales using Radio Occultation Measurements

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Owing to its spherical shape, the solar radiation received by the earth is surplus at the tropics and deficient at the poles. This uneven heating results in a latitudinal thermal gradient that drives the atmosphere and oceans to circulate heat from tropics to poles. The atmospheric component of this circulation is known as the Hadley circulation (HC), which plays an important role in transporting the heat and momentum from the tropics to extratropics. The HC consists of the ascent of moist air in the deep tropics, poleward flow aloft, dry descent in the subtropics, and equatorward flow near the surface. The converging surface winds of the HC known as intertropical convergence zone (ITCZ) is an important feature of the HC. Thus the HC is a planetary scale tropical overturning circulation spanning half of the globe and is responsible for the climatic features of the whole tropics as well as subtropics. Recent studies suggest that HC is expanding polewards at a rate of 0.25 to 3 degrees per decade. Since more than half the population of the world resides in subtropics, HC expansion is significant as it can cause a poleward shift of the tropical dry zones. The evidence for this phenomenon is observed through the declining trends in precipitation and frequent occurrence of droughts in southern Australia, Amazon, and the southwestern part of the US. The HC expansion is so important that 5 out of the 14 chapters of IPCC-AR5 are devoted to this feature and its impact.

The parameters of the HC, such as width, strength, center, ascending, and descending limbs are characterized by a few metrics. Most of these metrics provide zonal mean characteristics of the HC. However, the recent studies indicate the zonal asymmetries in HC parameters, including in its expansion rates. Further, variations in ITCZ width and its location are related to the width and location of the HC edges. However, there are very limited investigations on the co-variability of ITCZ and HC to arrive at any conclusion. In this regard, the present study focuses on characterizing the zonally resolved HC and its co-variability with ITCZ using space based remote sensing measurements as well as state-of-art ERA5 reanalysis datasets with 32 X 32 km grid resolution. An algorithm is developed to identify HC center and edges from the mass stream function (MSF) derived from monthly mean meridional winds from reanalysis. Further, zonal mean ascending and descending regions of HC are identified, which completely characterize HC in terms of its boundaries. It is noted that these results are consistent with the known characteristics of the HC. To investigate the co-variability of HC boundaries and ITCZ, space based remote sensing measurements of temperature and specific humidity by Constellation Observing System for Meteorology, Ionosphere, and Climate change (COSMIC) are employed. COSMIC provides high-quality profiles of temperature and humidity by using Radio Occultation technique. This is the first attempt to retrieve the HC boundaries as well as ITCZ position simultaneously from the single space based platform observations. It is envisaged that the present study will fill some of the gap areas in the present understanding of the zonally resolved HC dynamics at regional scales and bring out co-variability of HC and ITCZ, quantitatively.

Temperature and Rainfall trends over Meghalaya (1970-2019)

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In this study, efforts have been made to determine the trend in long term temperature and rainfall series at three selected stations, i.e. Shillong, Shora and Barapani of Meghalaya. 6 series of rainfall variables (viz. monsoon and annual total rainfall series; rainy days, heavy rainfall days during monsoon season and year as a whole) and 5 temperature variables (4 seasonal mean series and 1 annual mean series) each for maximum and minimum temperatures for all the three stations have been tested for trends using 50 years (40 years for Barapani) data. The trends have been detected through non-parametric Mann-Kendall test and Sen's estimator of the slope is used for determining the slope of variation. Seasonal and annual Mean maximum temperatures are showing a significant increasing trend over all three stations. A significance level of rise in minimum temperature is not seen in all seasons. However, there is a positive slope except for decreasing trend over Shillong and Shora during Post monsoon (Oct-Nov-Dec) season. There is no significant increasing or decreasing trend observed in both monsoon and annual rainfall pattern. However, Annual and Monsoon rainfall show slight decreasing slope.

Keywords: Mann-Kendall test, Sen's estimator, trend analysis, temperature, rainfall

Analysis of temporal trend of rainfall, temperature and extreme events over Jharkhand

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This study investigates the temporal variability of rainfall, temperature and extreme events over Jharkhand. The seasonal rainfall variability is examined for the period 1901 to 2018 and extreme rainfall events and temperature variability is examined for three stations (Ranchi, Jamshedpur and Daltonganj) for the period 1986 to 2018. To examine the temporal trend, a widely used non-parametric Mann-Kendall test applied at 95% confidence level. The trend analysis indicated that the seasonal rainfall significantly decreased for the study period at the rate of 13 mm per decade over Jharkhand. The average annual maximum temperature shows significantly increasing trend at the rate of 0.58°C, 0.47°C and 0.29°C per decade at Ranchi, Jamshedpur and Daltonganj respectively. Similarly, the average annual minimum temperature also shows a significantly increasing trend at the rate of 0.46°C perdecade at Ranchi and Jamshedpur and the increasing trend is 0.13°C perdecade for Daltonganj.

The analysis reveals that the change in rainfall over the period of time is directly associated with a number of rainy days, heavy rainy days and extreme rainfall events. The decreasing (increasing) trend of annual rainfall over Ranchi (Jamshedpur) is associated with decreasing (increasing) annual

number of rainy days and heavy rainy days. No significant trend is observed in annual rainfall, extreme rainfall and heavy rainy days over Daltonganj. Result also shows that the increase in the temperature over the period is associated with the increase in the number of heatwave days and a decrease in cold wave days. All three stations have an increasing trend of heatwave and severe heatwave and a decreasing trend of cold wave and severe cold wave days.

Keywords: Rainfall variability, Extreme events, probability distribution, normal frequency distribution, Mann-Kendall, Return period.

Study the changes occurring in the climatic condition after COVID-19 lockdown in Maharashtra and Odisha

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Just after the Indian government issued the first lockdown rule to cope with the increasing number of COVID-19 cases in March 2020. We have studied the changes occurring in the climatic condition after COVID-19 lockdown in Maharashtra and Odisha which is located at the west and east coast of India respectively. Lockdown shows a big improvement in the air quality, mainly for nitrogen dioxide (NO_2) levels, in major Maharashtrian megacities such as Mumbai, Nagpur and Pune. The fall in NO_2 levels is largely due to the sharp drop in fossil fuel combustion in transport, industrial and energy sectors after the lockdown. In addition to the pandemic and cyclone, locust swarms have been sighted in parts of eastern Maharashtra, in what is said to be the largest locust swarm in close to three decades. Drastic reduction in NO_2 over these cities post lockdown show that we can achieve breathable air and clear skies with emission reduction, and not necessarily by taking drastic measures such as shutting down all sources. By adopting emission load reduction or efficient emission control across sources such as vehicles, industries, petrochemical refineries and power plants, we achieve clean breathable air. The pollution levels in major towns in Odisha fell drastically during the lockdown. The air quality in Bhubaneswar got better by 60%, while there was a 59% improvement in the case Berhampur. There was a noticeable difference in the air quality of other towns in Odisha. The extreme weather events that have come to Maharashtra and Odisha and their coastal capital cities, against the backdrop of environmental degradation, are overlapping with COVID-19, which is widespread in these areas. The two cyclones highlight the urgency for climate adaptation and resilience in India's coastal cities. COVID-19 recovery offers a chance to further climate action by giving due importance to sound environmental responses, plans, and policies. The rise in temperature due to climate change has increased the vulnerability of Odisha on the east coast of India to intense cyclonic storms. After lockdown, the entire monsoon season, i.e. the period between June 1 to September 30 both Maharashtra and Odisha have received normal rainfall at 1165.0 mm and 1140.9 mm respectively. Renewable energy growth and impact of COVID-19 have led to the first year-on-year reduction in India's CO_2 emission in four decades. Emission fell by around 1% in the fiscal year ending March 2020, as coal consumption and oil consumption flatlined. Over the past year, CO_2 emissions, as well as air pollution levels, have declined more recently. The lower temperature in pre-lockdown from January to March 2020 could lower mixing height of air and cold condition, air pollution may be one of the causes of increasing concentration of all criteria pollutions during winter, while higher temperature during the lockdown phase and unlock phase may have to contribute in the dispersion of pollution. This is clearly evident in the significant negative correlation between temperature and most of the air pollutants. These findings indicated the influence of temperature on gaseous pollutant is much more effective in summer than other season due to higher

temperature range, although rainfall shows a weak relationship of the air pollutants. Overall, the effect of the immediate Covid-19 related restrictions is close to negligible and lasting effects, if any, will only arise from the recovery strategy adopted in the medium term. The results highlight that without underlying long-term system-wide decarbonization of economies, even massive shifts in behaviour, only lead to modest reductions in the rate of warming.

Keywords: COVID-19; Lockdown; Climatic condition; Temperature

Changes in the relationship between El Niño Southern Oscillation and Indian summer monsoon rainfall in future decades

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The El Niño Southern Oscillation (ENSO) is identified as one of the important external drivers of Indian summer monsoon rainfall (ISMR) variability. In this work, we explore the projected changes in the ENSO-ISMR relationships by the end of the 21st century using Coupled Model Inter Comparison Project Phase5 (CMIP5) models. The historical (1951-2005) and future (2050-2099) projections of ISMR was carried out in addition to the changes in the ENSO-ISMR relationship during both the periods. The future projections were carried out using five models (CNRM-CM5, GISS-E2-R, GISS-E2-R-CC, HadGEM2-CC, and IPSL-CM5A-MR), which were screened out from the 25 CMIP5 models based on Taylor diagram and the future projections were carried out in two Representative Concentration Pathways (RCP) scenarios; RCPs 4.5 and 8.5. All the five models simulate an increase in ISMR in both the RCPs; mainly over the northeast, west coast, foothills of the Himalayas, monsoon core zone and the peninsular Indian region in future periods. However, the increase is well simulated in RCP 8.5 scenario than in RCP 4.5. Noticeable changes in ENSO-ISMR relationship are observed from one model to another in both the historical and future RCP scenarios. The rainfall over most of the Indian regions shows a significant decrease (increase) during El Niño (La Niña) events in RCP 4.5. The changes in sea surface temperature (SST) and Walker circulation over the Indo-Pacific domain during El Niño and La Niña events are noticeably related to the ISMR patterns over the Indian region. However, the relationship is well represented in HadGEM2-CC and IPSL-CM5A-MR models than in the other models, particularly in RCP 4.5. The Indo-Pacific domain undergoes total warming (cooling) during El Niño (La Niña) events and the SST over the Indo-Pacific domain does not exhibit significant variations in the RCP 8.5 scenario. Hence they are not well related to the rainfall patterns over the Indian regions during El Niño and La Niña events.

Effect of Climate change on various Rainfall events and its global Teleconnections over South Peninsular India during Northeast Monsoon

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Northeast monsoon (NEM) rainfall which occurs during October–December (OND) is of a huge societal and economic importance over South Peninsular India (SPI) as the region receives a noteworthy rainfall only during this season. Aim of the present analysis is to unravel the behaviour of various NEM rainfall events over SPI in a long-term period to unravel the effects of global warming on regional rainfall. The India Meteorological Department (IMD) high-resolution rainfall data (0.25° × 0.25°) for the period of 116 years (1901- 2016) is used to calculate the long-term climatology, variability, trends, of the NEM rainfall and its associated events over the region. The relationship of various NEM rainfall events with climate indices (Niño–3.4 region SST, SOI, ISMR, and DMI) are also studied.

The results indicate that in the recent warming period, the seasonal mean rainfall remarkably increased in the eastern part of SPI, while a widely spread significant decrease is noticed over Kerala, South Interior Karnataka, and Coastal Karnataka. This increase in seasonal rainfall over Tamil Nadu and Rayalaseema is due to the increase in the number of high-intensity rainfall events. The decrease in the seasonal rainfall in other subdivisions in the recent period is mainly due to a huge decrease in the Moderate Rainfall events,. It has also been discovered that the relationship between NEM rainfall events and its associated rainfall with ENSO, IOD, and ISMR have weakened in recent decades after 1988. This study marks to be useful in determining the effects of heavy rainfall events and its variability on various sectors to help and assist the risk management sectors to adopt advanced technologies for a sustainable future in the present global warming era.

Keywords: Northeast monsoon, South Peninsular India, Rainfall events, trend analysis, Teleconnections

Observing the past trend of climate change through principle component analysis

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In the past few decades, the climate has manifested numerous shifts in its trend. Various natural and anthropogenic factors have influenced the dynamics and trends of climate change at a longer time scale. To understand the long term climate fluctuations, we have analysed forty years (1978 - 2018) data of ten climatic parameters that are responsible for influencing the climate dynamics. The parameters

involved in the present study are total solar irradiance (TSI), ultraviolet (UV) index, cloud cover, carbon dioxide (CO_2) abundances, multivariate (ENSO) index, volcanic explosivity index (VEI), global surface temperature (GST) anomaly, global sea ice extent, global mean sea level and global precipitation anomaly. Using the abovementioned climate entities; we have constructed a proxy index to study the quantitative measure of climate change. In this process, these indicators were aggregated to a single proxy index as global climate index (GCI) that has measured the strength of present climate change in semblance with the past natural variability. To construct GCI, the principal component analysis (PCA) has been used on yearly based data for the period 1978 - 2018. Actually, PCA is a statistical tool with which we can reduce the dimensionality of the data and it retains most of the variation in the new data set. Further, we have confined our study to natural climate drivers and anthropogenic climate drivers. Our result has indicated that the strongest climate change has been occurred globally by the end of the year 2018 in comparison to late 1970's natural variability.

Expected changes in the winter seasonal rainy days over IHR during 2020-2099

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This study attempts to quantify the expected changes in the winter period rainy day climatological pattern for the Indian Himalayan Region during 2020-2099 in comparison to a baseline period of 1980-2000 under two different warming scenarios, i.e. representative concentration pathways 4.5 and 8.5 (RCP 4.5 and RCP 8.5). The winter seasonal rainy day is characterized as any day during November to February of a winter season having total rainfall ≥ 5.0 mm. Five climate model products from the Commonwealth Scientific and Industrial Research Organization initiated Coordinated Regional Climate Downscaling Experiment (CORDEX) of the World Climate Research Programme over south Asia region are used for this purpose. Model biases are estimated with respect to observations for a baseline period of 1980-2000. Subsequently, model ensemble non-linear trends of the winter seasonal rainy day climatology, during 2020-40, 2041-70, 2071-2099, are estimated using Sen's slope estimator. Similarly, the ensemble average of expected changes in the number of winter seasonal rainy days for three futuristic periods are estimated; and attempts are made to identify the topographical ranges which are expected to be most affected by the changing winter seasonal rainy day climatology over IHR. Results show that the CORDEX-regional climate models are having a positive bias, ranging between 1-30 days, across the high altitudes of the entire Indian Himalaya, and model performances improve with an increasing number of rainy days per season. Although the impact of aggravated warming (i.e. RCP 8.5) is noted to enhance area-averaged non-linear trend of rainy days over northwestern (0.014 day) and eastern (0.005 days) Himalaya during 2071-2099, the model ensemble area-averaged reduction in rainy day climatology between 0.3 to 1.0 day is highly likely by the end of the century. It was also observed that the Himalayan region within 1000-2500 m above sea level may experience a decline in rainy day climatology up to 0.8 to 3.2 days under both the warming scenarios of RCP 4.5 and 8.5.

Keywords: Winter seasonal rainy day, Indian Himalayan region, CORDEX

Future projection of Northeast Monsoon Rainfall over South Peninsular India and associated subdivisions using CORDEX-SA experiments

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South Peninsular India (SPI), which falls under the shadow region of summer monsoon houses 250 million people, who are primarily dependent on Northeast Monsoon (NEM) rainfall as it contributes mostly to their annual rainfall. Aim of the study is to obtain the future projections of NEM rainfall over SPI representing three different greenhouse gas emission scenarios (i.e., RCP 2.6, RCP 4.5 and RCP 8.5) for two future time slices, i.e., near (2020–2049) and far future (2070–2099) estimated from a set of high-resolution regional climate model (RCMs) simulations performed under CORDEX-SA experiments. In order to achieve that, first, an assessment of 10 CORDEX-SA RCMs simulations is done for NEM rainfall over SPI for the historical period 1976-2005 using the India Meteorological Department high resolution ($0.25^o \times 0.25^o$) gridded rainfall analysis dataset.

The results suggest that most of the CORDEX-SA experiments are able to simulate the spatial distribution of NEM seasonal rainfall and its variability over SPI, but there is an inability in capturing realistic magnitudes, spatially the errors are moreover the East and west coast where most of the rainfall occurs. The experiment with RCA4 driven by EC-EARTH global model and REMO2009 driven by MPI-ESM has a fairly lesser bias than the other models, whereas the bias is most in LMDZ-IITM-RegCM4. The experiments by CCAM models have very similar characteristics in representing the rainfall pattern. The Standardized reconstruction Bias correction technique is used to adjust the bias present in the models and the change in NEM rainfall expected in the future time periods were computed. It was found to significantly improve the model outputs in representing the climatological mean and inter-annual variability of (IAV) of NEM rainfall over SPI, but in case of categorical rainfall years, improvement is seen only in the normal rainfall years. In the future, there is a rise in the NEM rainfall in the first half of the twenty-first century in all the 3 pathways. However, after that, in the RCP 2.6, rainfall is expected to decrease, whereas it was found to increase in the other two scenarios. It was also found that there may be more deficit than excess rainfall years in the near future in the RCP 4.5 and 8.5 scenario and no deficit rainfall years are projected in the far future in either of the scenarios with respect to present climate. The variability of NEM rainfall is also expected to remarkably increase in all three future scenarios which may potentially impact the water resources management sectors. Hence, this study is very useful in determining the effects on various sectors due to the variability in NEM rainfall over this region and for adapting to climate change using advanced technologies for a sustainable future.

Keywords: Climate projections, Northeast monsoon, CORDEX-SA, South Peninsular India, Representative concentration pathways

Changes in the relationship between ENSO and summer monsoon rainfall and its association with circulation features

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The All-India summer monsoon rainfall (ISMR) is defined as the rainfall received during June to September over India. The ISMR plays a vital role in both agriculture as well as the economy of the Indian subcontinent. The ISMR is showing different variabilities on Spatio-temporal domain and these variabilities arise from both internal and external feedback. The SST over the equatorial east and central Pacific Ocean related to ENSO phenomena have a general inverse relationship with ISMR. Recent studies found that a multidecadal variability between ISMR and ENSO due to concurrent variations in meridional temperature gradient over the tropics at upper troposphere. The objective of the present study is to explore how the ISMR - ENSO relationship varies on the multidecadal timescale and their possible connections with circulation features. Which of the Indian regions will get the effect from the multidecadal variability of ENSO? The datasets used for exploring the decadal variabilities of ENSO-Monsoon relationship includes HadISST1 (1° x 1°), IMD rainfall data (10 x 10), CRU precipitation data (0.5°x 0.5°) for the period 1901 to 2015. To explain the physical mechanism responsible for the variability we utilized NCEP–NCAR (2.5° x 2.5°)reanalysis wind, vertical velocity and specific humidity dataset for the period 1948 to 2015.

We divided the entire period into three 1931-1960, 1961-1990 and 1991-2015 based Nino3.4 index and ISMR relationship. We understood that the ENSO-ISMR relationship is subjected to variations in these three epochs. The early period was wet, but the middle and recent decades are relatively dry. The occurring of El-Nino is increased during recent decades. The ENSO phenomena are mostly effecting to the Monsoon Core Zone. The correlation among the Nino 3.4 SST and Indian summer monsoon rainfall is more during the middle period. Even though the number of La-Nina is more, the El-Nino has more strength during this period. During recent periods, the La-Nina condition is prevailing and it contributes more rainfall to the southwest coastal regions. The effect of La-Nina was more on that period accounts for the surplus rainfall over the most regions of the Indian landmass. The drying of the Northeast region cannot be linked with Nino 3.4 SST. The physical mechanism of the variability is explained on the basis of changes in circulation features. The weakening of Low Level Jet during the recent decade can be a reason to deficit monsoon rainfall during recent periods. It is evident that the reduced moisture transport also accounts for the reduced precipitation. The changes in Walker and Hadley circulation during the three periods were also studied.

Analysis of extreme winter precipitation over north India

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About one-third of annual rainfall over north India and adjoining region of the Western Himalayas is obtained during the winter season from December to February. The extreme

rainfall events in winter over north India is mainly associated with the passage of synoptic systems from the Mediterranean known as Western Disturbances (WDs). The complex topography and orography of the region play an important role in determining the precipitation. The snowfall over higher elevations during winter is important for the positive mass balance of glaciers which are critical for ensuring the availability of freshwater to a large fraction of the population over India. Thus, the variability of winter precipitation causes a serious threat to the livelihood of a significant fraction of the regional population. The spatial and temporal variability of extreme precipitation in winter over north India during the recent 41 years (1979-2019) is analysed using gridded rainfall data set of India meteorological Department. The frequency and intensity of extreme rainfall events show a decreasing trend over the region (29-37°N,70-80°E). The probable cause for this trend is investigated using teleconnection pattern and tropical-midlatitude interaction.

Influence of several local meteorological parameters on surface ozone concentration over semi-arid western tropical site, i.e. Udaipur (24.59° N, 73.12°E)

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The analysis of investigation has described the contribution of measured ground level ozone with their observed several surface meteorological and atmospheric boundary layer dynamic parameters, such as a rise or fall the values of ground level temperature (T, °C), relative humidity (RH, %), local wind speed (WS, m/s), wind direction(WD), solar radiation, total water vapor column content and planetary boundary layer altitude (PBL, m) at Udaipur for the period December 2009 to November 2014. The strong seasonal statistically positive correlation values were found between seasonal, diurnal pattern between surface ozone concentration and ground level, temperature, solar radiation in the short wave range, at fixed UV and IR solar radiation wavelength as well as planetary boundary height. Their order of decreasing trend is as follows, i.e., Pre-monsoon > Post- monsoon> Winter > Monsoon month. In contrast to this, the behavior of reduction of ozone with increasing of Rh and Total water vapour column values have been clearly demonstrated in their the seasonal patterns in the following decreasing order, i.e., Pre-monsoon> Monsoon> Winter> Post-monsoon. As far as concerned in case of surface wind parameters, seasonal surface ozone diurnal behavior along with their respective ground level wind speed varied diurnal exhibits the best and greater positive correlation value only in Pre-monsoon monthly only. The seasonal change in ground level ozone mixing ratio also changes in accordance with turning the observed most probable seasonal wind direction pattern. The present observations were also interlinked with alteration of the nature of the travelled path, their duration of the propagated type of source path regions before arriving the receptor side of backward air mass trajectory of 500m above surface level as regional air pollutants transportation effect due to long range transportation effect. The possible explanations and comparison of these findings with other earlier reported results would also be discussed in details.

Variability and time series trend analysis of rainfall and temperature over Kolkata

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Observing the variability of meteorological variables, mainly rainfall and temperature is important in the context of changing climate, particularly in the places where rain-fed agriculture is predominant. Farmers are mostly affected by climate changes due to their low adaptive capacity. In this study, the changes of rainfall and temperature over Kolkata and surrounding location have been investigated using gridded monthly precipitation and temperature data obtained from Global Precipitation and Climate Centre (GPCC V7) with 0.5° X 0.5° resolution from 1901 to 2014 to examine and understand the meteorological dynamics. Data have been analyzed using the coefficient of variation (CV), anomaly index and precipitation concentration index (PCI). Trend analysis revealed the fact that temperature has been increased all through the year. However, the temperature has been increased more in the winter season. It has been observed that non-monsoon rainfall has been increased. The box plots also show more outliers for the Winter season for rainfall. CV shows maximum value in the winter season and less variation in the monsoon season for temperature. PCI shows an increasing trend for temperature for the period 2001-2014. For rainfall, PCI shows a decreasing trend for 1901-2000 and for 2001-2014 a very slight increasing trend has been observed. (Depending) In view of the present analysis, some strategic recommendations can be made in agro based activities.

Examining Temperature Extremes during pre-monsoon season and their relation to elevation and glacial areas in various parts of the Himalayas in the past two decades

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Climate change in today's world is a global phenomenon. The Himalayas govern the climate, regional weather system and monsoon of Indian sub-continent. The mountains serve as the best indicators for detecting climate change. In recent times a great deal of climatic variability including frequent extreme events has been recorded in the Himalayas. This study attempts identification of the Temperature extremes and their Spatio-temporal variability in various parts of the Himalayas in the pre-monsoon season in the months of March-May over the past two decades and also to show their relation with elevation and glacial areas using MERRA-2 Air Temperature daily data, GLIMMS RGI Glacial inventory data and ASTER DEM elevation data. The daily mean data for the observation period was used to create long term seasonal mean, which was further used to calculate the standard deviation and standard anomaly for each year. Thresholding was performed for identifying extreme events of temperature, i.e. warm spell and cold spell based on the standard anomaly or the Z- score values obtained.

Cold spells have been more frequent than the warm spells in the various parts of Himalayas over the last two decades. The temperature extremes viz. warm spell and cold spell do not show any conclusive relation to an elevation over the Himalayan terrain.

In terms of warm spell area, Central Himalaya leads with 17.17 % followed by the Western Himalayas at 15.33 % and the least in the Eastern Himalayas at 12.38 %. In terms of cold spell area Eastern Himalayas leads with 29.60 % followed by Western Himalayas at 21.49 % and least in the Central Himalayas. Western Himalayas is cold spell dominated area by 6.15 %. Eastern Himalayas is cold spell dominated by 17.22 %, while Central Himalayas is slightly warm spell dominated at 0.43 %. In terms of glaciated areas, Western Himalayas leads with 9.61 %, followed by the Central Himalayas at 3.43 % and least in the Eastern Himalayas at 1.05 %.

Keywords: Himalayas, Temperature Extremes, Warm Spell, Cold Spell, Elevation.

Trend in Monsoon Inversion and its Impact on Rainfall over Indian landmass

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The sustained temperature inversion (TI) that is observed in the lower troposphere, during the summer monsoon over the western Arabian Sea (AS) has been termed the monsoon low level inversion (MI). MI is observed during the period, June to September with peaks of intensity and extent from July to August. The low level monsoon inversion is considered as a seventh semi-permanent feature of monsoon along with existing six (Pakistan Heat Low, Mascarene High, Tibetan High, Somali Low level jet, Monsoon Trough, and Tropical Easterly Jet). The fundamental, structural and physical differences between TI and MI are observed. A comprehensive analysis has been made in this study to investigate the spatial and temporal variability of the monsoon inversion (MI) over the Arabian Sea and its impact on the Indian monsoon rainfall is carried over a 37-year period (1980 to 2016) using MERRA version2 reanalysis and downscaled simulations based Weather and Research Forecasting (WRF) model. We analyzed the variability of MI from diurnal to seasonal scales. A seasonal analysis of the simulated winds and MI reveals that WRF reproduced the monsoon characteristics as observed in MERRA2 reanalysis, including the spatial and vertical orientation of the MI. We further investigated the variability of the lower tropospheric wind speed and associated changes in MI over the 37-year simulation period. The possible mechanisms involved in the formation of MI are investigated. This reveals a significant decreasing trend during the summer monsoon over the western Arabian Sea. We argue that this led to a decreasing trend in the lower tropospheric wind shear and advection of temperature, and hence, reduced the frequency of occurrence of the MI. Our results suggest that the decrease in the occurrence of the MI could directly affect the amount of moisture transported to the Indian subcontinent, which in turn could alter the amount of rainfall over this region.

Analysis of Trend in Extreme Climate Indices in Cherrapunji

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Cherrapunji located in the North-Eastern part of India received about 11,418±2,411 mm (1979-2019) of average annual rainfall, thereby called one of the wettest spots on earth. Due to heavy rainfall, the temperature is moderate throughout the year. But the changing climate of the earth also has influenced this spot on the globe, locally. So, in this paper, we have tried to figure out the significant changes in extreme climate indices for daily temperature as well as precipitation over a period of 41 years, i.e. from 1979 to 2019. For that, 27 extreme climate indices were calculated using RClimDex v 1.9-3, an open source R package. 10 indices for rainfall and 8 indices for temperature, being utmost important, were then considered for the study. A non-parametric Mann-Kendall test was performed to check the significance of trend among the indices and the magnitude of the trend was determined using Sen's slope estimator. The results showed that, among the precipitation indices, consecutive dry days (cdd) increased significantly with 0.58 days/year, while consecutive wet days (cwd) decreased significantly with 0.36 days/year. The other precipitation indices also showed a negative trend and most importantly, total annual wet day precipitation (PRCPTOT) showed a decreasing trend of 42.39 mm/year. Only very light rainfall (VLR) was found to be increasing significantly with 0.17 days/year. While among the temperature indices, summer days (su25) increased significantly with 1.56 days/year but in case of tropical nights (tr20) a slight negative trend was observed. Again a significant positive trend was observed for indices associated with daily maximum temperature with an annual change of 0.06 to 0.07 ^{0}C/year. And for indices associated with the daily minimum temperature almost no change or a slight negative change was observed, except for the month of February (which showed a significant positive trend with 0.03 to 0.05 ^{0}C/year). The analysis reveals that some of the extreme climate indices which explains the climatic conditions of Cherrapunji have changed a lot over the period of 41 years. The decrease in precipitation and increase in maximum temperature; decrease in wet days and increase in dry days; increase in summer days are the clear indication of such kind of changes in climate. Therefore, Cherrapunji is also under a threat when it comes to climate change.

Trends and variability of Indian summer monsoon rainfall over different homogenous regions

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The Indian summer monsoon rainfall accounts for 70–90% of the annual rainfall. It plays a crucial role in the agriculture and economy of the nation. In this study, features of summer monsoon rainfall are studied to understand the variability of rainfall in terms of intensity classes in different homogeneous regions utilising IMD gridded rainfall data for 1901-2018. The homogeneous regions

identified are Northwest India, Northcentral India, Northeast India, Westcentral India and Peninsular India. We classified the rain events into different intensity as percentile values, < 10: Dry, 10-50: Low, 50-90: Moderate, 90-95: High, 95-99: Very High, > 99: Extreme rainfall events for each region. The study period was further subdivided into four multidecadal periods and they are 1901-1930, 1931-1960, 1961-1990, and 1991-2018. The rainfall characteristics such as mean, number of rainy days and percentage contribution in different multidecadal periods were computed. Further, correlation analysis of the rainfall events between the regions was carried out. The results for the entire period indicate that more than 60% of rainfall is contributed by low, moderate and high rainfall intensity classes. Variation in rainfall pattern in extreme and dry intensity classes is responsible for the changes in the total rainfall received in different periods. From correlation analysis among the homogeneous regions, it is found that dry, low and moderate events are more homogeneous over India or can be treated as rainfall events attributed by large-scale events. However, very high and extreme rainfall events are localized phenomena and are caused by the geographic and dynamic features of the region. In other words, the homogeneous rain events become out of phase towards the recent decades. The inter-region correlation analysis between Northeast & Peninsular India, Northeast &Westcentral India and Northeast & Northwest India indicates contrasting behaviour in rainfall pattern and can be interpreted as different rain producing mechanism prevails over these regions. Another interesting feature is that Northeast India shows an increasing trend in the total rainfall in the recent multidecadal periods contributed by the extreme rainfall events. However, the behaviour in Northcentral India is different with an increase in dry and extreme events during 1961-1990 and a decrease during the recent period.

The Impact of Cumulus Convection in the evolution of the Indian Summer Monsoon for two contrasting years using a Regional Climate Model

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The Indian summer monsoon is very crucial for the agricultural produce of the Indian subcontinent. India's economy mainly depends on the performance of the summer monsoon. The study of the summer monsoon, particularly the rainfall in India, has a long history with long range forecasts of seasonal rainfall being issued by the India Meteorological Department (IMD) since the late 19th century. The International Centre for Theoretical Physics (ICTP)'s Regional Climate Model (RegCM4.7) is used to simulate the Indian summer monsoon circulation for two contrasting years in terms of rainfall. The model is integrated for the South-Asia CORDEX domain during the period May to October for the years 2013(flood) and 2014 (drought) at a resolution of 25km. The sensitivity of the model to cumulus convection has been tested using Mixed convection (Kain-Fritsch over Ocean and Emanuel over Land), Tiedtke, Kain-Fritsch (KF) and Emanuel schemes. The mean circulation features are validated with ERA5 and the rainfall with IMD rainfall. Results indicate that, of all the schemes, the Emanuel and the Mixed convection schemes come very close to the analysis for pressure distribution. The Emanuel scheme slightly under-predicted the winds at 850hPa in the Arabian Sea compared to the KF scheme. Of the four schemes, the Mixed convection scheme showed better overall performance over the land region as well as in the two seas of Arabian sea and the Bay of Bengal while in the case of 100hPa winds all the schemes showed similar strength in terms of intensity. The Tiedtke scheme seems to have performed well for the temperature distribution at 850hPa compared to the other schemes and came very close to the ERA5 reanalysis. All the four schemes under-predicted the rainfall, especially over the Western Ghats with Emanuel scheme coming closure to the ERA5 while the Mixed convection scheme was performing reasonably well over the Western Ghats and North-Eastern parts of India.

Keywords: Regional Climate Model (RegCM), CORDEX, Cumulus Convection.

Critical analysis for increase in number of cyclonic storms over Arabian sea during 2019

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Importance of prediction of intensity and track of intense low pressure systems is well established due to its operational need from users' point of view, which IMD is doing accurately during past years for the track of the system, intensity and time of landfall, which naturally reduces losses of life, animals and crops significantly. The paper discussed critically the rare event of cyclogenesis of five systems of cyclonic storms and above intensity occurred over the Arabian sea during the year 2019 against the normal (1891- 2018) of 1 (one) per year and formation of more intense storms. And a rare event of simultaneous occurrence of storms in the Arabian Sea in the post-monsoon season.

The study observed that Arabian sea had been found more active during 2019, due to increase in Sea Surface Temperature (SST) and positive Indian Ocean Dipole (IOD) which might have occurred due to interannual variability as a result of global warming. The same has been outlined in the present paper. It resulted in the formation of 8 Cyclonic Disturbances which occurred against the normal of 1.7 cyclonic disturbances per year. 2019 witnessed 5 cyclones over the Arabian sea (against the normal of 1 per year) and 1 deep depression and 2 depressions. Out of 5 cyclones over the Arabian sea, 4 were severe cyclonic storms and above the intensity of cyclones, which previously happened way back in 1902. The year 2019 had the maximum number of cyclonic disturbances exceeding the previous record of 1998 and frequency of cyclones equalling the previous record of 1902. The year 2019 also witnessed the development of more intense cyclones over the Arabian Sea, as out of 5 cyclones, there has been one super cyclonic storm (Kyarr), 1 extremely severe cyclonic storm (Maha), 2 very severe cyclonic storms (Vayu, Hikaa), and 1 cyclonic storm (Pawan). Two cyclones occurred concurrently in the Arabian Sea, with the formation of Cyclone 'Maha' (30th October -7th November) even as Super Cyclonic Storm 'Kyarr' (24th October - 2nd November) prevailed over the region. Climatologically, no such occurrence of two cyclonic storms over the Arabian Sea had been observed during the period between 1961-2018. This event was soon followed by co-existence of Cyclonic Storm 'Pawan' over the southwest Arabian Sea and deep depression over the southeast Arabian Sea in the first week of December. In the current scenario of climate change, the frequency of extreme events is increasing in one form or other, which needs to be studied further.

Keywords: Arabian Sea, Cyclogenesis, Cyclonic disturbance, Global warming, sea surface temperature (SST) and Indian Ocean Dipole (IOD).

Numerical simulation of the Indian Monsoon system using WRF model

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The Indian monsoon system is one of the important branches of the Earths atmospheric general circulation. Knowledge of monsoon variability is highly essential on different space and time scales for the agrarian community of India. The present paper envisages simulating the climate for the historical period 1976-2005. The scientific tool used is the time tested WRF model run on a climate mode at 25km resolution driven by the Community Climate System Model version 4 (CCSM4). The model physics has been configured along the lines of Betts-Miller-Janjic (BMJ) for Cumulus convection, Yonsei-University (YSU) for PBL and Noah for land surface processes. The model simulations for the two seasons, namely June-July-August-September (JJAS) (South-west Monsoon) and October-November-December (OND) (Northeast Monsoon) are validated with ERA40 reanalysis. The performance of the WRF model is assessed by comparing the distribution of Temperature, Pressure, Wind filed and Rainfall. Results indicate that the reversal of the meridional temperature gradients over the Indian subcontinent for the winter and summer seasons are produced with reasonable accuracy. The present study will be useful for agriculture, water resource management and also as a reference database for future climate study.

Keywords: Indian Monsoon, WRF model, CCSM4

An Investigation of diverse vegetation fires and its carbon dynamics in India - A Remote Sensing approach

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Climate variability and fires regimes are now being the centre of subjects in climate studies as they share a causal relationship in a climate feedback cycle. Understanding the emissions from fires and their role in the environment is inevitable in the accurate prediction of climate change projections. However, current climate change estimations were solely based on emission inventories without the inclusion of its associated role in the environment, which may deceive the authorities while framing climate mitigation policies. Hence an investigation of carbonaceous aerosols emission from open fires and its contribution to the carbon feedback cycle is studied spatially and temporally with the help of remote sensing techniques. This study specifically focusses on carbonaceous aerosols because they pose different feedback to the climate cycle. We estimated that the mean organic carbon and black carbon emission were about 3.53×10^{6} Giga grams per year and 3.05×10^{5} Giga grams per year during the study period. On a national scale, cropland fires contributed towards the largest portion of total carbonaceous aerosol emissions from open fires which are then followed by forest and shrubland fires. Fire emitted aerosols deposition flux and residence time estimation is attempted to identify its role in the feedback cycle. The resultant mean dry deposition fluxes of BC and OC emission were 1.01×10^{-5} kg/km/day (BC) and 5.74×10^{-5} kg/km/day (OC) for shrubland, 3.32×10^{-5} kg/km/day(BC) and 5.13×10^{-4} kg/km/day (OC) for forest and 5.14×10^{-1} kg/km/day(BC) and 11 kg/km/day (OC) for cropland ecosystem respectively.

The average residence/lifetime of black carbon emitted from different vegetative ecosystem fire is estimated to be between 8.63-11.65 days. An alternating feedback variability is exhibited by the burned ecosystem, which is quantified by measuring the changes in the carbon stock. Interestingly mean carbon stock of the vegetative ecosystem is found to grow from 48% to 234% irrespective of emission and mineralisation trade-off. Our study revealed the dynamics, interannual and long-term estimation of absorbing and cooling aerosols in the environment which will help minimize the errors in radiative forcing calculation in climate models.

Keywords: Black carbon, organic carbon, carbon sequestration, vegetation, remote sensing, carbon flux and residence time.

Spatial and temporal variation of maximum and minimum temperature over North-East Region of India

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In the present study, an analysis has been performed on maximum and minimum temperature of the north-east region of India. Two approaches are used for analysis- spatial and temporal. For spatial analysis, temperatures of 10 locations of NE region are used and interpolation has been performed using these locations' observation. Interpolation creates a surface of continuous temperature using known value. While interpolating the observation, seasonal maximum and minimum temperatures are used. Each year is divided into four seasonal clusters. The first cluster includes January and February to analyse winter temperature. The second cluster includes March, April and May to analyse pre-monsoon season. The third cluster includes June to September to analyse monsoon season. The fourth cluster includes October to December to analyse post-monsoon season. Total of 20 years of temperature data is used in the study. For temporal analysis, maximum and minimum temperature maps are created for each year. In this study, both hilly and non-hilly stations are selected for observations so that it can extract variation of temperature with respect to spatial variation.

Keywords: Spatial, temporal, maximum temperature & minimum temperature

Climate Change Impact on North-East India Summer monsoon rainfall

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World's largest rain falls over north-east India during boreal summer and is characterized by large spatial inhomogeneity. Quantification of global warming impact on the northeast India rainfall (NEIR) is, therefore, a crucial factor for the region's food security and delicate bio-diversity. Such quantification efforts, however, have been unsuccessful so far due to unavailability of long records of precipitation in the region. Here, using a long (~200 years) record of seasonal mean NEIR, we separate oscillatory modes of variability from the secular trend using the Improved Ensemble

Empirical Mode Decomposition (ICEEMD). The long term change in NEIR estimated from this nonlinear trend is unbiased by the oscillatory modes and leads to a climate sensitivity of NEIR of (-3.2 ± 1.65)%/0 K. Similar estimate of the impact on daily rainfall extremes, however, has been lacking due to absence of long daily rainfall data on a sufficiently large number of fixed stations. Towards this end, a 90 year long daily rainfall data based on 24 well-distributed fixed stations over north-east India (NEI) is constructed through a data mining effort. Even as the seasonal mean decreases, our estimate indicates that the frequency of occurrence of daily extremes (exceeding 99.5 percentile) over the NEI is increasing at (+51 ± 4.99)% /0K while the intensity is increasing at (+12.5 ± 3.32)% /0K over the past century, a rate much faster than envisaged by Clausius-Clapeyron scaling. In contrast to a significant multi-decadal variability (MDV) of summer rainfall over rest of India, we find that a much weaker MDV of NEIR tends to go out of phase with that over the rest of India not only on inter-annual but also on multi-decadal and centennial time scales, with significant implications on interpreting past rainfall reconstruction from caves in the NEI. Our findings suggest that vulnerability to mesoscale hydrological disasters over the NEI in the coming years is much higher than that over the rest of India.

Keywords: North-East India monsoon rainfall, Climate sensitivity, Driver of multi-decadal mode, Improved Ensemble Empirical Mode Decomposition

Spatio-temporal variation of extreme rainfall events during the southwest monsoon period and their association with global forcing mechanisms

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The characteristics of extreme rainfall events over India during the southwest monsoon period and their linkage with global climate indices were investigated in the present study. Daily rainfall data were taken from APHRODITE products and Sea Surface Temperature (SST) from Hadley Centre. Extreme events and associated floods lead to major hydrological disasters. The cause of floods may be due to topographic features of the region as well as the frequency of occurrence of high-intensity rainfall. Most of the South Asian regions are vulnerable to extreme rainfall events and such events are adversely affecting flora and fauna, also making large scale damages to the livelihood and economy of the region. In the present study, the characteristics of extreme rainfall events during the southwest monsoon season are analysed for the duration of 65 years (1951-2015). Here we attempted to explore the Spatio-temporal features and heterogeneity of these extreme events at a finer resolution. We also elucidated the linear trend of these extreme rain events on the spatial domain and found that extreme rainfall is decreasing over northcentral Indian and southwestern coastal belts. An increase in the frequency and amount of rainfall from extreme rain events are observed in the western coastal belts between 16 to 20 N and central Indian regions. The linear trends of extremes are showing differences from the trends of mean rainfall patterns. The statistical method based on 99thpercentile (>99p) is used for identifying areas of extreme rainfall. The spatial and temporal variations of extreme precipitation events and their percentage contributions are also examined over these regions. In addition to the spatial trends, we analysed the relationship of various climate indices (Nino3.4, Modoki, DMI, PDO, AMO, and AZM) with the mean and extreme

rainfalls. Most of the indices show a significant inverse relationship with mean and extreme rainfall. The areas of the level of significance are comparatively smaller in the extreme rainfall cases. The AMO shows a positive correlation in the peninsular and northern regions. Similarly, AZM also shows a positive correlation in the southwest peninsular India and northeastern regions.

Epochs/stages of rainfall variability in summer monsoon overall India and its homogeneous region in changing climate

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The variation of precipitation in the context of climate change during summer monsoon season (JJAS) is mainly constrained by rainfall activity and climatology of precipitation. The rainfall has a high degree of variability on temporal and spatial scale, as compared to the other atmospheric indicators. This current study is based on the analysis of summer monsoon (JJAS) rainfall for India and its five homogeneous regions during 1891-2010. The rainfall analysis has been done for climatological variation, decadal and tricadal variation (The epochs of increasing/decreasing trends)based on the observed seasonal rainfall anomaly overall India and its five homogeneous regions – North West, West-central, North East, Central North East and Peninsular region. The overall rainfall trend from 1891-2010, all the regions except peninsular region showed a decreasing trend with the maximum decrease in the North East region. Furthermore, Mann-Kendall trend test has been utilised at 95% confidence level for all the six regions and observed that all the regions except peninsular region showed a decreasing trend in third tricade (1951-1980), in fourth tricade (1981-2010), there is an increasing trend only in North West and Central North East. The decadal analysis depicted that except for the peninsular region and North West region, all other regions showed a decreasing trend. The period 2001-2010 is really a matter of concern as the mean rainfall decreasing trend than the previous decades in all region signifying the reduced mean rainfall. The precipitation increase/decrease help to understand the effects of climate change trends on the dynamics of the Indian summer monsoon and how it impacts rainfall variability. The seasonal variation of monsoon rainfall linked with global warming and also affect climate change are associated with it. In recent years the monsoon rainfall and distribution are irregular and unpredictable nature has caused extensive financial loss damage to lives and agriculture consequently leads to food insecurity issues. Knowledge and awareness of such variability can advantage to enhanced risk management systems in agricultural and other industries.

Keywords: Summer monsoon, Rainfall variability, Mann-Kendall trend test, Climate change

Institutional Capacity Building through networking of State level Academic and R&D institutions for addressing climate change in the Indian Himalayan Region

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National Mission for Sustaining the Himalayan Ecosystem (NMSHE) is one of the eight national missions under the National Action Plan on Climate Change (NAPCC). NMSHE envisages evolving suitable management and policy measures for sustaining and safeguarding the Himalayan ecosystem by developing capacities at the national as well as state-level to continuously assess its health status. For this purpose, the NMSHE has embarked into building human and institutional capacities in the different Institutions in the Indian Himalayan region through a Pan-Himalaya Mega programme called Human and Institutional Capacity Building (HICAB). Under NMSHE, a major initiative has been launched to establish and strengthen State Climate Change Cells (SCCCs) in the Indian Himalayan Region.

HICAB focuses exclusively on the researchers, faculty and students of universities and academic institutions in the Indian Himalayan region. The programme comprises of Centres of Excellence (CoEs), Major R&D Programmes(MRDPs) and State Network Programmes (SNPs). So far, 3 Centre's of Excellence (CoE), 8 Major Research & Development Programmes (MRDP) and 6 State-level Network programmes with 18 projects have been established. The insight from these studies conducted by the Centre of Excellence and MRDP projects are expected to help in formulating long-term adaptation strategies for sustaining the Himalayan Ecosystem vis-a-vis the economic development of the region. These initiatives will be further strengthened through a long-term partnership with various national institutions/ universities for a sustained and meaningful research effort with a better understanding of climate change science and its impacts on various sectors and to unravel the future challenges for appropriate policy interventions.

The SCCCs are mandated to undertake work on Vulnerability& Risk Assessment at district and sub-district levels, human and institutional capacity building and public awareness programs. The SCCCs in the IHR regions have already carried out a detailed vulnerability assessment in their respective states using a common unified vulnerability framework and a pan-Himalayan vulnerability map at the district level has been brought out. The vulnerability profile developed by the Himalayan States has helped them gain insight into aligning developmental plans to climate change.

All these programs are being networked together to strengthen the knowledge support to the state climate change cells for preparing the climate change adaptation strategies.

DST's National Network Programme on Urban Climate: An emerging research area on Climate Change

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Urbanization and the developing cities are the faces of the economic growth of India. Urban areas are seats of socioeconomic activities. While the impact of global climate change has been well documented and studied extensively, how climate change will impact cities is currently poorly understood. However, the impact of climate change on cities is of enormous economic and societal relevance because of the many infrastructural investments and population in the region. Cities, additionally, create their own microclimate due to urban heat islands and modifying regional hydrology (through rainfall changes), and air quality (urban aerosols). Thus, the future climate change over cities is a combination of both the future global warming and local urban warming– and can likely even make cities 6 to 10 degree C warmer than they are today. The cause of these urban climate changes is high concentrations of pollutants such as carbon monoxide, oxides of nitrogen hydrocarbons, oxidants and particular matter which emitted into the air by industrial processes, fuel combustions and the burning of solid waste.

The changes of urban climate increased urban land use and occupation which alters the local thermal fields resulting in the development of urban heat islands where the surface temperature and air are concentrated in the urban areas rather than surrounding rural areas. These urban areas also produce particles of dust which act as hygroscopic nuclei and encourage rain production. Wind speed is often lower in cities than the countryside because the building act as barriers, on the other hand, long streets with tall buildings can act as wind tunnels.

To understand the dynamics and the science behind the urban climate the Department of Science & Technology under the National Mission on Strategic Knowledge for Climate Change (NMSKCC), set up a network of institutions to study various aspects of urban climate based on the concept of urban heat islands, changes in land use land cover and modelling of the urban climate changes, urban flood modelling, impact of changing aerosol loading and urbanization on surface temperature and rainfall over select cities over India. The programme in its pilot phase is covering 3 cities, Bengaluru (Inland), Bhubaneswar (Coastal) and Dehradun (Sub Himalayan). Preliminary studies show urbanization/ land use land cover change is found to contribute to as much as 0.7°C. The paper presents some of the early results of these studies.

Need for the S & T based Information System and Climate Adaptation Plans for the Sustenance of Himalayan Ecosystem

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Mountain environments, in particular, the Himalayas are potentially vulnerable to the impacts of global warming.The warming in the Himalayas has been much greater than the global average. The per capita fossil fuel CO2 emission from the Hindu Kush Himalayan (HKH) countries is one-sixth of the global average. However, the region immensely suffers from the impact of climate change. Global warming is having a severe impact on the amount of snow and ice, which has serious implications for downstream water availability in both short and long term as up to 50% of the average annual flows in the rivers are contributed by snow and glacial melting. The Himalayan region is subjected to the most threatening changes which are probably related to the frequency and magnitude of extreme weather events. Various factors such as climate change and human conflicts, infrastructure development, migration, tourism, urbanization etc. are the main contributors.

The Indian Himalayan region is projected to experience higher levels of climate change than the Indo-Gangetic plains or the southern region of India. Recent studies show that adverse impacts of climate change on agriculture, forests and water resources which further pose a significant challenge to the communities. An urgent need has been felt to understand the short and long-term implications of these impacts and simultaneously address the knowledge gap. Climate change induced hazards such as floods, landslides, and droughts will impose significant stresses on the livelihoods of mountain people and downstream populations. Society will need to improve its adaptation strategies and therefore, building up the resilience in vulnerable communities becomes imperative. According to 5thIPCC Report (AR5), 2014, the first step towards adaptation to future climate change is to reduce the vulnerability and exposure to present climate variability. The vulnerability assessment is required to understand the risks posed by climate change and provides information for identifying measures to adapt to climate change impacts. It is a necessary starting point for initiating any adaptation measures.

India's policy response to climate change has been the National Action Plan on Climate change(NAPCC) launched in 2008 under which National Mission for Sustaining the Himalayan Ecosystem(NMSHE) is being implemented by the Department of Science & Technology(DST). NMSHE is the only location specific mission which is focussing on the Himalayan sustainability aspects and creation of the S&T based knowledge base for the decision-makers. A common methodology framework and a unique vulnerability profile of Indian Himalayan Region (IHR) has recently been developed, which is planned to be followed by risk assessment. State Action Plans on Climate Change(SAPCC) are being prepared to mainstream climate change concerns at subnational levels as well. Several attempts are being made to provide adequate science and technological inputs and build the knowledge base for devising appropriate climate adaptation strategies for the vulnerable Himalayan communities.

Decadal Analysis of Air Temperature Over East and West Coast of India

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Rising global temperature is the prime point of concern within the realm of climate research. The current study analyses air temperature data at two levels to document changes and trends in temperature over the east and west coast of India. Air temperature data is taken for 1000mb (ground) and 850mb (2m) level. Previous studies have shown that an increasing trend in temperature can contribute to high climate variability and frequency of disasters. Temperature trends in coastal regions of India is therefore crucial in understanding regional climate. The present study provides a detailed assessment of air temperature over the region for a period of 37 years, from 1982-2019. The period is divided into four decades (1982-1989, 1990-1999, 2000-2009, 2010-2019). The first interval consists of only eight years due to the unavailability of data. The study area extends from 5 degrees north to 26-degree north latitude and 65degree east to 90-degree east longitude. This is further divided into east (78°E-90°E) and west (65°E-78°E) coast of India. The annual mean temperature, minimum temperature and maximum temperature are observed and analyzed for each decade. Air temperature data and wind data from NOAA NCEP Daily Global Analysis data with spatial coverage 2.5-degree latitude x 2.5-degree longitude global grid (144x73) is used in the study.

It is observed that for the last two decades (2000-2009 and 2010-2019) the annual mean temperature shows a stationary trend with little fluctuations in both surface level and 2m in both east and west coasts. However, the annual mean temperature over the east coast shows slightly high values than its counterpart (the difference between annual means of east and west coast is 0.1674 at surface level and 0.026 at 2m). The period 1982-1989 exhibits a sharp increase in temperature at both the levels and both coasts. On the other hand, the period 1990-1999 shows a gradual stabilizing trend with lesser fluctuations than the previous decade. The analysis of maximum temperature shows a fluctuating trend over decades, but minimum temperature analysis reveals an increasing trend in all four decades for both the coasts at both levels.

Water quality and climate change perception study in the river Satluj basin, northwestern Himalaya

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Today water pollution is one of the most important problems due to the rapid growth of developmental activities. Water pollution means pollution of the water by getting some elements unnecessarily into the water. For the past few decades, the magnitude of the problem of is increasing day by day all over the world. Rivers are the most important freshwater resources for human. The availability and distribution of freshwater in the riverine systems have been largely related to social, economic and political development. The perception study was conducted in the villages of Kinnaur, Himachal Pradesh. Respondents in Tangling village (Kinnaur) perceived that they did not depend, directly or indirectly, on River Satluj water, for livelihood and agricultural options. By using prioritize matrix questionnaire, the most destructive activities are road construction, dumping wastes in the river, tunnel construction and deforestation. Among the natural hazards, landslides are increasing in the Kinnaur region, e.g., Urni village, Pangi village, etc., which are due to construction activities like dams, tunnels, etc. About 29% of the respondents viewed that climate change has been impacting hydropower, 61% of water level of the river is reduced due to river diversion for hydropower and disturbs its natural regime. As the river water level decreases due to diversion, it further leads to a decrease in water flow quantity. The observed values for water quality indices (WQI) at 9 different sites give an idea about remedial measures to be taken to shrink pollution. The quality varies from 'Good to Medium' by NSFWQI and 'Acceptable to slightly polluted' by OIP method. Further, the quality of the river falls between B & C as per CPCB standards for surface water, showing the water is fit for outdoor bathing and drinking with conventional treatment. The hardness and DO exceeded permissible limit indicates deteriorated water quality due to lack of proper sanitation, discharge of untreated waste and partially treated wastewaters and waste into the river. 67% villagers responded that groundwater is deteriorating. Approximately, 80% know about the climate change in terms of rainfall, temperature etc. 55% individuals responded that fishes found in bulk a decade before but now rarely found in the upper region of the Satluj basin such as Powari, Spillo, etc. due to construction activities like dams, tunnels, roads, etc. 99% villagers have pits for sewage disposal and proper sanitation but open defecation is also being practised in some places. Effects of construction activities have found affecting the local temperature that has a mixed response. There is a need to maintain all alike aspects with a view to sustainable development.

Keywords: Water Quality Index (WQI), National Sanitation Foundation (NSFWQI) Limits, Overall Index of Pollution (OIP), Central Pollution Control Board (CPCB), prioritize matrix

A study on the trend in southwest monsoon rainfall over Jammu & Kashmir

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Using IMD's high-resolution datasets from 1901 to 2015, the trend and interannual variability of southwest monsoon rainfall is studied here. The Jammu & Kashmir receives only 281mm (1901-2015) rainfall during southwest monsoon season. Large interannual variability is observed in the summer monsoon rainfall with a standard deviation of 127mm and coefficient of variation of 39%. Continuously below normal rainfall epochs (1966-1974,1998-2004) and continuously above normal rainfall epochs (1992-1997) are observed in the recent decades over this region. The decadal rainfall analysis reveals that the SWM rainfall is consistently increasing from 1901 to 2015 with a 130mm rainfall increase from the early (1901-1910) to the recent decade (2005-2015). The linear and Mann Kendall trend analysis reveals that SWM rainfall over Jammu & Kashmir is increasing significantly. The long term 115- year trend (1901-2015) is more significant (at 1% level) than the recent 50-year (1966-2015) trend (significant at 5% level). A decreasing trend in the tropical easterly jet stream is related to the increasing trend in SWM rainfall over Jammu & Kashmir. The wind analysis by using NCEP/NCAR reanalysis datasets shows that the mean zonal wind over the region (10°S–25°N and 30°E–120°E) at 200, 150 and 100 hPa levels are decreasing

significantly with a maximum decrease at 100 hPa level wind and minimum decrease at 200 hPa level. This decreasing trend is found to be related to the decreased land-sea temperature contrast in recent years. The correlation analysis reveals that the zonal wind at all three levels is negatively correlated with Jammu & Kashmir rainfall. The correlation is more significant (at 1% level) with the zonal wind at100 hPa level. Spatial correlation analysis also reveals that the negative correlation is high over the northwestern part of Jammu & Kashmir.

Assess and Forecasting the rainfall over the Himalayan region using statistical downscaling approach

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The spatial and temporal distribution of rainfall is crucial for the administrators to manage various socio-economic sectors such as agriculture, industrial development and water resources of the region. The Himalayas are the mountainous region, highly prone to flood episodes and cloudbursts due to its complex topography. In this work, we use statistical downscaling model (SDSM), a multiple regression-based method, for generating future scenarios to consider the impact of climate change on different hydrological variables such as rainfall, solar radiation, relative humidity, temperature etc. Multiple linear regressions method of SDSM is a parametric approach to finding the empirical relationship between large scale climate model output and local climate variables. It has the ability to trap the inter-annual variability better than other statistical downscaling approaches. The model requires two types of daily data, i.e., (i) the local data are known as 'Predictand' (rainfall, minimum and maximum temperature) and (ii) the different atmospheric variables known as 'Predictor'. In this study, downscaling will be carried out using the SDSM tool for the north Himalayan region. The essential predictors will be obtained from reanalysis data and significant predictor will find out using the IMD data (observed data) of rainfall, minimum and maximum temperature. Finally, monthly rainfall will be projected on the basis of forecasting future rainfall for the periods the 2020s, 2050s, and 2080s under the consideration of RCP4.5, RCP 2.6 and RCP 8.5 emission scenarios of CMIP6. Detailed results will be discussed.

Keywords: Rainfall, Statistical downscaling, Himalayan region, Climate change

Analysis of rainfall and temperature trends in Assam and the comparative study of climate of different regions of Assam

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The state Assam covering an area of 78,438 square km and it is bordered by Bhutan and the state Arunachal Pradesh in Northern side, Manipur in the south-east, Nagaland in the east, Meghalaya in the south-west, and Tripura, Mizoram and Bangladesh in the south. It is one of the most rainfall prone areas in the North-Eastern region (NER) of India which covers an area of 0.26 million sq. km.

The topography is surrounded by sub-Himalayan region namely Bhutan, and Arunachal Pradesh, which causes flooding in Assam during SW Monsoon seasons due to its hilly surrounded topography. The NE-region is one of the highest rainfall-receiving regions on the earth, including Assam. It has huge water and hydropower potential due to its topography and orography, and the analysis of rainfall trends would be of interest to the planner of hydrological management and energy generation. The study is regarding the trends in monthly, seasonal and annual rainfall and also the temperature trends are in the study of maximum, minimum, mean temperatures and the diurnal range of temperature of Assam. Trend analysis of rainfall data series was done for the years 1871–2008 did not show any clear trend as done by S K Jain et al. for North East Indian region. During the preliminary study, it has been found that in some of the stations of Assam has shown (by using Sen's slope and Man-Kandal analysis)slight decreasing trend during the SW Monsoon in the later part of the period 1971-2019. The comparative study of the climate of representative stations of Assam was done for the rainfall distributions and temperatures trends.

Variation of summer and winter dirunal temperature range over the subdivisions of India

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The diurnal temperature range (DTR) is the difference of maximum and minimum temperature over the region. In this study, MAM (March, April and May) summer and DJF (December, January and February) winter seasons are considered for the period 1951 to 2020. Based on India Meteorological Department (IMD) high-resolution data of maximum and minimum temperature the mean, standard deviation and trend of DTR is calculated to understand its variability over 34 metrological subdivisions of India for the total period (1951 – 2020) and 7 decades (1951 – 1960, 1961 – 1970, 1971 – 1980, 1981 – 1990, 1991 – 2000, 2001 – 2010, 2011 – 2020). The mean DTR is less than 12°C over Northeast subdivisions and east and west coastal subdivisions of India in both summer and winter season; whereas greater than 12°C DTR is observed over central and North West Indian subdivisions. The standard deviation of summer and winter DTR varies throughout the study period in each subdivision and large value of standard deviation is mostly seen in the Central and North West subdivisions. A large value of standard deviation in DTR during the winter season as compared to summer season indicates that DTR is largely variable during the winter season than in summer for all subdivision. A non-significant positive and negative trend in winter DTR is observed over the subdivisions of India and it is not varying consistently from one period to another, for most of the subdivisions. In summer, DTR shows a non-significant increasing tendency over most of the subdivisions of India in all considered study period except for the period 1981-2010 where the negative trend is seen over Central and North West subdivisions and the period 2001-2010 shows the negative trend over South, East Coast and North East subdivisions.

Correlating weather parameters with Forest Fire Fuel characters in mid-hills of Himachal Pradesh

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The present investigation was carried out in pure pine, pure oak and mixed forests of Solan district of Himachal Pradesh, with the aim of correlating forest fire fuel characteristics viz., live understorey biomass density (t ha^{-1}), surface litter thickness (cm), surface litter biomass density (t ha^{-1}) and surface litter moisture content (%) with weather parameters viz., air temperature (°C) and relative humidity (%), using correlation and regression techniques during post-monsoon and pre-monsoon seasons of 2016-2018. Results divulged that pure pine forests showed highest surface litter biomass density (5.82t ha^{-1}) during the post-monsoon season and lowest live understorey biomass density (1.87 t ha^{-1}) and surface litter moisture content (1.91%) during the pre-monsoon season, which makes it more prone to forest fire incidences. Surface litter moisture content (%) showed highly significant Pearson's correlation (r) and coefficient of determination (R2) with relative humidity (r = +0.603; R2=0.364) and air temperature (r = -0.474; R2=0.225). The overall high incident of forest fire in the study area was attributed to the combustible fuel characteristics of pure pine forest due to drier weather conditions.

Keywords: Forest Fire, Forest floor characters, weather parameters, forest fuel

Analysis of long-term rainfall variability over western agroclimatic zone of Haryana

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The daily rainfall data of different stations of Western Agro-climatic Zone of Haryana were collected for the period from 1980 to 2018 from IMD, Pune. The latitude and longitude coverage of the state extends between 27° 39' to 30° 35' N and 74° 28' to 77° 36' E. The descriptive statistical techniques were carried out to study the monthly, seasonal and annual rainfall variability and trend by applying appropriate statistical techniques viz., mean, standard deviation (SD), coefficient of variation (CV). For seasonal trend, the whole year was classified into four different seasons viz., winter(January and February), pre-monsoon(March to May), monsoon (June to September), post-monsoon (October to December). The normal annual rainfall mean and coefficient of variation of the overall western agro-climatic zone of Haryana were 416.2 mm and 37.7 % respectively. Annual rainfall was decreasing significantly in four districts viz. Fatehabad, Jhajjar, Rohtak and Sirsa @ -3.08 mm, -7.54 mm, -12.25 mm and -4.78 mm per annum respectively. The normal monthly rainfall received in the month of July and August was higher as compared to other months. Monthly mean maximum rainfall of 152.6 mm (August) at Jhajjar, 150.4 mm (July) at Jhajjar and 146.3 mm (August) at Rewari was observed. Monthly mean minimum rainfall occurred in the month of November and December of the winter season. Post

Monsoon rainfall exhibited significant decreasing rainfall trend @ -0.33 mm per annum in Rohtak. Monsoon season exhibited significant decreasing rainfall trend @ -3.42, -5.58, -9.12 and – 3.23 mm per annum in Hisar, Jhajjar, Rohtak and Sirsa respectively. Winter Season exhibited significant decreasing trend @-0.68 mm and -0.40 mm per annum at Rohtak and Sirsa. Pre-monsoon season showed an increasing trend in most of the stations. The higher variable of rainfall can be noted due to the high value of standard deviation and coefficient of variation in western Haryana during the study time period, which results in high irrigation water demand for agriculture.

Keywords: Rainfall, Western Agro-climatic Zone, Trend, Mann Kendall test.

Variations of Trace Gases at High Altitude Region of Western Ghats, Southern India

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Trace gases concentration in the lower atmosphere plays a major role in atmospheric chemistry and the overall metabolism of the biosphere. Trace gases also influence the stratospheric chemistry indirectly by affecting reactive species concentration at lower atmosphere. Prevalence of trace gases concentration at high altitude region significantly alters the photochemistry of the region that would influence the local biodiversity. In order to observe the occurrence of traces gases level, the continuous monitoring of ozone (O_3), oxides of nitrogen (NOx), sulfur dioxide (SO_2) and carbon monoxide (CO) were carried out from 2010 to 2018 at high altitude region of Nilgiri mountains (11.25oN, 76.43°E, 2520 meters mean sea level), the Western Ghats in southern India. Observed trends in traces gases level were showed diurnal and seasonal variations. Diurnal cycle of ground-level ozone concentration showed higher values at night hours and lower values observed at daytime. Other precursors such as NOx (NO and NO_2), SO_2 and CO showed day time peak. Seasonal mean values (ppb) of ozone were 54.43±7.47, 20.40±2.4, 29.43±6.7 and 43.03±5.38 for summer, monsoon, post-monsoon and winter, respectively. Mean seasonal variation of NOx over the years showed higher value during summer (1.85 ppb) and low in monsoon (0.19 ppb). Diurnal variation of SO_2 concentration increased after morning hours and reached a maximum at evening hours. The maximum value of SO_2 found during summer (1.00 ppb) and minimum value (0.10 ppb) observed in the month of November. Diurnal variation of NOx, SO_2 and CO showed build up during the morning and late evening hours which act as ozone-forming precursors. The minimum concentrations of trace gases during monsoon seasons were associated with rainfall that leads to wet deposition. The air trajectory analysis showed that the pollutants were transported with wind from northeast to east inland to the observational site during summer and south-westerly advection during monsoon were confirmed the pollutant sources. Hence, the prevalence of trace gases at high altitude region of Nilgiri mountains would alter the plant ecosystem that supposed to monitor for evaluating the productivity of the forest biodiversity.

Heatwaves over India

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Heatwaves are studied to understand their regional vulnerability, causation over the Indian subcontinent in the context of the current global warming scenario. An updated, high resolution gridded surface air temperature data sourced from the India Meteorological Department (IMD) for the recent 69-year period (1951-2019) is used to ascertain the regions of maximum temperatures and heatwave vulnerability during the hottest month of April and May. Results reveal three distinct regions of maximum temperatures, over West Rajasthan in Northwest, North Madhya Pradesh and Southwest Uttar Pradesh in North-central, and East Maharashtra in South-central parts of India based on both the magnitude and frequency days of maximum temperatures. Contrastingly, three localised regions of heatwave vulnerability were identified in the north, northeast and southeast parts of India incontrovertibly different from the three maximum temperature zones. Soil temperature data confirm the regions of the maximum temperatures and the heat waves indicating the accentuation due to local radiative heating. The causation of heatwaves was identified as the advection of heat by anomalous southwest, west and northwest wind flow from the three maximum temperature zones. Heatwaves over southeast India, manifesting since 1970 denote the impact of global warming in recent decades. Climate model simulations of the current climate conform to the observed maximum temperature zones indicating the role of radiative heating. This study discerns the regions of maximum temperatures and heatwave vulnerability and identifies the causation to be triggered by wind flow from the maximum temperature zones under favourable atmospheric circulations. Results from this study would find wide application not only in the prediction but also in the risk and vulnerability assessment.

Keywords: Maximum temperatures, Heat Waves, atmospheric flow patterns, Model simulation

Human Comfort in Western Himalayas- Himachal Pradesh

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The Himalayan region also referred to as The Third Pole, is an abode to the most extensive and rugged high altitude areas on the earth. This fragile region is highly sensitive to climate change causing thermal discomfort to human life. As the climate is a dominant driving factor that pulls people for inhabitation, tourism and recreational activities, the present study focuses on the impacts of rapid climate change on human comfort zone in the western region of Himalayas viz. Shimla, Bhuntar, Sundernagar. To protect humans from heat stress risks and thermal discomfort, Temperature Humidity Index (THI) has been computed to determine and quantify comfort zones within the different temperature and humidity combinations. The THI has been computed for the synoptic hours from dawn to dusk based on available daily data for the ten-year period (2010-2019). The THI values have been categorized on the basis of feeling of the people. The frequencies of comfort level at different hours have also been computed. The maximum hot discomfort was noticed in the months of July, August followed by June. The maximum cold discomfort was noticed in the months

of January, February followed by November and December. Some warming trends have been noticed in Shimla and Bhuntar, but not significant. Available meteorological data with Meteorological Centre, Shimla has been used to deduce the conclusions.

Keywords: THI, Thermal discomfort, Synoptic hours

The transformation in Banni Grasslands

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The Banni grasslands; was at one point of time regarded as the finest grasslands in the entire continent of Asia. Located in Bhujtaluka of Kutch, the biggest district of Gujarat, it covers an estimated area of around 2617.72 sq. km. It is situated at 23°19'N to 23°52'N to 68°56'E to 70°32'E. However, many factors right from the introduction of the Prosopis Juliflora, making of dams, desertification to the ecological dynamism have contributed to transforming it into a shrub forest. It is major grassland and supports a diverse ecosystem. The name is derived from a Gujarati word – BanaiHui that in Gujarati means 'made up'. Apart from the more than a hundred plant species; it also supports equally large species of birds and mammals, reptiles and amphibians. It is found that the local grass species, specifically the Madhanu (Dactylocteniumsindicum) and Siyarpuchcha (Chloris Barbata) are reputed for their adaptability to the existing climate and can sustain in spite of the very minimal average rainfall of approximately 300 mm in the district. It is known to be a very nutritive source to the milchcattles, specifically to the Kankrej cattle and the Banni Buffalo. The proposed work is an attempt to understand the factors that caused this transformation. Mapping of the entire region is also done. It also highlights the efforts put up by the various government and non-government organisations in this direction.

Characterizing Warming Through Observed Changes in Temperature Extremes Over Himachal Pradesh and Punjab

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During the past century, significant temperature changes have taken place and are likely to escalate coupled with human induced forcings. This projected warming may induce drastic changes in the thermal profile of the region like northwestern India where an increase in mean annual temperature may be causative for monsoon vagaries. This research paper examined the long-term trends in select indices of temperature extremes in parts of north-western India. The results reveal striking facts about the direction and magnitude of change. The cooling of Punjab Plains and warming of mountainous areas of Himachal Pradesh is exhibited by indicators of warm spell duration indicator (WSDI) and cold spell duration indicator CSDI. These warming rates are most conspicuous in the Middle and the Greater Himalayan regions. An increase in the frequency of warm days (TX90p) and warm nights (TN90p), especially in temperate and cold semi-arid/arid regions of Himachal Pradesh raises serious concerns about imminent water stress, vulnerability and disruption of hydrological balance upon which rests the economic development of the region.

Keywords: Extremes, water stress, vulnerability, hydrological balance

Rainfall Variability in Hilly terrain of Jharkhand particularly in Damodar Valley area during pre-monsoon, monsoon, post-monsoon and Winter seasons in last 20 years

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Study on rainfall variability in the region of the hilly terrain of Jharkhand state covering 10 districts of Jharkhand particularly in Damodar Valley area. This region is one of the important areas for the origination of thunderstorm in the Eastern part of India during pre-monsoon season. The river Damodar originated in hills of Chattonagpur (Jharkhand) and drains in a fan shaped catchment area (about 22000 sqkm). Multipurpose river valley project mainly for flood controlling of the Damodar river started from 1949. Study on 50 years rainfall data in Damodar Valley area findings are (I) Rainfall in pre-monsoon season increased in the last 20 years. (ii) Rainfall in the month of June and August decreased, but in the month of July, September increased. (iii) Rainfall in post-monsoon season in the month of October increased (iv) It is observed Winter is more dry.

Keywords: Normal rainfall, Trend analysis, Catchment, heavy rainfall Regression line

Long-term variability of climate parameters over major high altitude stations of North-East India

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This study depicts the climate condition of 39 (1970-2009) years over four high altitude stations of North East India (NEI) based on India Meteorological Department's observed station data. Four high altitude stations are selected in this study – Gangtok (1,650 m), Shilong (1,525 m), Imphal (786 m) and Cherrapunji (1,430 m). Extreme rainfall and flash flood events are the major disasters NEI faces every year. The drying of the summer monsoon is already observed in different studies using long term satellite and GCM (Global Climate Model) data. Long term variation of summer monsoon rainfall, maximum temperature and minimum temperature are investigated over the aforementioned stations using observation data. The trend of long-term climate indices based on rainfall and temperature (extreme rain events, rainy days, consecutive rainy days etc.) have also investigated over these four stations which will be very informative for further study over NEI.

Statistical characteristics of heat waves over India

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The climate of a place has a decisive role in human adaptations. Man's health, adaptability, behavioural patterns, food, shelter and clothing are mainly influenced by the temperatures of the area. Hence, a study is undertaken to analyse the spatial distribution, frequency and trend in the heat waves over the country. The statistical characteristics of heat waves over India are attempted in this study. Gridded daily temperature data sets for the period 1951-2019 was used to compute the arithmetic mean (AM), standard deviation (SD), coefficient of variation (CV) and Trends of monthly maximum temperature. The number of heatwave days was evaluated using the criteria that heatwave occurrence is recognized when the daily maximum temperature exceeds the daily normal maximum temperature by 5°C (4°C) where the normal climate values are < (≥) 40°C. Computations were confined to the two summer months of April and May only. The spatial distribution of the AM show higher values during May, and the hot core region with temperatures exceeding 40°C lies over central India extending towards the northwest. The SD distribution shows higher values over the northeast of central India, decreasing towards the southwest. The CV distribution shows higher values over north decreasing toward the south. Higher numbers of heatwaves are observed during May and the number is higher over Andhra Pradesh and south Telangana regions of southeast India. This study concludes that a moderate hot region experiences a higher number of heatwave days over India.

Keywords: heat waves, maximum temperatures, Climate

THEME 8

Land-Ocean-Atmosphere Interactive Processes

Evolution of Iod Events and Associated Air-Sea Interaction Processes

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In this study, evolutionary features of IOD events and associated air-sea interaction processes in the equatorial Indian Ocean are examined. The air-sea interaction processes are studied during August, September and October in the Eastern Equatorial Indian Ocean for the negative IOD years (2010, 2014 and 2016) and in the Western Equatorial Indian Ocean for the positive IOD years (2006, 2012 and 2015). The objective of the study is to bring out a detailed account of the evolution of positive and negative IOD events through air-sea interaction processes and to understand the influence on the Indian Summer Monsoon Rainfall. The analysis was carried out utilizing Argo Sub-surface, GPCP Rainfall, NOAA AVHRR SST daily anomaly, NCEP reanalysis upper air and Tropflux daily data. It is found that SST, heat budget components (viz., Latent Heat Flux, Sensible Heat Flux, Net Heat Flux) and subsurface temperature exhibit a dipole like behavior in the equatorial Indian Ocean. Further, enhancement in precipitation over the Western Equatorial Indian Ocean (WEIO) and subdued precipitation over the Eastern Equatorial Indian Ocean (EEIO) occurs during positive IOD events and exact reversal occurs during negative IOD events.

Keywords: Indian Ocean Dipole (IOD), Dipole Mode Index (DMI). Positive IOD(PIOD), Negative IOD (NIOD), Western Equatorial Indian Ocean (WEIO), Eastern Equatorial Indian Ocean (EEIO)

Impacts of various rainfall forcings on soil moisture distribution over India for a three year period using Land Information System

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Precipitation is one of the most important forcings that determine land surface characteristics. Various types of precipitation data sets are available from satellites, rain gauges, merged data sets, analysis products etc. The present study evaluates the uncertainty in soil moisture estimates using the three different forcing precipitation data sets GDAS (Global Data Assimilation System), TRMM (Tropical Rainfall Measurement Mission) and IMD(Indian Meteorological Department) gridded data over the Indian domain by using Noah LSM (Land Surface Model) land surface states in LIS (Land Information System).

Three simulations are conducted using the three different precipitation data sets over the Indian subcontinent for a period of three years from 2012 to 2014. Except for the rainfall forcing, there are no other differences in all the three simulations in terms of model configuration and physics. All simulation results are validated with the IMD weekly soil moisture station data for the years 2012-2014 at different depths. Results indicate that the soil moisture estimates of Noah LSM forced with IMD rainfall data performs best as compared to the other two simulations. Improved soil moisture for the IMD rainfall forced run attributed to the fact that the IMD gridded rainfall is closest to the observed rainfall(ground truth),

while the TRMM rainfall, severely overestimates and the GDAS rainfall moderately overestimates the observed rainfall.

TTL Transport and convective sources during active and break phase

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The convective source of air at the tropical tropopause layer (TTL) is studied using backward Lagrangian trajectory analysis during the active and break phases of the Indian summer monsoon (ISM). Back trajectory simulations have been performed using meteorological fields from ERA -5 data following diabatic vertical velocity approaches. The convective sources have been estimated from high-resolution GRIDSAT measurements.

The tropical domain is subdivided into three continental regions (India, Tibetan plateau, South China) and two oceanic region (Bay of Bengal and Sea of China) and the convective sources and age of air parcel at TTL are estimated separately for both the phases of ISM. We show that the water vapor at TTL fluctuates between active and break phases of monsoon and these can be attributed to the variability in the strength of Asian monsoon anti-cyclone and convective sources at TTL. The convective sources from the Tibetan plateau and Indian subcontinent play major roles in transport of water vapor to TTL.

Rain isotope variability associated with Monsoon intra-seasonal oscillation and stratiform process: Results from the northern Bay of Bengal and their implication to process interpretation

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Isotopic studies of rainwater are useful for identifying moisture sources and understanding different rain processes. Considering isotopes as conservative tracers, many atmospheric general circulation models simulate rain isotopes through various isotope parametrization schemes. The relationship between rain isotope and rain amount has been used to reconstruct past Indian summer monsoon rainfall (ISMR) from various natural archives. The monsoon intra-seasonal oscillation (MISO), a quasi-periodic occurrence of rainfall spells (June–September) associated with large-scale circulation and convection, is considered the most dominant mode of the variability of ISMR.

The present study investigates the control of MISO and stratiform process on the rain isotopic variability through observations and an isotope-enabled general circulation model. Rainwater samples are collected (from 2004 to 2014) from two stations near the north coast of the Bay of Bengal. Based on the northward propagation of negative anomaly in Outgoing Longwave Radiation, 16 convective MISO phases were identified during this period. Out of 69 samples associated with these MISO phases, 46 samples have isotope ratios depleted in heavier isotopes. These ratios are well correlated (R = 0.81) with the MISO propagation speed and enhanced rainfall (R = – 0.71) over the Bay of Bengal (BoB). The isotope ratios also show a significant anti-correlation (R = – 0.94) with satellite-derived stratiform rain fraction.

On the other hand, the model simulation reproduces the amplitude of variation in the observed values reasonably well. On average, the model hydrogen and oxygen isotope values are higher than observation and display weaker correlations with MISO propagation speed and rain amount over BoB. Our study thus concludes that the effect of MISO propagation characteristics in lowering of isotope values through the rain out over the BoB and contribution from the stratiform rains both control rain isotope variability in the northern Bay of Bengal.

Impact of surface roughness parameterization on prediction of tropical cyclones using the coupled ocean-atmospheric model

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In this study, we analyzed the sensitivity of tropical cyclones simulations with different surface roughness schemes using the coupled mesoscale Weather Research and Forecasting-Ocean mixed layer model (WRF-OML). We configured the WRF-OML model with double nested with 9 and 3 km horizontal resolutions and 71 vertical levels. To carry out this study, we have considered seven TCs cases and conducted three experiments by varying roughness schemes of Option 0, Option 1, and Option 2 are used. The model well predicts the deepening of the mixed layer depth and sea surface temperature cold wake. The results are exhibit that the parameterizations of ocean surface bulk exchange coefficients of momentum and moist enthalpy with the coupled model have a significant influence on the TC prediction. The roughness experiments namely Opt-0, Opt-1 and Opt-2 produced the mean CSLP and MSW errors are 2.68, 1.27 and 0.37 hPa; and -3.45, -2.06 and -0.81 m/sec respectively in all cases. Out of three surface roughness experiments, Opt-2 produces better results in term of the simulated track, intensity, structure, ocean-atmosphere feedback processes, and thermal features of the cyclones. The Option 0 scheme poorly predicted the cyclones, but the Option 1 experiment produced moderate results. For the seven TC case, the simulated intensity errors considerable reduced with Opt-2 experiment. Moreover, Opt-2 captured the observed pattern of the latent and sensible heat fluxes and SST parameters, as seen in the buoy observation data.

Keywords: Tropical cyclones, WRF-OML coupled model, roughness parameterization, intensity, movement, MLD, SST, rainfall

Flavours of El Niño and associated genesis with special emphasis to 2006-07

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The temporal and spatial evolution of westerly wind events (WWEs) and El Niño evolution in the last century are explored using observations and reanalysis data in this study. The formation of El Niño is mostly associated with WWE in the equatorial Pacific and changes in the Warm water volume. To identify WWE, European Reanalysis 20 Century (ERA-20C) daily zonal wind data for the period 1900-2010 is used. In addition, the Extended Reconstructed Sea Surface Temperature (ERSSTv5) data set is used to estimate Niño indices as well as to understand the eastern and central Pacific SST anomaly evolution associated with El Niño. The study period is divided into four epochs, with a 30 year period, namely, 1895-1924, 1925-1954, 1955-1984, and 1985-2014. The spatial patterns of SST variability displayed intense modulations in the central Pacific along with the eastern Pacific in recent era than earlier, when a higher magnitude of SST variability was confined to the eastern Pacific. This spatial pattern of SST variability in the central Pacific is consistent with the occurrence of more El Niño Modoki events than earlier in the recent period. The analysis also suggests that the regional and temporal features of WWEs vary. Hence they are classified in western Pacific, Central Pacific, and eastern Pacific WWE. It is noted that the central and eastern Pacific WWE contributes noticeably to the formation of the canonical or modoki El Niño. The frequency of these events is found to be high during the recent period of 1956-2010 as compared to 1900-1955, mostly during the fall and winter season. Our results suggest that five El Niño events are formed without the WWE during the study period, out of which three events are El Niño Modoki, one canonical El Niño, and the other one is 2006-07, its spatial pattern is unlike canonical and El Niño Modoki. Further, to understand the role of oceanic adjustments during 2006-07, a detailed analysis of terms involved in temperature tendency (averaged at upper 50m) was carried out. The zonal advection that is mean temperature zonal gradient multiply by anomalous currents ($u'\frac{\partial T}{\partial x}$), for Nino1+2 and Nino 3.4 is seen to contribute positively during the transition to peak phase of 2006-07. Two Ocean General Circulation Model experiments are carried out by interchanging the momentum flux forcing. In the first experiment momentum forcing of 1997-98 is used for the 2006-07 ocean features, and in the second experiment, 2006-07 momentum forcing is used for 1997-98. These two experiments using Modular Ocean Model version 5 (MOM5) concludes that the temporal and spatial evolution of eastern and central Pacific temperature anomaly associated with El Niño is dependent on the WWE strength, pattern, and frequency.

Understanding the role of Land-Ocean-Atmosphere Interactive Processes in monsoon intraseasonal oscillations

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Understanding the link in the ocean-land-atmosphere coupled model framework is essential to

improve the sub-seasonal variability and prediction skill. Several studies show that monsoon is a coupled land-atmosphere-ocean system with the interaction between land, atmosphere, and oceans. Both ocean and land surfaces contribute to the variability of climate and atmospheric patterns during the monsoon season. However, scientific understanding of monsoon's sub-seasonal variability as a component of an interactive coupled land-ocean-atmosphere system is not comprehensively achieved. The prediction of Indian summer monsoon in the s2s (sub-seasonal to seasonal) scale is widely studied. The predictability of the same is understood in terms of the low-frequency variability and the associated teleconnections. The monsoon rainfall inherently exhibits intraseasonal oscillations (ISO) that are evident in the sub-seasonal active and break spells of monsoon rainfall over the Indian region. It is generally accepted that such low-frequency variabilities in the land-ocean-atmosphere system can be generated through interaction between its components. Both the Ocean fluxes and land fluxes play an important role in preconditioning in monsoon intraseasonal oscillation (MISO).To understand the difference between land-atmosphere and ocean-atmosphere feedback, we have studied a lead-lag analysis for active days over land and Ocean region. ERA-Interim data has been used for the period 2002-2015 to identify the active days over four homogeneous Indian regions and over the ocean, based on filter data (20-100days), when the standardized anomalies of rainfall exceed 1, it is considered as active days. The analysis showed that the lead-lag relationship between surface fluxes and large scale convection is different over land and the ocean; also, preconditioning over different regions is different. To get a proper low-frequency oscillation, we need to understand the land-ocean- atmosphere interaction in the dynamical models.

Analysis of TCMI features of three Very Severe Cyclonic Storms over the Bay of Bengal utilizing Brown Ocean Theory

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Tropical Cyclone Maintenance and Intensification (TCMI) scheme explains the behaviours of three Very Severe Cyclonic Storms (VSCS) after their landfall events. The exclusive feature of a cyclonic storm of maintaining the Maximum Wind Speed (MXWS) is often elucidated by Brown Ocean Theory (BOT). This theory addresses the mimic function of the land surface as that of the ocean by supplying an adequate amount of soil moisture and optimized rates of evaporation. VSCS PHAILIN, VSCS FANI and SCS AMPHAN made their respective landfalls on the coastal parts of Orissa and West Bengal during October 2013 and May 2019 and May 2020 respectively. Both storms originated during the active period of the Bay of Bengal (BOB) and had similar intensification schemes initially and the distance between their landfall locations is found to be 100±5 kms. Still, they experienced a completely different fate. PHAILIN went on performing TCMI schemes and intensified further. On the contrary, FANI dissipated avoiding all anticipations of MXWS rise while AMPHAN lost its velocity during the land interaction process. Present work tries to address these differential features between these two storms with the applications of BOT through differentiating among contemporary meteorological (viz. Sea Surface Temperature, Vertical Wind Shear, Mid Tropospheric Relative Humidity) as well as topographical (viz. Forest Cover, Surface Roughness, Land surface type) parameters. Prevalence of Pre-monsoon and Monsoon rainfall amount are also considered for their contribution in providing moisture to the soil. Finally, the importance of

Land surface properties in determining the fate of a tropical cyclone is highlighted.

Keywords: BOT, Landfall, TCMI, Topography, VSCS

Thermodynamic wave train connection of monsoonal heating to the Canadian Arctic in NCMRWF Unified model (NCUM) forecasts

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Medium range forecasting of the monsoon and its teleconnections to both poles is of great interest to the scientific community, but such relationships remain unexplored in forecasting systems. The monsoonal link is one of several ways that heat is conveyed to the Arctic region from the tropics and this seems to be an important factor for the rapid melt scenario. The behaviour of thermodynamic wave trains emanating from the summer and winter Asian?/ Indian? Monsoons heating the Canadian Arctic from the NCMRWF Unified model (NCUM) for 2017 rainfall events is addressed in this study. We examined heat content anomalies for 30th August and 4th February 2017 monsoon heavy rainfall events with European Centre for Medium-Range Weather Forecasts (ECMWF) ERA Interim (ERA-I), NCUM analysis and NCUM forecasts. The NCUM analysis shows a weaker eastward-propagating wave train towards the Canadian Arctic during Pakistan and North India heavy rainfall events with respect to a reanalysis (ERA-I). This circumglobal thermodynamic teleconnection becomes weaker as forecast lead times increase from day1 to day7. 10-days forward-trajectory analysis during the events also supports this weak teleconnection in NCUM forecast system in comparison to ERA-I. Further, terms of heat content analysis explain this weak relation due to the improper representation of specific humidity. The vertical profile of specific humidity for NCUM analysis and forecast concludes that the erroneously limited formation of cloud in the middle-atmosphere and hence the less heat generation over the tropics. Further wind analysis supports the idea that too-weak upper tropospheric circulation in NCUM leads to a weaker heat-flux transport for heavy rainfall events. This unrealistic specific humidity and wind representation are indicative of inappropriate model physics which weakens the thermodynamic wave train from the tropics to the Arctic.

Influence of soil moisture on mean daily maximum and minimum temperatures over India

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Land atmosphere interactions play a critical role in controlling the variability of climate over a region. Soil moisture is an important variable in land-atmosphere coupling due to its longer memory. Soil moisture partitions incoming solar energy into sensible and latent heat flux, thus has a controlling effect on temperature, boundary layer stability and precipitation. Strong land-atmosphere interaction is found over the transition zones between dry and wet climate. Observations and model studies have shown that Central India and Northwest India are hotspots of strong land-atmosphere coupling.

Many studies have pointed out the influence of soil moisture on monsoon precipitation. But only a few studies have tried to examine soil moisture - surface temperature relationship using observational data. This relationship is important to understand the role of soil moisture in the persistence of drought and heatwaves.

Our study aims to investigate soil moisture coupling on mean daily maximum (Tmax) and minimum (Tmin) surface temperature over Indian region using Global Land Data Assimilation (GLDAS) soil moisture and IMD observational temperatures. Coupling is computed statistically using a feedback parameter based on the ratio of lagged covariance. The results show that soil moisture exhibits negative feedback on maximum and minimum temperatures over central India and northern India. Whereas positive feedback values are observed over small regions of north-west India. In general, stronger negative feedback are observed for Tmax than Tmin. The negative feedback induced variability accounts for 20 to 30 per cent of the total variability of temperature.

Impact of rainfall on net ecosystem exchange of a Chir-Pine dominated vegetation of Western Himalaya

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Dynamics and distribution of rainfall events are known to have a larger impact on ecosystem fluxes than other environmental parameters. Subsequently, the Himalayan forests are anticipated to be highly influenced by monsoon and winter season variability in rainfall. Quantification and understanding of Himalayan forest ecosystem responses to the spell-duration and amount of rainfall are anticipated to play a vital role in the context of climate change, especially for water limiting conditions. Given the significant lacuna on understanding coupling mechanism between ecosystem exchange and seasonal rainfall distributions of Western Himalayan forests, the current study is aimed at assessing the scale interactions between ecosystem fluxes, i.e. net ecosystem exchange (NEE) and rainfall. The coupling mechanisms between rainfall and ecosystem fluxes of a mature Himalayan Chir-Pine (Pinusroxburghii) dominated mixed vegetation are assessed using wavelet spectra and rainfall pulse analyses using daily observed ecosystem fluxes and rainfall of 1446 days of 2014 to 2017 at Kosi-Katarmal, Almora, Uttarakhand, India. The mixed vegetation under investigation is a net sink of carbon having annual NEE of – 3.36 gC.m^{-2}.day^{-1} during the period of observation. Results of the wavelet coherent analyses indicated that the average daily NEE of monsoon season is having a statistically significant correlation to rainfall > 0.7 (at 95% confidence level) where rainfall leading to NEE. Individual rainfall events of monsoon season are noted to increase NEE at an average band period of 4 days; whereas the same for winter season noted have an average band period of 15 days indicating that the winter rainfall acts as an amplified stimulator for instantaneous vegetative growth. The rainfall pulse – ecosystem response analyses for the monsoon periods of 2014-2017 indicated that the carbon assimilation rate by the vegetation increases (i.e. changes from -2.75 to -4.0 mmol m^{-2}s^{-1}) up to 7th day of rainfall events from 0th day of initiation, indicating continuous rainfall events for more than 7-days in monsoon reduces NEE of the vegetation. Subsequently, it can be concluded that climatological change in rainfall events and amounts over Western Himalayas under a changing climate scenario could have significant potential to alter forest productivity.

An analysis of the Tropical Cyclones and Atlantic Hurricanes during 1979 to 2018 with the variation of Sunspot number and the influence of solar flux F10.7 and other solar activities

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The variation of occurrence of the Atlantic Hurricanes (AHU) over Atlantic and East Caribbean region and Tropical Cyclones (TC) over the Bay of Bengal and the Arabian Sea during 1979 to 2018 has been studied in this paper. A correlation and regression analysis has also been done between solar activity and the occurrence of Atlantic hurricanes and Tropical cyclones in the Indian Ocean. As a proxy of solar activity, the 10.7cm solar flux (F10.7) and the Sunspot Number (SSN) has been used. In order to find the correlation, we derived a normalised occurrence rate of AHU based on the data of National Hurricane Center-NOAA and National Ocean services –NOAA. Here also we used the data of Indian Meteorological Department (IMD) like Bestpara data, Best track data and data from Cyclone e-atlas for TC. Using these distributions, we calculate the correlation coefficient, which amounts 0.646 for f10.7 solar flux and 0.82 for SSN with the significance of 83% in the case of TC. On the other hand, the correlation coefficient is 0.65 for f10.7 solar flux and 0.82 for SSN with significance of 78% in the case of AHU. In addition, we calculate the correlation coefficient of Lyman Alpha flux and Total Solar Irradiance (TSI) with the occurrence of AHU and TC in Indian Ocean regions.

Impact of Heatwaves on vegetation cover and Groundwater

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Climate projections show that the future heat waves are to be more intense, frequent and longer than the recent decades. Increasing trend and variability of heat waves over India are associated with global warming, El Nino-Southern oscillation, variations in the Sea Surface Temperature and re-curving of tropical cyclones over the Bay of Bengal. There are few studies focused on the impact of heatwave on different components of the ecosystem due to non-availability of high resolution (HR) climate data. Here we develop a high-resolution data through dynamical downscaling, the method involves nested limited area weather to produce finer resolution gridded information, with coarse-resolution climate information providing initial and lateral boundary conditions. Weather Research Forecasting (WRF version 3.6.1) model is used for downscaling for the months of April to June during 2001-2016, which are validated with station observations. The Spatio-temporal variability of heatwave impacts on vegetation cover and groundwater storage quantified from NDVI (Normalized difference in Vegetation Index) extracted from MODIS (Moderate Resolution Imaging spectrometer) and Equivalent Water Thickness (EWT) from GRACE satellite. The distribution of heatwaves shows that an increasing trend in annual heatwaves coverage (22240 km2/year), annual frequency (0.04 days/year) and average intensity (0.07 °C/year) during the study period over the north and southeastern Indian states. Groundwater storage and vegetation growth depend on the amount of precipitation. The active monsoon (weak) regions have the positive (negative) anomaly of groundwater storage in the month of June and the correlation between precipitation and groundwater storage is 0.7. An increasing trend

in heat waves are associated with the lack of pre-monsoon precipitation led to excessive groundwater depletion and also leads to a significant loss of vegetation. The area of vegetation loss is 27.4%, 57.3% and the area of groundwater depletion is 46%, 21% respectively during the heatwave years 2005 and 2009.

THEME 9

Weather and Climate Services for Farmers

Recent Advances in Agrometeorological Services for farmers in Uttar Pradesh

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Uttar Pradesh occupies an important place in the polity and economy of the country. The economy of U.P. is predominately agrarian. Uttar Pradesh, bound between 24°-31° N latitude and 77°-84° E longitude, is the most populous state of India which occupies 7.33% area of the country comprises of two meteorological subdivisions and eight agro-climatic zones. The total area of the state is 240928 sq. km that have been divided into 75 districts, 300 tehsils & 813 community blocks with a total cultivated area of 166.83 lakh ha and the gross cropped area of 255.24 lakh ha. The cropping intensity of the state is 153%. The agriculture contributes highest 66% to the Gross State Domestic Product (GSDP). The varying weather/climatic conditions in these agro-climatic zones and various geographical features play a dominant role in year-to-year fluctuation in crop production and pose a significant challenge to minimize the losses to a considerable extent through timely agricultural operation and accurate weather forecasts. Generalized forecasts have, however, limited use in farming that's why a tailored product viz. Agrometeorological Advisory Services (AAS) for benefits of farmers in the country under the scheme "GraminKrishiMausamSewa (GKMS)that can effectively be utilized in crop planning and its management has been instituted by IMD in active collaboration with ICAR, SAUs and other allied organizations for rendering weather forecast on district/sub-district scale for which state of the art technology is used to advance weather information along with crop specific agromet advisories to the farming community with an efficient delivery mechanism to enable farmers to take appropriate actions at farm level.

UP state AAU was established in 1987 for rendering meteorological services to the farming community in the state which regularly issues Bi-weekly State Composite Agromet Advisory Bulletins (Bi-Lingual) on every Tuesday and Friday in co-ordination with SAUs & SADs for the benefit of the farming community in the state, however, seven AMFUs of the state are issuingdistrictwiseAgromet Advisory Bulletin. In the wake of changing climate leading to more uneven distribution of rainfall and other weather elements spatially and temporally, block level weather based services to farmers is being implemented by IMD and ICAR by establishing DAMUs at KVKs in each district and 17 such District Agro Meteorological Units (DAMUs) are already functional in the state which are issuing Block Level Advisories in consultation with respective AMFUs & MC Lucknow, while the process for the establishment of further 37 DAMUs is in the final stage.

District/Block NWP forecast is also issued Bi-weekly on every Tuesday and Friday which is valid for the next five days for the 8 Agro-Climatic Zones covering all the 75 districts of state. Quantitatively Deterministic Forecast for 8 different meteorological parameters, which are considered useful from the agriculture perspective, for 5 days at different spatial scale (District/Block) is being issued and a thorough verification mechanism is followed for evaluation of the performance. In this study, the advancements in the forecast performance of various meteorological parameters have been discussed during different seasons for the state of U.P.

In order to boost the outreach, various components of GKMS service viz. weather observation, monitoring and forecast; crop specific advisory bulletin and feedback have been digitized on an integrated platform, called automated AgrometDSS, which is based on a dynamic framework to link the existing knowledge base on crop weather calendar, contingency action plan and other elements to translate weather forecast into actionable farm advisories for efficient decision making.

These bulletins are transmitted to media viz. AIR, Doordarshan, Community Radio etc. in local language for the use of farmers and other user agencies, while also being sent through SMS to more than 1.35 Cr farmers of the state on their registered mobile numbers through m-Kisan Portal. Besides mass media, other modes of communication such as Kisan Call Center and Text To Speech, are aggressively being utilized to ensure the outreach till end user.

An Exposition of Synthesized Astro-Met Weather Predictions for Telangana and Andhra Pradesh States in India

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Need to learn of the future is not a weakness but essential to prepare for an eventuality. The present study is an evaluation of the Astro-met (astrology- meteorology) methodology to predict weather systems for four regions of Andhra Pradesh and Telangana states (Telangana, North coastal AP, South Coast AP & Rayalaseema) of India. With the joint effort of Astro-Met team (comprising of meteorologists & Astrologers), a methodology is realized and validated to provide Annual weather forecast for a region and described. These forecasts are to meet the requirements of the farmers and agro-advisers.

Origin of the weather predictions by astrological approach was well documented in BrihatSamhitaby Vaarahamihira(550AD) as proponented by the ancient astronomers Bhaskara (1150BC), Brahmagupta (628BC), Aryabhatta(499BC), Kepler(1593AD) and Newton (1750AD) and few others. Since ancient times, traditional almanacs provide weather forecasts for one year, based on astronomical calculations of the position and inter-relational aspects of the nine planets of the solar system. Current official weather predictions are provided as short, medium, extended and long-range based on synoptic weather measurements.

The concept of Astro-Met is “Planets do not cause the weather; they reflect weather conditions”. Climatology of the region and Astrological features depicted in the planetary chart for a specified location and time constitute the main inputs for this method. Similar works are reported by several research teams from India, USA, UK, Japan, Australia and other nations. Significant weather events like heat/cold waves, floods and drought, low pressure systems, thunderstorms, heavy rain events are predicted by this method. Spatial weather forecasts covering from National to Local regions, and for various time ranges namely Very Long Range Forecast (season to a Year), Medium range (week to ten days) and short range forecast (24-72 hours) are provided.

Our Astro-Met team, working since 2016, designed a methodology to identify probable synoptic weather features with a blend of astrological features and seasonal climatology of the region as Low/ high pressure systems, Heat/ Cold Wave zones, onset/ withdrawal of monsoon season. Weekly/ monthly/ Seasonal weather forecasts were prepared and validated with IMD observations during 2016 to 2018 and the results are quite encouraging.

Annual weather calendar is prepared for Lunar years "Vikari (from 6th April 2019 to 24th March 2020), for Telangana& AP states and issued on 6th April 2019. The forecast on Temperature, Humidity, Wind and Rain in terms of "Below/Mean/Above normal" with reference to climatological normal of the region and significant weather events are highlighted. The same is validated with Daily Weather bulletin of IMD and our forecasts were successful as 80% of significant weather events whereas 20% are partially predicted. The forecast validation table was presented in the annual weather calendar of next Telugu Year, Sharvari (16-3-2020 to 19-4-2021) and circulated on 16th March 2020. The advantage of Astro-Met forecast is of no time limit for a specified location, whereas the limitation lies with quantification. The Astro-Met forecasting possibilities, with the combined wisdom of Meteorology and astrology intellectuals, are abundant.

Passive Microwave Sensors for Providing Services to the Farmers

OPN Calla

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The services that can be provided to farmers for their crops are in terms of when and how much water they will get from clouds with better accuracy in time and intensity. For this purpose, the Parameters that we have to monitor are the amount of liquid water in clouds at any time. Along with the liquid water we have to monitor the water Vapour Present in the atmosphere Present at any time. Along with these two parameters, namely liquid water in the clouds and water Vapour in the atmosphere, one has to monitor wind speed and wind direction on the Sea Surface. When the information for these parameters, namely Liquid water in clouds, Water Vapour in atmosphere and the wind speed and direction are made available one can provide Service to the farmer. These Four Parameters have been obtained using Passive Microwave Sensors. The Microwave Radiometers operating at the frequencies that are Sensitive to these parameters are:-

(i) The frequency 31.6 GHz is Sensitive to Liquid water content in the clouds.

(ii) The frequencies 22.235 GHz and 183.0 GHz are Sensitive to water Vapour in the Atmosphere.

(iii) The frequency 19.35 GHz is Sensitive to wind speed and wind direction on the ocean Surface.

Thus these THREE Frequency Radiometers onboard spacecraft will give us information regularly about Liquid water in clouds, Water Vapour in Atmosphere and Wind speed and direction. Then using these parameters, one will be able to predict rain and this will be a very important input for the Farmers. So one has to plan to have a Spacecraft that has these Three Radiometers operating at 31.6 GHz, 22.235 GHz / 183 GHz and 19.35 GHz. There are examples where these radiometers have been used for weather Prediction.

Analysis of budget allocation, expenditure and corresponding improvement in services of India Meteorological Department during 2007-08 to 2019-20

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In the budget formulation of any Department, more analytical inputs in programme prioritization/ allocation within the indicated budgetary ceilings based on analysis of expenditure profiles of each programme/sub-programme can lead to maximum utilization of the allocated funds. When funds are optimally utilized, it will help the organization transform it's a vision into reality in the long-run through efficient implementation of the programs and improvement in services. Service enhancements not only have a direct impact on the development of socio-economic activities of the country but also build the organization's brand, reputation, and credibility.

To provide Meteorological services for optimum operation of weather-sensitive activities like agriculture, irrigation, shipping, aviation, offshore oil explorations etc. is at the core of India Meteorological Department's (IMD) mandate and achieving excellence in this area requires careful evaluation, planning and execution. The weather and climate services are dependent on sustained investments in Research & Development and capacity building so that advances in weather and climate sciences get inducted into service through the successful conversion of R&D results into fully operational products and effective means to develop linkages with decision-makers and users.

In this paper we have discussed the trend of actual expenditures in terms of Budget Estimates, Revised Estimates during the period 2007-08 to 2019-20 covering Eleventh Five Year Plan (2007-08 to 2011-12), Twelveth Five Year Plan (2012-13 to 2016-17) and Three Year Action Plan (2017-18 to 2019-20). Separate analysis of budget allocation and expenditure incurred under (i) Central sector schemes (Plan) and (ii) Establishment (Non-Plan) have been made. Achievements in terms of augmentation of Communications and Observational networks during the period of study have been discussed. Improvement in weather forecasting and the introduction of new services have also been discussed. While there has been an almost steady rise in the non-plan expenditure over the years, desired growth was not witnessed in the plan expenditure. However, a remarkable surge was seen in the Plan expenditure since 2018-19 owing to efforts being made to augment the IMD's observational network. It has been observed that the delay in the procurement process is the major cause for under-performance in respect to financial targets. It has been observed that for non-plan expenditure, the salary component has major contribution whereas for expenditure under plan schemes, procurement of equipment plays a major role in determining the performance of expenditure in a financial year. It may be remarked that growth in Plan expenditure is essential for the development of infrastructure and facilities of an organization and at the same time Establishment related expenditure should remain static. Therefore IMD needs to adopt a focused approach on the Central sector schemes for expeditious development and improvement of its infrastructure and services.

How October 2020 rain affected the areas of Maharashtra?

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Importance of South-west Monsoon rainfall for an agrarian India is well established. This year withdrawal of south-west monsoon of our State started late and ultimately withdrawn from full state on 28th October 2020. This year as predicted by IMD, the south-west monsoon was good enough (towards the higher side of normal). The major crops during the period are known as Kharif season crops which are rice, soybean, maize, groundnut etc. Most of the standing crops in their harvesting stage were damaged due to excess of October rain which tempted the authors for this study. The paper discussed the quanta of October rain in different meteorological sub-divisions with special reference to Pune districts vis-à-vis Madhya Maharashtra. October 2020 rainfall was 168% more in Pune district. (As compared to 11 years mean value of 144.5 mm rainfall). While during other years, rainfall was significantly less, though during 2010 rainfall was 118% more than normal. The study showed that October 2020 is characterized by consecutive days of moderate rain in a number of occasions while on 15th October, it recorded near to very heavy rain. Adjacent areas of Pune districts and ghat areas also recorded heavy to very heavy rain which created inundation in low lying areas. Agromet advisories during those periods and other media reports suggested that there was the stagnation of water in standing crop's field which was almost ready for harvest. The study revealed that though the farmers were advised for different mitigative measures but still crops suffered a huge loss.

Keywords: Monsoon 2020, Withdrawal, Agromet advisories, Kharif season

THEME 10

Impact of Climate Variability/ Change on Agriculture

Role of Geoinformatics in Assessing the Impact of Climate Variability/Change on Agriculture

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Geoinformatics is an integration of several technologies for collection, storage, processing, databases creation, and dissemination of spatial information about Earth system functioning for decision making. Commonly used technologies are:remote sensing (RS) for data collection, image processing andanalysis for converting data into information, global navigation satellite system (GNSS), popularly known as GPS, for geo-coding and spatial referencing, geographic information system (GIS)for analysis and generating inputs for planning and decision making.

There is enough evidence that the climate change has been taking place at an unprecedented manner due to anthropogenic causes.Extreme weather events, such as increased coastal flooding, intense precipitation, heat waves and longer forest fire seasons, ecosystem change etc, are some of the symptoms of climate change. The agriculture and rural communities in India are more vulnerable to the impact of climate change because of their dependence on uncertain monsoon rains in nearly 60 percent of the cultivated area. The impact on agriculture could be of two major types: by altering the location of main food-producing regions, and by affecting the physiological mechanisms regulating plant and animal productivity. Normally, increased CO_2 in the atmosphere can help to increase the rate of photosynthesis if water and nutrients do not become limiting factors. C3 and C4 plants (i.e., those which have a 3-carbon or 4-carbon path for photosynthesis) respond differently. C3 crops like wheat, barley, rice and potatoes could respond positively to CO_2 enrichment. There are several studies that predict the climate change using Global Circulation Models (GCM) and its impact on crops through Crop Growth Simulation Models (CGSM). For wheat and barley, yield increases of as much as 40 percent have been reported (Cure 1985). According to International Institute for Applied Systems Analysis, (Parry et al 1988 a & b), a 1° C increase in mean annual temperature would tend to push the thermal limit of cereal cropping in mid-latitude northern hemisphere regions by about 150-200 km, and raise the altitudinal limit to arable agriculture by about 150-200 meters. The arid and semi-arid areas of the tropics in Africa and South Asia will be extremely vulnerable.

Sinha and Swaminathan (1991) examined the integrated impact of a rise in temperature and in CO_2 concentration on the yield of rice and wheat in India. Their study showed that for rice, increasing mean daily temperature decreases the crop growing duration(number of days from transplantation to maturity). Such a reduction in crop duration is often accompanied by decreasing crop yield. Increasing levels of CO_2 increase photosynthesis rate and hence dry matter production but, an increase in temperature reduces crop duration and thereby yields. In the case of wheat, there will be an adverse impact on yield if mean temperatures rise by 1 to 2°C. For each 0.5°C increase in temperature, there would be a reduction of crop duration of 7 days, which in turn would reduce yield by 0.45 t/ha. Lal et al(1995) have reported that yields of soyabean in India would vary between - 22 to 18 % under different climate scenarios considering 2° and 4°C change in temperature and 20 and 40 % change in precipitation. A comprehensive review on impact of climate change on Indian agriculture was given by Mall et al 2006.

There are many potential impacts from slow accumulation of toxic materials in soils and sediments over the long term. Desertification of the dry lands, land degradation due to soil salinity/alkalinity in the irrigated command areas may also be considered as climate change. The Aral Sea basin is an example of some of the negative impacts of intense cultivation of irrigated agriculture, mainly cotton crop, the area under that crop increased from 3 million to 7 million hectares. Water withdrawals for irrigation led to the drying of the Aral Sea, its delta wetlands, loss of habitat and species.

The annual crops, with shorter life cycles than trees and horticultural crops have better adaptability to extreme temperature and rainfall variations.Die-back or decline of orchards (e.g., citrus decline) in the north-eastern region of our country has been related to succession of warmer winters and drier summers. The study carried out by North Eastern Space applications Centre (NESAC) is worth mentioning here. The Citrus Decline Index (CDI) developed using Soil Brightness Index(SBI), Normalized Difference vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) derived from IRS-P6 LISS III data of 2004 gave sufficient clues that the citrus decline was mainly due to loss of nutrients due to soil erosion in addition to rising winter temperatures and deficient rainfall.

Ramakrishna R Nemani et al (2003) reported climatic-change induced enhanced plant growth in northern mid-latitudes and high latitudes. They presented a global investigation of vegetation responses to climatic changes by analysing 18 years (1982 to 1999) of both climatic data and satellite observations of vegetation activity. Their results indicate that global changes in climate have eased several critical climatic constraints to plant growth, such that net primary production increased 6% (3.4 petagrams of carbon over 18 years) globally. The largest increase was in tropical ecosystems. Amazon rain forests accounted for 42% of the global increase in net primary production, owing mainly to decreased cloud cover and the resulting increase in solar radiation. Hashimoto et al (2011) investigated the vegetation response to climate change using MODIS satellite images of India from 2001 to 2010. They found high spatial variability in vegetation indices in response to climate variability. They found that in addition to the precipitation variability due to El Nino Southern Oscillation (ENSO), the other climate variables, such as shortwave radiation that has major role in net primary production, also perturbed the vegetation response to climate changes.There are studies showing that the apple belt of the state of Himachal Pradesh in the Indian Himalaya has been migrating to higher elevations, especially in Kinnaur District. Forests and pasturelands that were once uncultivable and least accessible are gradually becoming preferred land for orchards, while some older, lower elevation orchards are experiencing lower productivity (e.g., Amit Kumar et al 2008, A. Rahimzadeh, 2017). Kundu et al 2018 have predicted changes in the actual evapotranspiration using Surface Energy Balance Algorithmfor Land (SEBAL) due to changes in land use and climate (rising temperature) in parts of Narmada basin in Madhya Pradesh.

Though several studies in India and elsewhere are convincing that the modern tools of spatial information collection and processing using geoinformatics are the best to convince the decision makers on the measures needed to decelerate pace of climate change, their operational use in our country is not perceptible. What is needed urgently is to create awareness on these modern tools, map the vulnerable areas, evolve a set of adaptation strategies, convince people and implement the strategies keeping in view the socio-economic-ecological benefits to the local people on one hand and the global implications on the other.

Drying of North India during Indian Summer Monsoon

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This study focuses on drying trend rainfall over North India during the Indian summer monsoon (ISM) from June through September (JJAS) as the major amount of rainfall is received during this season over here. All the previous studies have mentioned either considering North India along with a part of Central India or only Indo-Gangetic plains of North India. The circulation features over North India are different from that of Central India. Also, the study of rainfall during ISM over North India has been reported less than that of over central India. Therefore, the monsoon circulation is poorly understood over this region. The main objective of the present study is to understand the interannual variability of rainfall during ISM over North India. The present study has been carried out using 71 years (1948-2018) of data. We have found that most of the parts of North India showing a drying trend of rainfall during ISM (ISMR). To investigate the relationship of ISMR over North India with zonal and meridional components of wind and sea surface temperature (SST), the correlation and regression analysis is being carried out. It showed that the upper-level north-easterlies are playing a significant role in modulating ISMR over North India. At the lower-level, the moisture supply is coming from the Bay of Bengal to this region. The equatorial eastern Pacific Ocean SST has a significant negative correlation with ISMR over North India. It may be the reason which leads to a decrease in rainfall during the summer monsoon over North India.

Detection of ozone stress using spectral reflectance

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The presence of ozone at near earth surface is an important air pollutant and act as a strong oxidizing agent. Tropospheric ozone influences the photochemistry of lower atmosphere and changing global environment. Ozone also reacts with a wide range of cellular components and substantially reducing economically important crop yield across many parts of the world. Evaluation of ozone stress and yield loss at large scale is difficult through visual, physiological and biochemical examination. In the current scenario, ozone stress identification in crops through remote sensing could be useful technology due to a rapid and non-destructive method. In the present study, rice cultivars (Rice CO51, ADT36, ADT(R)48, ASD18, Rice MDU6, TRY(R)2, and PMK(R)3) were exposed to an average ozone concentration of 100 ppb (10:00–17:00 h) from 51 to 80 days after sowing (DAS). The response of six rice cultivars to an elevated level of ozone was examined using leaf hyperspectral data, ozone injury percentage, leaf physiological and biochemical parameters. Specifically, canopy reflectance data measured at 80 DAS were used to assess the spectral indices. Normalised Difference Vegetation Index (NDVI), Simple Ration Index (SRI), Photochemical Reflectance Index (PRI), Anthocyanin Reflectance Index (ARI), Ratio Vegetation Index (RVI), Leaf Chlorophyll Index (LCI), Infrared Red Index (IRI) and Green Normalised Difference Vegetation Index (Green NDVI) were calculated from canopy reflectance percentage. The Pearson's correlation for spectral indices with ozone injury percentage, leaf physiological and biochemical parameters was

strong for most of the studied indices. Among the correlations, a photosynthetic rate with PRI (r = 0.95***), chlorophyll content with LCI and Green NDVI were showed strong positive correlation (r = 0.91*** and r = 0.88***). A strong negative correlation observed between ozone injury percentage and PRI (r = - 0.78*). The outcome from the current work confirms the potential application of remote sensing technology in ozone stress identification in rice cultivars. Furthermore, spectral reflectance of injured leaf canopy at large scale could be used to expedite ozone stress identification and crop yield modelling studies to project food security.

Simulating the impact of climate change on rice yield using DSSAT model

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Rice (Oryza sativa L.) is the second most important food grain after wheat in World. A decline in productivity of rice in recent years has been ascribed to decrease in soil organic carbon and reserve of nutrients, non-uniform distribution of rainfall, and increase in temperature and carbon dioxide because of climate change. To assess the impact of climate change on rice yield, crop simulation DSSAT model CERES – rice was calibrated and well evaluated for short and medium duration varieties through experimental field data at Jagdalpur, India. Using past 10 years (2010 – 2019) weather data, the CERES-Rice model predicted higher yield variability of the medium duration variety (130 days) "Mahamaya" as compared to the Long duration (145-150 days) variety "Swarna" under rainfed condition of Jagdalpur, India. However, NDR – 359 simulated the higher mean yield. With the increase in atmospheric CO2 level by 150 ppm, the grain yield of Mahamaya and Swarna was increased by 7.16% and 5.86% respectively under irrigated condition. Increase in average air temperature by 3°C resulted in a decline in yield of long duration variety but an increase in yield of the medium duration variety. The medium duration variety showed better adaptability to climate change than the long duration variety under optimum input management condition.

Keywords: DSSAT CERES-rice model, climate change, rice yield, simulation

Preparation, characterization and performance of climate adaptive biochar as a biofertilizer in the nutrient management of paddy

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Rice is a staple cereal crop in most of the Asian countries including India. Rice is grown in all agricultural seasons in eastern and north-eastern India due to climate suitability and food habits.

Continuous use of chemical fertilizers to increase the productivity of rice degrades the quality of soils and increases the carbon footprints of agriculture. Therefore, we need to recycle the nutrient-rich agro-residues, such as legume stover in the climate adaptive valorised form (e.g., biochar) to improve soil quality and maintain crop yield with minimum impact on the environment. We prepared, characterised and tested legume biochar fertilizer in a controlled environment to assess its impact on the nutrient leaching, grain yield, and potential GHG emissions in comparison to conventional organic and mineral fertilizers using emission coefficient in paddy crops. The results suggest that a relatively small dose of soil-test based balanced fertilization (75% of required nutrients) together with that of biochar (25% nutrient equivalence; 3t ha^{-1}) is the best combination compared to other fertilization methods. Biochar fertilizer showed similarity in total–N content to compost, although there are noticeable differences in other macro, secondary, and micronutrients. The surface area and C: N ratio was significantly higher for biochar (i.e., 4.47 m^2g^{-1}; 37.68) as compared to that of compost (i.e., 0.87m^2g^{-1}; 10.5). Integrated biochar and compost applications with mineral fertilizers enhanced soil organic carbon at the harvest of paddy by 44 – 54% and 10 – 15%, respectively, while reducing nitrate leaching over the just mineral fertilizer application. We also estimated the potential GHG emissions from different nutrient management treatments using IPCC emission coefficients for chemical fertilizers, and observed that yield scaled GHG emissions can be reduced by 50 – 53% in case of the integrated biochar fertilization as compared to sole mineral fertilizer treatment. Further, we observe the highest yield response for the integrated low-dose biochar fertilization. Henceforth, this study suggests an environment friendly biofertilizer alternative that can have policy implications towards developing a carbon-negative fertilization technique in paddy farming for mitigating climate change.

Keywords: Biochar, Nutrient management, Paddy, Climate change, Carbon footprint

Influence of weather parameters and sowing windows on grain yield of wheat under lower Shivalik hills of NWPZ

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Under sub-tropics of N-W low altitude plains of lower Shivalik hills range of Himalayas under Jammu and Kashmir UT region, weather parameters especially maximum and minimum temperature and rainfall influenced the growth and development of wheat crop. The stress is more prominent, particularly during reproductive/grain filing stage. These weather parameters influence the development and expression of phenological stages and finally yield of the crop. It is a unique crop among the major food crops by virtue of its extent and adaptability to a wider range of edaphic, climatic and cultural conditions. Time of sowing plays an essential role in its production; as perfect sowing environment exploits the full genetic potential of a particular variety by providing optimum growth conditions such as temperature, light, humidity and rainfall. Adequate growth and augmentation of the crop could be obtained by adjusting the sowing environments, which leads to better yield. The unfavourable

environments created by high temperature mostly during reproductive stages especially grain filling stage could be minimized by adjusting the sowing time to an optimum date for different varieties, which are suitable for early, normal and late sown environmental conditions for assured higher yield. The interaction of weather parameters/abiotic stress can be used as an aid for weather based management of the crop. Field experiments were conducted at Agromet Research Centre, SKUAST-Jammu in rabi 2015-16 and 2016-17, to study the influence of different sowing environments and nitrogen levels on phenology and yield of wheat varieties. The treatments comprised of 3 varieties; HD-2967, RSP-561 and WH-1105, with 3 sowing environments; 25th October (early), 14th November (normal) and 4th December (late) and 3 N-levels 100, 125 and 150 kg N/ha laid in a split split-plot design.

Low mean temperature during early growth period resulted in longer vegetative phase in the late sown crop in comparison to early and normal sowings; while as high mean minimum temperature shortened the vegetative growth period in the early sown crop. However, the duration of the reproductive period decreased with an increase in mean minimum temperature. High mean maximum temperature shortened the vegetative period in the early sown crop. High temperature during the reproductive period is not suitable for wheat crop.

The crop was naturally subjected to about 3 and 10C higher mean maximum and minimum temperature, respectively above their respective normals during the anthesis stage of the crop sown on 14th November in rabi 2015-16. During milking stage, 14th November sown crop, maximum and minimum temperature was higher by about 2 and 1.50C than their respective normals in rabi 2015-16. Some researchers also have envisaged the similar type of findings and also reported a reduction in productivity of wheat by with 30C rise in temperature during this period, and adjudged to be the most critical stage. However, during rabi 2016-17, the mean temperature was higher during anthesis stage of wheat. In the early sown crop, the temperature was optimum during the grain development stage, which was conducive for the proper development of grains.

Keywords: Sowing environments, varieties, nitrogen levels, wheat

Effect of Non-Conventional Sources of Nutrients through Diverse Application Methods on Maize Productivity and Soil Health in the Rainfed Hinterlands of North-West Himalayas

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Maize is the most important staple crop grown extensively during Kharif season in rainfed areas of Jammu region. The economically viable production of maize crop is affected by many factors such as poor soil fertility due to undulating lands due to moisture scarcity and water erosion hazards. Excessive nutrient mining is a common phenomenon in soils where maize is grown as it is a widely spaced Kharif (rainy) season crop often encounters dry spells causing moisture scarcity and intense rains lead to excessive nutrient losses from the topsoil owing to erratic rainfall and aberrant weather. As a result, the soils are not only thirsty but predominantly hungry of macro and micronutrients. Poor water holding capacity, coupled with low soil organic carbon content further adds to the low productivity of maize and other crops in the region leads to the distress of the farmers. Further, the adverse effects of chemical fertilizers on soil health, high cost of chemical fertilizers and inclement weather conditions restricts their usage by the resource-poor farmers of the environmentally fragile region. On the other hand, organic manures are natural sources of nutrients and inclusion of the organic manures like FYM and mule compost in nutrient management has become a necessity to improve the soil fertility and to sustain the productivity of maize crop. Therefore, a field experiment was conducted during 2019 at the research farm of Maize Research Station, Udhampur, J&K (UT) under All India Coordinated Research Project on Dryland Agriculture, SKUAST-Jammu, Rakh Dhiansar to study the effect of non-conventional sources of nutrients through diverse application methods on maize productivity and soil health in the rainfed hinterlands of Jammu region. The study comprised of ten organic manures and inorganic fertilizer based treatments viz., Control (no fertilizer application), 100 % recommended NPK, 100 % recommended NPK +1 % ZnSO4, 100 % recommended NPK + 0.1 % Borax, 75 % recommended N + 25% FYM, 75 % recommended N + 25% N Mule, 75 % recommended N + 25 % N FYM + 1 % ZnSO4, 75 % recommended N + 25 % N FYM + 0.1 % Borax, 75 % recommended N + 25 N FYM + 1% ZnSO4 and 75 % recommended N + 25% N Mule + 0.1 % Borax. Maximum grain yield of maize (2842 kg/ha) was obtained with the application of 100 % recommended NPK +1 % ZnSO4 which was statistically at par with 100 % recommended NPK + 0.1 % Borax, 75 % recommended N + 25 N FYM + 1% ZnSO4 and 75 % recommended N + 25% N Mule + 0.1 % Borax and grain yield 2754, 2673, 2587. The minimum grain yield of 1814 kg/ha was obtained in control. The highest net returns to the tune of Rs 36274/ ha were realized with the application of 100 % recommended NPK +1 % ZnSO4 with the corresponding benefit:cost ratio of 2.48 and also recorded maximum RWUE of 5.66. The minimum net return, benefit: cost ratio and RWUE were observed in control. Besides this, soil organic carbon, available nitrogen, available phosphorous and available potassium were significantly affected by the application of organic and inorganic fertilizers. The maximum organic carbon content was recorded in 100 % recommended NPK + 0.1 % Borax (6.20 g/kg) followed by 75 % recommended N + 25% N Mule + 0.1 % Borax, 75 % recommended N + 25% N Mule, 75 % recommended N + 25 N FYM + 1% ZnSO4 and 75 % recommended N + 25 % N FYM + 0.1 % Borax. The lowest organic carbon was obtained (5.73 g/kg) in control. The highest value of available N, P and K (215.6, 17.48 and 189.8 kg/ha) was recorded with the application of 100 % recommended NPK +1 % ZnSO4 and lowest value of available N, P and K (184.1, 13.28 and 169.4 kg/ha) was recorded in control, respectively. From the present study, it can be safely concluded that integrated application of chemical fertilizers along with organic manures hold the promise to enhance maize productivity while improving soil fertility in rainfed subtropics of North-West Himalayas under variable climatic conditions.

Influence of Different In-Situ Soil Moisture Conservation Techniques in Maize under Rainfed Agro-Eco System of Jammu Region

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Maize being the dominant *Kharif* crop of rainfed areas of Jammu province is seriously suffering due to erratic and unpredictable rainfall. The uneven distribution of rainfall in time and space often causes dry spells of two weeks or even more resulting in moisture stress conditions during critical stages of maize crop, especially during the cob formation/grain filling stage which is the most critical stage with respect to productivity. Keeping this fact in view a field experiment was conducted at the Research Farm of Advanced Centre for Rainfed Agriculture, ACRA Dhiansar of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during the *Kharif* season of 2016 to find out the effect of different *in-situ* soil moisture conservation techniques in maize under rainfed agro-eco-system. The experiment consisted of 9 treatments viz. Flat Bed, Broad Bed Furrow, Flat Bed + mulching with *in-situ* raised Dhaincha, Broad Bed Furrow + mulching with *in-situ* raised Dhaincha, Flat Bed + mulching with *in situ* raised Sunhemp, Broad Bed Furrow + mulching with *in-situ* raised Sunhemp, Flat Bed + mulching with *Leucaena* prunings, Broad Bed Furrow + mulching with Leucaena prunings and Farmer's practice. The experiment was laid out in a randomized block design with three replications. The experimental results revealed that all the soil moisture conservation techniques showed significant results over the other treatments. However, the treatment Broad Bed Furrow + mulching with *in-situ* raised Dhaincha recorded significantly higher values of growth and yield and yield attributing characters with highest net returns, B:C ratio and RWUE (kg/ha/mm) while the lowest net returns and B:C were recorded in farmer's practice.

Keywords: Maize, *in-situ* moisture conservation, Broad Bed Furrow and Flat Bed.

Adaptation to Climate Change and Its Impact on Small holders' Income and Welfare: Estimation Using Matching

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Rural people involved in agriculture, particularly in developing nations, are most vulnerable to climate change due to its extreme weather events. South Asian countries are particularly affected by climate change because of the massive population and most of them predominantly depend on agriculture for their livelihood. The World Bank's South Asia Climate Change Strategy Report confirms that poor rural households in this part of the world largely susceptible to climate change due to limited assets, unfavorable geography, and reliance on climate-sensitive income sources. Change in precipitation, rise in temperature, and incremental intensity of heatwaves impact crop yield,

income, and subsequently the poverty, food security, and per capita consumption of the smallholders. To minimize the detrimental impact of climate change on agriculture, various adaptation strategies have been adopted at the farm level. Such strategies include crop diversification, alteration in the time of operation, advances in water management technique, promotion of new crop varieties, and adaptation of Govt. policies. Although climate change adaptation strategies are crucial, not all smallholder farmers use such practices. Hence, this study identifies the constraints of climate change adaptation strategies by paddy farmers in Eastern India and their impact on household income, per capita consumption, and food security.

To assess the influence of the determinants in farmer's adoption of climate change adaptation practices and its concomitant impact on household income and welfare (food security and per capita consumption) using household-level data from 315 farmers from major paddy growing state (West Bengal) in India. First, a probit regression model is used to identify the variables affecting the adoption of climate change adaptation strategies. Then, the censored least absolute deviation (CLAD) is computed to investigate the constraints of the number of adaptation practices used. Finally, the propensity score matching (PSM) model is deployed to analyze the impact of adaptation practices on income, food security, and per capita consumption.

Use of drought-tolerant varieties (22%), an adjustment in sowing time (12%), shifting to new water management practice (7%), adopting crop insurance scheme (9%), are the four major adaptation strategies used by the paddy farmers in the study area. Results show that young and educated farmers and farmers with mobile, television, and access to formal credit are more prone to use the adaptation practices. Factors like landholding size, extension services, membership in farmers' association, access to credit, and social capital were found to be positively associated with the number of adaptation strategies. Farmers with more adaptation practices have better farm income (22-25%), greater food security (13-16%), and enhanced per capita consumption (9-11%) compares to those who do not adopt any adaptation strategies.

Hence, farmers' level policy should emphasize two aspects: (i) enhancing the smallholders' affordability of climate risk coping capacity by decreasing the cost of adaptation; and (ii) increasing the cognizance of climate change and its risk managing practices and its welfares.

Value addition to climate forecasting: predictability of the Kharif Rice crop association with various Indo-Pacific climate drivers

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In a recent study, we have demonstrated that the tropical Indo-Pacific drivers, namely, the El-Nino-Southern Oscillation (ENSO), ENSO Modoki, and Indian Ocean Dipole (IOD) not only impact the summer monsoon rainfall and temperatures in India. Each of these drivers also has a statistically significant correlation with the Kharif rice production (KRP) of several rice-growing states in India. Importantly, the Indian Institute of Tropical Meteorology (IITM), Pune, India, has generated seasonal and extended range hindcast products for 1981-2008 and 2003-2016 using the IITM-Climate Forecast System (IITM-CFS) coupled model at various resolutions and configurations. In this paper, using the available hindcasts, we evaluate whether these state-of-the-art retrospective forecasts capture the relationship of the KRP of multiple states with the local rainfall as well as the tropical Indo-Pacific drivers, namely, the canonical ENSO, ENSO Modoki and the IOD. Using techniques of anomaly correlation, partial correlation, and pattern correlation, we surmise that the IITM-CFS successfully simulate the observed association of the tropical Indo-Pacific drivers with the local rainfall and temperature of many states during the summer monsoon. Significantly, the observed relationship of the local KRP with various climate drivers is predicted well for several Indian states such as Andhra Pradesh, Karnataka, Odisha, and Bihar. The basis seems to be the ability of the model to capture the teleconnections from the tropical Indian pacific drivers such as the IOD, canonical and Modoki ENSOs to the local climate, and consequently, the crop production.

Keywords: CFSv2 Seasonal and Extended range hindcasts, ENSO, Kharif Rice Productions

Impact of changing behavior of microclimate on population dynamics of mustard aphid in Gangetic Bengal

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The mustard growing areas in India are now experiencing vast diversity in the agro-climatic conditions and the attack of mustard aphid, particularly in Gangetic Bengal area, making the situation further worst in terms of productivity. For getting relief, most growers indiscriminately use synthetic insecticides which negatively impact the environment. This calls for the immediate adoption of an eco-friendly aphid pest management technique under altered microclimatic conditions. Introduction of Companion cropping technology can mark a distinct benefaction in this aspect. Considering these facts, the present study was conducted during rabi seasons of 2017-18 and 2018-19 at Kalyani 'C' Block farm of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, to evaluate the effects of combined use of companion cropping with different mustard cultivars on *Lipaphis erysimi* infestation in an open field. The experiment was laid out in Factorial Randomized Block Design (FRBD) with two popular mustard cultivars (B-9, V_1; B-85, V_2) and three companion crops (C_1-Pea, C_2- Marigold, C_3-Garlic) with sole mustard (C_4). Results revealed that canopy temperature of mustard had lowered significantly in association with Pea (C_1) and Marigold (C_2). Maximum canopy temperature was recorded by B-85 (33.47°C) irrespective of crop seasons. Quite sharp and fluctuating canopy humidity range was noticed in case of V_1. Besides, V_1 reported the highest humidity inside crop canopy as 83.23 per cent in comparison to V_2 (77.85%). Mustard-Pea companionship maintained least humidity environment. Among different PAR component, transmitted PAR within mustard canopy varied significantly. TPAR remained varying between 299.84 µmoles m^{-2} s^{-1} to 682.33 µmoles m^{-2} s^{-1} for V_1 whereas, V_2 recorded TPAR ranging from 181.56 µmoles m^{-2} s^{-1} to 451.76 µmoles m^{-2} s^{-1}. On considering the mean seasonal TPAR, then trend remained as C_4(Sole Mustard)>C_3(Mustard-Garlic)>C_1(Mustard-Pea) >C_2(Mustard-Marigold). The population density of aphid was in increasing trend from its onset of appearance in the field (52 DAS) up to 80 DAS in case

of the first year and from 45 DAS till 73 DAS during second crop season and then the density decreased sharply as the crop moved towards physiological maturity. V_1 reported aphid population ranged from 2.59 (6.33) to 7.80 (60.69) whereas, for V_2, aphid count remained between 2.50 (5.82) to 7.65 (58.33). The trend of aphid infestation within different companion and sole crops were C_4(Sole mustard)>C_1(mustard-pea)>C_2(mustard-marigold)>C_3(mustard-garlic). A significantly strong positive correlation was recorded between aphid population and canopy humidity particularly at 50% flowering (r=0.578) and silique formation stage (r=0.271) whereas, a prominent significant negative association was noted between aphid development and mustard canopy temperature particularly at silique initiation (r= -0.340) and 50% silique formation stage (r= -0.354). However, transmitted PAR and aphid dynamics remained positively correlated after aphid incidence till their disappearance. Forewarning model to predict aphid dynamics under changing micro weather elements reflected that canopy temperature, humidity and transmitted PAR explained about 86.25% variability in aphid population during peak infestation.

Keywords: Mustard aphid, Eco-friendly pest management, Companion cropping, FRBD, TPAR, Aphid dynamics

Analysis of cropping systems under changing climatic conditions using geo-spatial techniques and crop simulation model in Southern Uttarakhand

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The present study entitled "Analysis of cropping systems under changing climatic conditions using geo-spatial techniques and crop simulation model in Southern Uttarakhand" has been conducted in Udham Singh Nagar district during 2012-13 and 2013-14. LANDSAT-ETM+/TM and LANDSAT-8 OLI/TIRS multispectral satellite data were used to discriminate the major crop grown in different seasons viz. Kharif, Rabi and Zaid using ENVI-4.8 image processing software. Maximum likelihood classifier was used to classifying the major crop and acreage estimation under each crop class. Different crop rotation maps were used to generate cropping system map in Udham Singh District with the help of decision tree. It was observed that the rice crop was extensively grown in a large area (61.67%). The RMSE (%) between the estimated area and reported area was found to be 17.65% for Kharif season. During Rabi season, wheat was the major crop covering an area 60.71% of the net sown area recorded RMSE (20.58%) between estimated area and reported area while RMSE=31.54% for Zaid season. The remote sensing approach identified a total of 27 cropping systems. Out of these cropping systems, 20 (including Kharif and Zaid) were rice-based systems covering 74.06 % while the wheat-based cropping system coverage was 25.92%. Rice-wheat-fallow (R-W-F) cropping system occupied the largest area (32.93%) followed by Sugarcane-Sugarcane-Sugarcane (S-S-S=15.69%) of the agricultural area. Other important classes of the crop rotations were Fallow-Wheat-Fallow (F-W-F=8.62%), Rice-Wheat-Others (R-W-O=8.05%), Rice-Wheat-Summer Rice (R-W-SR=6.08%) and Other Minor systems of the agriculture area. Under the changing climate, the yield is increasing with increasing the CO_2 concentration in the 2100th century, while yield get reduces with increasing temp over the study area.

Keywords: Cropping System, Geo-Spatial techniques, Climate change

Simulating climate change impacts by free-air carbon dioxide enrichment on seed cotton yield using the CSM-CROPGRO-Cotton model in South-Western Punjab

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The present study was conducted at the Punjab Agricultural University, Regional Research Station, Bathinda during the *Kharif* season of 2019 and 2020 to quantify the effect of climate change by free-air carbon dioxide enrichment on the productivity of Bt cotton hybrid. During both the years of study, cotton crop was sown at normal sowing (last week of April) and late sowing (last week of May). A hybrid cotton variety, i.e. RCH 773 BGII was selected for the experiment, which is popular in the study region and has better tolerance to the cotton leaf curl virus (CLCuV) and sucking pests. For the growth and development of the hybrid, the medium and heavy textured soils are most suitable and take 160-170 days to mature. First, the CROPGRO-cotton model (v.4.7) was evaluated using the experimental data of *Kharif* 2019 and 2020, in which the genetic coefficients used in the model for the present study were derived and calibrated by Dhir (2019) for the *Bt* cotton hybrid RCH-773 BGII. For the model evaluation in terms of phenology and seed cotton yield having present weather conditions, current free air CO_2 concentration level of 411ppm measured at Mauna Loa Observatory in Hawaii was used in DSSATv4.7 by default. Furthermore, phenology and seed cotton yield were simulated due to environmental modification using DSSAT CROPGRO-cotton model by free-air carbon dioxide enrichment of 25ppm, 50ppm, 75ppm and 100ppm over current CO_2 concentration level of 411ppm upto 685ppm, which would reach by 2050 (OECD Environmental Outlook Baseline; ENV-Linkages model). Results of model evaluation revealed close proximity between observed as well as simulated values in respect of anthesis (deviation 8.77%, R^2: 0.27, d-Stat.: 0.59 and RMSE: 6.1), physiological maturity (deviation 0.71%, R^2: 0.36, d-Stat.: 0.73 and RMSE: 3.2) and seed cotton yield (deviation 5.75%, R^2: 0.98, d-Stat.: 0.98 and RMSE: 173.1), furthermore, which was used as a baseline for the simulated analysis for phenology and yield using free-air carbon dioxide enrichment. The effect of enriched CO_2 concentration at all the levels was non-significant with the number of days to attain anthesis and physiological maturity among the sowing time. Seed cotton yield was found increased as CO_2 concentration increased at all the levels till 685ppm by 2050 over the current CO_2 concentration level of 411ppm (2020) with timely and late sown crop, respectively. In which timely sown crop (last week of April) showed a large increase in seed cotton yield at all projected CO_2 concentration levels. As CO_2 concentration increased from 411ppm to 685ppm seed cotton yield was increased, which showed a positive impact on yield among the dates of sowing. Maximum yield was simulated with increased CO_2 concentration by 685ppm in 2050.

Keywords: Cotton, CROPGRO-cotton model, climate change, free-air carbon dioxide enrichment, sensitivity analysis

Climate-optimized irrigation scheduling for *Bt* cotton hybrid (*Gossypium hirsutum*) and its evaluation using simulation and statistical relations

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To determine the optimum irrigation level for Bt cotton hybrid under semi arid conditions in South-Western region of Punjab, a field experiment was conducted at PAU, Regional Research Station, Bathinda (Agroclimatic zone V) during *Kharif* season of 2019. The experiment was laid out in a strip plot design with three replications. The main plot treatments included three dates of sowing; 30th April (D_1), 15th May (D_2) and 30th May (D_3) and four sub-plot treatments of irrigation schedules; 60% of Et_c (I_1), 80% of Et_c (I_2), 100% of Et_c (I_3) and 120% of Et_c (I_4). The first irrigation applied to the crop was common to all the treatments, which was given after the recommended time of 30 DAS. Recommended cultural practises were followed as per the package of practices of Punjab Agricultural University except for for the experimental treatments. CROPGRO-cotton model (v.4.7) was evaluated using the experimental data of *Kharif* 2019, in which the genetic coefficients used in the model for the present study were derived and calibrated by Dhir (2019) for the *Bt* cotton hybrid RCH-773 BGII. Furthermore, a sensitivity analysis was also performed for mean temperature (±1 to ±3ºC) than rainfall (±10 to ±30%) and solar radiation (±1 to ±3MJ m^{-1} d^{-1}). Moreover, equations of multiple regressions were also developed for estimating the number of days taken to phonological stages as well as for the seed cotton yield among dependent and independent parameters. Results revealed that, observed as well as a simulated number of days taken to achieve various phenophases and yield were recorded higher under 30th April sowing followed by 15th May and 30th May sown crop. Similarly, higher values of phenology and yield attributes were recorded under more number of irrigation level (120% Etc) and decreased with decreased in irrigation frequency. CROPGRO-cotton model showed 0 - 12.9%, 0.7 - 7.0%, 0.14 - 7.82% deviation in simulated values in terms of anthesis, physiological maturity and seed cotton yield, respectively over observed data. Moreover, % deviation in simulated values over observed showed almost increasing trend with delayed sowing and decreased irrigation frequency in respect of phenology and seed cotton yield and also model showed underestimation among the treatments and crop character. The statistical model showed overestimation in respect of the number of days taken to phenological stages, while, values of seed cotton yield were under predicted. Though, predicted values were within acceptable limits (standard error <20 of observed). Observed and simulated seed cotton yield was decreased by 20.4 and 14.6% with 15 days delayed in sowing from 30th April to 15th May and also decreased by 19.4 and 10.4% with further 15 days delayed in sowing from 15th May to 30th May. Moreover, seed cotton yield was reduced by 35.88 and 34.1% with 30 days delayed in sowing from 30th April to 30th May. Similarly, the per cent reduction in seed cotton yield was found by 1.74, 8.74, 4.96 and 14.77% for observed values and by 6.81, 3.26, 4.48 and 13.89% for simulated values due to decrease in irrigation frequency from I_1 to I_2, I_2 to I_3, I_3 to I_4 and I_1 to I_4 respectively. Among the crop characters used for sensitivity analysis of the model, higher deviation in simulated value over observed was found with incremented/ decremented mean temperature than rainfall and solar radiation. CROPGRO-cotton model showed 0.98 - 15.53%, 0.39 - 9.58%, 1.72 - 10.21% deviation in seed cotton yield due to incremented/decremented mean temperature, rainfall and solar radiation, respectively, hence, mean temperature was found more sensitive.

Keywords: Cotton, irrigation scheduling, dates of sowing, CROPGRO-cotton model, regression equations, sensitivity analysis

Ensuring food security in the era of climate change: Addressing challenges of changing thermal and moisture regimes in agriculture

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It's been reported by the scientist, researchers and validated by the IPCC (Inter-Governmental Panel on Climate change) that warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The rise in temperature and less water availability causes crops to enter into thermal and water stress resulting in poor plant vigour, shrivelled grain size and reduced grain weight ultimately the yield loss. Rice and wheat are the two major crops grown in India. Rice is cultivated primarily in irrigated areas and wheat with residual moisture conditions imposing huge pressure on underground water sources for irrigation demand during Kharif season. Though the total food grain production has increased in the country, still it is suffering largely due to weather aberrations. Earlier floods and droughts were considered major weather related threat to the crops but now in recent years, rising temperature, depleting water table, reduction in the amount of monsoon as well as annual rainfall, reduced number of rainy days and drought events have also affected agriculture sector negatively. Reducing groundwater availability in the near future needs to be addressed to use water resources in a smart way for sustainable agriculture. Sowing time adjustments in crops can help them to escape stress during maturity, particularly in wheat. Though it requires less water as compared to rice still need based irrigation system needs to be studied. Keeping all these things in mind, a field experiment was conducted at ICAR- RCER, Patna during 2018- 2020 for rice and wheat, where both the crops were sown/transplanted at 3 dates at 15 days' interval to mock the thermal variations with three irrigation treatments. Critical growth stages based irrigation schedule was developed for wheat crop whereas for rice concept of "pani pipe" (developed by IRRI) alternate wetting and drying (AWS) system was adopted. As a result, 18 -35 % of irrigation water was saved in rice and 16-23 % less irrigation water was used for wheat crop. It was also reported that crop yield can reduce up to 26 % with delay in sowing.

Impact of climate on paddy production over Koppala for the period of 1979-2018 and future projections under different climate scenarios up to 2100 using APSIM crop model

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With regard to global climate change due to increasing concentration in greenhouse gases, particularly carbon dioxide (CO2), it is important to examine its potential impact on crop development, production, precipitation and the interaction of these elements. In this study, we investigate sources of uncertainty in yield response to climate change. Agricultural Production Systems sIMulator (APSIM) is internationally recognized as a highly advanced platform for modelling and simulation of agricultural systems. Model is used for simulating paddy production in Koppala region of Karnataka using 40 (1979 to 2018) years of weather data. Field experiments are used to identify genotypic coefficients, for better simulation of paddy yield over Koppala district. The past simulations indicate the role of rainfall more significant in modulating paddy yield. The model predicted the phenological variables, yield, leaf area index, nitrogen content and biomass of plant parts (including grain) on a daily basis is investigated. To generate future projections, we use CMIP5/6 climate scenarios for the period 2021-2100. The results show that rainfall and temperature play a vital role in modulating paddy production. The differences in yield change under different climate scenarios will be presented.

Keywords: Agricultural Production Systems sIMulator (APSIM), Calibration, Crop Modelling, crop production, Climate change

Better Farm Management Data for precise impact assessment of climate change/climate variability

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Intergovernmental Panel on Climate Change (IPCC) provides unequivocal evidence for the role of anthropogenic forcing in driving the observed warming of the Earth's surface by about 1°C during the last 150 years. Consequences of this warming have already manifested in several other global-scale changes such as melting glaciers, rising sea levels, changing precipitation patterns, and an increasing tendency of weather and climate extremes and these are already visible in India in one or parts of the country. The average temperature over India during the year 2019 was above normal. During the year, annual mean surface air temperature, averaged over the country, was +0.360C above (1981-2010 period) average. The year 2019 was the seventh warmest year on record since nation-wide records commenced in 1901. A small change in climate or its variability will impact the agricultural productivity and thereby affect the livelihood, food and nutritional security of the small and marginal farming community, which is about 80-85 % of the total farming community. The assessment of climate change on agricultural productivity can be done using crop simulation models (DSSAT, APSIM, InfoCrop etc.) and linking it with socio-economic models. There will be a lot of uncertainty with GCMs and also with the crop management

decisions at the farm level. There is a need to assess the climate change/climate variability using the actual management practices at the farm level, so that accurate assessment can be evolved. Under ICAR-AgMIP collaborative project, we have analysed the climate change impact at farm level in Meerut district and found that rice yield will decline by 12 % and wheat yield by 24 % in the 2050s and 74 % households could be vulnerable to climate change in the 2050s. Net farm returns decline by 14 % and per capita income by 9 % under the hot/dry climate scenario in the 2050s. Such type of studies needs to undertake in different agroclimatic zones of the country to get an accurate and reliable assessment of climate change/climate variability on agricultural productivity.

Agricultural Drought Area Mapping and Estimation using Sentinel 1 SAR Data

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Drought is a recurring yet intermittent climate phenomenon. Agricultural drought demotes to a condition when soil humidity is no longer sufficient to meet the needs of growing crops in the field. Careful monitoring of signs of drought and early warning is important in the successful management of the catastrophe. There have been a significant increase in the frequency of agricultural drought and their spatial extent in Assam. Agricultural practice in Assam is mostly rain-fed and in the absence of proper irrigation system, any amount of drought turns into a disaster for the poor farmers of the region and causes a direct impact on the economy of the concerned state. Assam has experienced meteorological drought leading to inadequate rainfall over several districts of the state, particularly in winter seasons and subsequently, the Rabi crops were severely affected by drought. Once we get the overview of the district that was under the meteorological drought, the next step is to find the areas that are under the agricultural drought. Remote sensing technique has become crucial, due to the timely available Spatio-temporal data, particularly for the timely identification and monitoring of drought. The most widely used Normalized Difference Vegetation Index (NDVI) from remote sensing is often unable to predict drought events instantaneously. Hence, the NDVI value can not only be used for the identification of the drought districts so further we analysed the soil moisture dataset from which we could get a better picture for declaring the drought districts. Thus for further accuracy, it was compared with production data also. The state experienced meteorological drought leading to inadequate rainfall in several districts in 2012, 2014 and 2016. During the 2012 winter season, Assam recorded 70 per cent lower rainfall than average and subsequently, the Rabi crops were severely affected by drought. After integration of all the datasets in GIS domain for a period of ten years, it was found that the districts that were severely affected by the drought in comparison to other districts were Golaghat, Nagaon, and Kamrup Rural in the years of 2011-12, 2014-15 and 2016-17 as it showed a decline in the values in all the factors that may lead to drought condition in comparison to the normal years. This was further verified with the backscatter values from Sentinel 1 SAR data for the drought year 2017 with the non-drought year 2016 and it was found that the Rabi crop area in drought year has less backscatter values than the normal year. And also drought area mapping and estimation over Nagaon district for the year 2016-17 was done using the Sentinel 1 SAR data and the results indicate that nearly 24 per cent of the total Rabi crop area was affected by drought in that particular year. Agricultural drought assessment varies from district to district depending on the type of crops grown and other agronomic practices. Availability of better surface observation at the spatial and temporal scale will improve the accuracy of assessment on the impact of agricultural drought. The identification of drought vulnerability is an essential step in addressing mitigation-oriented drought management.

Keywords: Agricultural Drought, Remote Sensing, GIS, NDVI, Soil Moisture, Sentinel 1 SAR data

Crop Weather Advisories at Block Level for Climate Resilient Agriculture from DAMU (District Agromet Unit) by IMD and ICAR

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Our Indian agriculture is gambling with the monsoon. Nowadays the climate change and climate variability are also effecting in lowing the agriculture products, including its allied sectors also. To enhance the resilience of Indian agriculture (including crop, livestock and fisheries) to climatic variability and climate change with this problem, our IMD and ICAR introduced a project called District Agro-Met Units (DAMUs) operating at block level for providing crop weather advisories. By utilizing the meteorological parameters, they provide the crop-specific advisories to the farmers through different ways like print/ visual/Radio/ IT-based media, including short message service (SMS). This DAMU service is provided to every district of India at KVK level helps the farmer to get early weather actives and their advisories make an increase in production and decrease in weather risk to the crops.

Keywords: DAMU, Crop weather advisories, Climate resilient agriculture

Impact of strict lockdown due to COVID-19 pandemic on air pollution over major locations of Uttar Pradesh

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Lockdown during the COVID-19 pandemic has significantly changed air pollution worldwide. In India, the nation-wide lockdown came into effect from March 22, 2020 onwards, and continued until the end of May. During the lockdown, severe restrictions were imposed on industrial and transport sectors, which are the most prominent sources of anthropogenic emissions in the atmosphere. Most of these anthropogenic emission sources remained halted during partial lifting of lockdown until the end of July. Thus, resulting in a widespread reduction of atmospheric pollution and aerosol loading over the Indian subcontinent. The present communication presents a study of air quality in major cities of Uttar Pradesh during the lockdown period using observations from the Central Pollution Control Board

(CPCB) monitoring sites. We estimate the temporal and diurnal changes in air pollutants, including particulate matter and gaseous pollutants during the period, and correlate it with the same period from 2017 to 2019. Significant reduction in PM2.5 and NO_2 has been observed at Varanasi (56.62% and 42.03%), Kanpur (41.68% and 65.32%), Agra (34.60% and -11.29%), Lucknow (55.01% and 27.52%) and Noida (77.14% and 71.96%) respectively. SO_2 showed mixed behaviour, with a slight increase at some sites but a comparatively significant decrease at other locations. It is observed that Ozone rather than other trace gases were dominant over the study regions during the lockdown period. Diurnal variation of $PM_{2.5}$ and NO_2 showed there was absolute decrease during peak morning traffic hours (08:00 to 10:00) and late evening (20:00 to 24:00), but the percentage of reduction is almost constant throughout the day. During total lockdown period, the air quality improves significantly, which provides useful information to establish a scientific air pollution control strategy for the future.

Impact of both Harsh Environment and Climatic Changes on the Agriculture of Sundarbans

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Sundarbans has a rich natural resource base and a rich history of local people and new migrants by immigration, especially in the Post-Independence Era, pushing into a harsh environment to access land and other natural resources. Thus man-resource-animal conflicts, lack of supplementary or alternative livelihood patterns and income generation, lack of knowledge as well as inadequate infrastructure to use these natural resources properly for obtaining maximum economic benefits from them are the main reasons for the poverty of the inhabitants of Sundarbans. About 90% of the populations are solely dependent on traditional agriculture for their livelihood. A widespread agricultural technique in Sundarbans is mono-cropping (i.e. *Aman Paddy* cultivation) which fully depends on monsoonal rains. This method of mono-crop growing has implications on soil quality where continually planting the same crop, year on year can leach the nutrients from the soil. Furthermore, economic security also becomes an issue because families would have no alternate source of income with regards to farming. Due to the intrusion of saline tidal water into rivers, the surface water irrigation from rivers through river lifting is absent in Sundarbans. In the event of non-availability of electricity in most of the villages, longtime irrigation by expensive irrigation pump set by poor farmers is not possible there. Hence, growers prefer to dig wells and construct shallow tube wells (STW) near agricultural fields. So, intensive groundwater irrigation plays rapid depletion, salinization and pollution related problems which threaten the region with sustainable groundwater balance. Historical data on adverse climatic condition in Sundarbans indicates that almost every year the rainfall is associated with cyclonic storms. During cyclonic storms, saline water gushes in; breaching the river dykes and inundates houses and lands. Under these types of conditions, large areas render uncultivable and become unsuitable for cultivation. Moreover, during rainy season water logging in agricultural fields become a great problem which affects the farming operation as well as the crops. Due to climatic change, the Sundarbans faces numerous challenges with rising sea levels, islands are disappearing and the increasing salinity in water and soil has severely threatened the health of mangrove forests and the quality of soil and crops. These constraints present limitations to agrarian practices and food production. Now, it is crystal clear that as the whole agriculture in Sundarbans mainly depends on mono-crop cultivation, the monsoonal variability and climatic changes both together make the poor people of Sundarbans more vulnerable. This paper aims to show how already existing unfavourable environmental conditions along with climatic changes, create a negative impact on the main occupation; i.e. agriculture of the local residents of Sundarbans. The original records from local Block Development Office and secondary data collected through censuses, several books, journals, articles, web pages; blogs etc. qualitative methodologies or qualitative researches are used to prepare this paper. This paper recommends to enhance the economic development of the poor inhabitants of the Sundarbans by exploring the feasibility of alternative or diversified livelihoods other than agriculture and allied activities. In this regard, the Blue Economy may be a feasible alternative livelihood option.

Keywords: Harsh environment, agriculture, climatic variability, climatic change, alternative or diversified livelihoods

Assessment of Weather Parameter Current and Future Agricultural Scenario

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The clear evidence of climate change impact is the great task to scientists, agronomist and meteorologist with regard to precision forecast, food safety and ever growing agriculture especially in the tropical region. The crop simulation model suggests probable growth, development and crop yield for soil-plant-atmosphere dynamics assessment cause by climate variability and climate change. Decision Support System for Agro-Technology Transfer Model (DSSAT) is application based model gives the best suited recommendations to achieve sustainability in the agriculture with the help of simulation by inputting experimental crop & weather data.

Validation and calibration of crop simulation model provides ompact of temperature, radiation & CO_2, on phonological stages, growth of plant, dry matter partitioning to different plant organ in all seasons. Based on these results formulation of:

a) A multi-pronged plan of using wider adoption of existing technologies, concerted R&D efforts for evolving new technologies required for adaptation and mitigation in rainfed and irrigated areas. To initiate new cost effective policies for global cooperation.

b) More precise weather based agromet advisories on spatial/temporal basis will minimize losses and increase economy of farmers & country. Optimize inputs like Land preparation, selection of crop/cultivars, Date of sowing, Date of harvesting, Irrigation scheduling, Pesticides & Fertilizer application, crop growth, extreme weather events, Adaptation & Development of flexible and dynamic Farm Management Information System (FMIS) strategies as well as other value added services etc. can be easily accessible for farming community.

The proposed study can also be extended in future to estimate soil moisture, ocean salinity (SMOS), evapo-transpiration, insolation, vegetation index, growing degree days, standard precipitation index, land surface temperature etc. The statistical study will be involved probability distribution, root means square which will be applicable for hydro-meteorological, agricultural applications over arid/semi-arid zones and forecasting systems.

Keywords: Decision Support System for Agro-Technology Transfer Model (DSSAT), crop simulation modeling, Climate change, adaptation, mitigation, sustainability, agromet advisories

Changes observed in the seasonal rainfall and temperature over a tropical station, Punalur, Kerala

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Punalur is a city in Kottayam district of Kerala, located in the western side of Western Ghats near the Aryankavu pass (Aryankavu Gap). Due to its geographic location, Punalur experiences severe hot weather due to the dry, hot winds from Tamil Nadu region flow towards the city through the Aryankavu gap during the summer season. Same time this place receives a good amount of rainfall during both the south-west monsoon(137.45cm) and north-east monsoon (63.94cm). This study attempted to see the changes observed in the monthly and seasonal rainfall and temperature patterns observed over Punalur over the last 63 years (1957-2019). There is not much variation observed in the annual rainfall amount over Punalur, however there is a significant (90% and 95%) decrease observed in the south-west monsoon (JJAS) rainfall for the entire period (1957-2019) also for the last thirty years (1989-2019). In pre-monsoon (MAM) rainfall an insignificant decreasing trend observed and in post-monsoon (OND) rainfall an insignificant positive trend observed for the last 30 years period. It is also observed that a significant (90%) decrease in the number of rainy days (rainfall>2.5mm) JJAS rainfall in the entire period (1957-2019) and an insignificant decreasing trend in last thirty years (1989-2019). The annual number of rainy days was observed a significant (99%) decreasing in the last thirty years. Maximum temperature over Punalur is observed to be increasing significantly (90 to 95%) for all the seasons except for summer (MAM), which showed an insignificant decreasing trend. In minimum temperature, all seasons except winter (JF) showed an increasing trend in which post-monsoon(OND) minimum temperatures are observed to be very much significant (99%).

Keywords: Trends, Rainy days, Maximum Temperature, Minimum Temperature

Indo-Pacific's large-scale circulation changes and its association with extreme flood over Kerala in 2018

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In the present study, we have investigated characteristics of recent extreme flood in Kerala during August 2018. The changes in large-scale circulations over the Indo-Pacific region and their association with regional circulation resulting in extreme rainfall in Kerala are analyzed in the

present study. The west Pacific subtropical high (WPSH) is one of the large-scale circulations over the Indo-Pacific region. The geopotential height, sea level pressure and surface winds from NCEP-NCAR reanalysis (2.5x2.5-degree resolution) data sets are used to study the abnormal changes of WPSH during 2018 summer monsoon period. Further analysis of high-resolution daily rainfall data set, available from Indian Meteorological Departments (IMD), reveals that variability of WPSH during this period modulates the regional rainfall over south India. The extreme rainfall event (8-19 August 2018) over Kerala, the particularly southern part of Kerala experienced excesses rainfall of about 80-100 mm/day. The northward shift and intensification of WPSH during the extreme event tends to form a cyclonic circulation over north-west Pacific. In addition to this, there is a blocking high over East Asia. The outflow from blocking high along with northward transport from the equatorial Indian Ocean tend to induce organised convection and subsequently leads to extreme rainfall over Kerala region. The patterns of regional features such as outgoing longwave radiation, updraft and sea surface temperature over the west equatorial Indian Ocean during August 2018 are favourable for the organisation of convective clouds and moisture transport towards the southern parts of India.

Impact of climate on phenological changes in paddy over Koppala, Karnataka for the period 2002-2020 using remotely sensed multispectral Imagery

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Paddy is grown in a flooded field using water from streams, rainfall or the land should be irrigated. The subsoil is impermeable holding up to four to six inches of water through 75% of the growing period. Climate change in India is getting noticeable, and the changes are much more evident in India. Due to which, the extreme factors like drought, floods, heavy rains, high and low temperatures, salinity and frost damages are causing serious threats to rice productions and also are unfavorable for the farmers earning a livelihood from rice cultivation. Hence understanding the impact of climate on phenological changes is necessary to develop mitigation strategies. Time-series data of remotely sensed Moderate Resolution Imaging Spectroradiometer (MODIS) - Normalized Difference Vegetation Index (NDVI) of 250-meter resolution of the 8-day window period for the years 2002 to 2020is used. Numerous algorithms have been developed to understand the phenological changes in various crops using time-series of remotely sensed vegetation indices. In this study, we use the Savitzky-Golay filtering technique in smoothing data to reduce the noise and suppress the disturbances in order to estimate phenological parameters. The seasonality parameters are used to understand the phenological changes are (a) sos – start of the season, which is also known as a green-up date, (b) eos – end of season, the day when the crop is harvested, (c) los – length of the season, also known as green-season length. Typically, the time between sos and eos. To understand the role of climate, we perform PCA and EOF analysis to quantify the relative variability. The results show that rainfall and temperature play a vital role in modulating phenological cycle.

Keywords: Crop phenology, Paddy, Remote sensing, Rainfall, Temperature

THEME 11

Hydro-meteorological Disasters and Management

Hydrometeorological disasters and management

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The rainfall record of the year 2020 indicates that East and North East India (E & NE India) received normal rainfall, Central India and South Peninsula received more than sufficient rainfall while North West (NW) India got less rainfall than its normal but as a whole country received more than normal monsoon rainfall with 109% of its Long Period Average (LPA) and moreover, since 1990, the all India seasonal rainfall in 2020 was the third highest, after 1994 and 2019 as per IMD record.

Hydrometeorological aspects of data in terms of Flood in India shows that other than Flood prone states like Bihar, UP, North Eastern states, new flood areas like Chattisgarh, Maharashtra, Odisha, Andhra Pradesh, some hilly regions of Tamilnadu, Madhya Pradesh, Kerala, Karnataka are evolving in recent years which got flooded severely in 2020 and most of the rivers were above danger level (DL) or above HIGHEST Flood level (HFL). In flood prone Bihar the rivers were more than 2 to 3 months above danger level and subsequently flooding affected the state severely due to rainfall. New episodes of flooding are resulting in some drought prone areas of Rajasthan, Telangana, North Interior Karnataka and Marathwada in Maharashtra in season 2020 too which became usual now since last few years. Operation of the reservoir during flood also plays vital importance role for dealing with Hydrometeorological aspects. Important events have been discussed to elaborate the Flooding pattern in some of these states for highlighting the Hydrometeorological features and their analysis. The most important conclusion is that flooding pattern is now shifting to the driest part of the country due to changing rainfall pattern and since management of Hydrometeorological disasters is challenging task, a composite effort provides an opportunity to deal with the situation.

Keywords: LPA, Danger Level (DL), Highest Flood level (HFL) Flood Prone States, New Flood areas

Understanding the development and progress of extremely severe cyclonic storm 'Fani' over the Bay of Bengal

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The Bay of Bengal (BoB) experiences the occurrence of tropical cyclones (TCs) almost throughout the year. However, the extremely severe cyclonic storm (ESCS) Fani formed in April 2019 has shown uniqueness in terms of its location of origin, the direction of track and landfall location. Therefore, in this study, an attempt has been made to examine the development and progress of ESCS Fani over the BoB. The analyses have shown that a low pressure area has formed near the equator (approximately 2.7°N latitude) over the southern BoB on 25th April, 2019 and strengthened into a depression on 26th April at the same location. This depression has further strengthened into cyclonic, severe cyclonic, very severe cyclonic and extremely severe cyclonic storm and moved northwestward. Then, it has recurved and

moved northeastward and make landfall over Orissa coast. The analyses of large-scale dynamic and thermodynamic conditions have shown a favourable environment for the development of cyclone over the southern BoB. The consistent strong convective activity, high SST (approximately 30ºC), more relative humidity, strong vertical motion, low level cyclonic vorticity and less vertical wind shear have supported for further intensification of cyclonic system. The cyclone Fani has followed the recurving track which has been chiefly steered by an upper tropospheric level anticyclonic circulation.

Effect of anti-hail net on apple plants of wet temperate zone in Himachal Pradesh

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The investigation on the effect of anti-hail net installation on apple plants of the wet temperate zone in Himachal Pradesh was conducted and observed that Theog was most adversely hit by the hail in 2019. The study revealed that the microclimate was majorly affected by the installation of anti-hail nets. Mean temperature, light penetration and mean soil temperature under the net was found to be lower. On the other hand, the mean relative humidity under the net was higher. No effect was observed on soil pH, EC, organic carbon content and soil N, P, K. The study revealed that the hail nets do alter the microclimate, but they are economically convenient and essential for protection against hail and other naturally occurring events.

Satellite applications in the management of hydrometeorological disasters

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The Indian subcontinent is highly prone to hydrometeorological disasters. Floods, droughts, heatwaves, cyclones, hailstorms, avalanches and landslides are the most frequent phenomena in India. These disasters have a significant impact on national development. A paradigm shift has happened in disaster management by moving towards an effective forecasting and warning system and preparedness to take up effective rescue measures to reduce the loss of life and property. Preparedness and planning for disaster management taken up along with environmental concerns can only lead to the sustainable development of the country. Satellite-based applications have emerged as a vital tool for disaster management. Two areas of applications are planning and mitigation. The data multispectral and multi-temporal data from satellite platform is used for monitoring, modelling and prediction and the other as decision-making for rescue and relief operations.

Based on the inherent characteristics of satellite data viz., spatial continuity, uniform accuracy,

multi-temporal coverage and access to remote and inaccessible areas, the satellite data helps to (i) provide early warning to the affected population, (ii) quickly assess the severity and impact of damage due to cyclones, flooding, drought, landslides, flooding; (ii) planning evacuation from coastal areas during cyclone season;(iv) monitoring reconstruction or rehabilitation after a major disaster; (v) developing, maintaining or updating digital databases and maps for use in disaster management and (vi) preparing hazard assessment maps for multi disaster-prone areas.

The satellites can provide all-weather, day and night coverage of areas. The satellites being operated by ISRO such as IRS, RISAT, INSAT are capable of providing digital data in spectral regions covering visible, thermal and microwave regions. Further, a host of foreign satellites such as NOAA, RADARSAT, MODIS also provide multispectral coverage ensuring continuous monitoring of hydrometeorological disasters. Several techniques have been operationalized for monitoring and forecasting of disasters. The Dvorak technique for cyclones, the Vegetation Index method for drought, mapping of flooded areas, GIS-based landslide zonation, radar detections of hailstorms, thermal mapping of heatwave conditions is some of the examples. The paper highlights these applications with specific case studies to bring out the potentials of remote sensing data besides reviewing the future developments in this field.

Tropical cyclone risk analysis for India using Hotspot Analysis

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Tropical Cyclones (TCs) are one of the most destructive weather systems that occur every year in the tropical oceans causing severe damage to people, agriculture and infrastructure. Having sufficient information beforehand about the potential risk/threat due to TCs can save both lives and livelihood. Therefore, a risk index (district wise) is prepared using long time datasets of tropical storms occurred in both the Bay of Bengal and the Arabian Sea. Several key parameters such as the maximum sustainable wind speed, maximum daily rainfall and probable maximum storm surge height are considered for this analysis. The index also considers important social-economic components like the population density, household density etc. at the district level. For sufficient coverage, a buffering distance of 50 nautical miles is considered for each district in evaluating the above factors. The values are normalized and weightage was given to each factor and finally, Hotspot analysis is applied to prepare the risk index. Application of risk index is primarily helpful in disaster management. It is also helpful in the construction sector [to adopt practices that make buildings that withstand the intense TCs] and agriculture sector [for better crop management particularly in crop selection as well as modifying existing practices to prevent damage due to TCs]. It is handy to the government agencies in long time preparation and planning as well as to the general public of India.

Forecasting for i-FLOWS Mumbai using NCMRWF Unified Model

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Extreme weather events are on the rise in recent years all over the world and a large part of it is due to

climate change. Extremely Heavy Rains (EHR;>21cm/day) over India often cause localized flooding. The impact of such events is all the more grim when India's megacities experience EHR. Integrated Flood Warning System (IFLOWS) is a monitoring and flood warning system that will be able to relay alerts of possible flood-prone areas anywhere between six to 72 hours in advance. A joint initiative between the Ministry of Earth Sciences (MoES) and Brihanmumbai Municipal Corporation (BMC), the system can provide all information regarding possible flood-prone areas, likely height the floodwater could attain location-wise problem areas across all 24 wards and calculate the vulnerability and risk of elements exposed to flood.

NCMRWF's Unified Model forecasts are used in real-time for rainfall forecasts over the city of Mumbai. The state of the art modelling system has a global model (NCUM-G) of 12km grid spacing, a regional model (NCUM-R) of 4km grid spacing which is used for providing the crucial rainfall forecasts over Mumbai. Additionally, very high resolution (1.5km and 330m grid) experimental models are also being tested and evaluated for predicting the EHR over Mumbai. The rainfall forecasts are evaluated in real-time based on the high density network of observations over Mumbai. The paper summarizes the critical evaluation of the rainfall forecasts over Mumbai during JJAS 2020.

A Hydrometeorological Analysis of a flash flood over the megacity of Bangalore: Assessing the forecast skill of the model and the impact of urbanization on flash flood

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Limited understanding of the impact of urbanization on hydrometeorological disasters portends poor forecast skill of meteor-hydrological models in predicting flash flood, both in terms of lead time and intensity. The present study is aimed at assessing the forecast skill of the coupled WRF-Hydro model (1-way and 2-way coupling) in predicting the flash flood over the megacity of Bangalore for two different land-use scenarios; less urbanization (1992 USGS data) and more urbanization (2017, ISRO data). The flash flood was triggered by the intense short-duration rainfall due to the passage of westward propagating low-pressure system during the morning of 15 August 2017 in various parts of the city which caused extensive flooding and damage. The first set of simulations have been carried out with stand-alone WRF-Hydro using different precipitation as forcing datasets; Global Precipitation Measurement (GPM-hydro) and WRF-precipitation datasets with different urbanization scenarios (One-way coupled). The simulations are then carried out using a coupled WRF/WRF-hydro model to evaluate its skill against the stand-alone model. The simulated variables (rainfall, runoff, depth of inundated water, peak stream discharge) are evaluated and compared with observation to assess the forecast skill of the model and the impact of urbanization on flashflood. The resulting simulations from the selected configurations of the coupled meteo-hydrological model demonstrate potential skill in generating the forecast of heavy-rain induced flash floods.

Climatological interlink study of rapid urbanization and extreme rainfall events over megacities in India

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In India from past two decades, the rate of migration of people, industrialization, and rise of population in metro cities are burgeoning, which has led to the exponential growth of urbanization and sprawling, stressing over the utilities of the natural ecosystem. Hydrometeorological disasters, particularly the extreme rainfall events (EREs) associated with flash floods, frequency, intensity and duration has increased unprecedentedly. As a result, a megacity of India has faced artificial waterlogging, traffic congestion, inundation of low lying areas, which leads to massive destruction of life and property, and in the long run, makes adverse socio-economic impacts over the country. The objective of this study is to find out the role of rapid urbanization in modulating the frequency and intensity of EREs over megacity of India. Moreover, factors affecting changes in short duration EREs over the urban environment are even less known because of complex dynamics of destabilization caused by urban heat Island, induced thermal perturbation. An approach combining modelling, computing and data analysis is an essential tool for developing advanced prediction system as well as finding the climatological link of urbanization with EREs. Mesoscale models are considered as one of the most widely used tools in the simulation and advance prediction of EREs. The prediction of EREs and its mechanism of evolution in an urban city is generally difficult using numerical models because of the challenges in capturing the effect of urban heating and local convection arising due to large spatial inhomogeneity. A climatological study of urbanization with long-term high resolution observed data and mesoscale simulation of various EREs can find out the possible link of various thermodynamic parameters role in inducing and enhancing the frequency and intensity of EREs is a major scientific challenge. The present study is aimed at improving the simulation of urban extreme events and to understand its linkages with rapid urbanization for Indian megacities.

Impact of LULC in simulating river discharge and evapotranspiration Upper Jhelum river basin using SWAT

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Land use and land cover (LULC) change are one of the key driving elements responsible for altering the surface hydrology of a watershed and it is a dynamic process that is driven by human-induced activity. In this study, we used The Soil and Water Assessment Tool (SWAT), a GIS hydrologic modelling program using watershed data (LULC, soil weather, elevation), a calibrated and validated model was produced and run for the study period of 1979-2018 to analyse the impacts on river water discharge at multiple gauge stations and evapotranspiration (ET). We also examine the different role resolution from ALOS PALSAR (12.5m), CARTOSAT (32m) and SRTM (30m)along with multiple LULC maps for

India at decadal intervals for 1985, 1995 and 2005 were examined. The impact LULC and spatial resolution of DEM on both discharge and water-balance components were analysed. The model calibrating and validating with available discharge data and then simulated with different decadal land use. The results indicated that the sensitivity of runoff parameters, watershed surface area, and elevations changed under different DEM resolutions. As the distribution of slopes changed using different DEMs, surface parameters were most affected. Furthermore, large amounts of runoff were generated when DEMs with finer resolutions were implemented. From the study, we found that the ALOS PALSAR 12.5 m DEM showed more realistic results than with the DEMs of CARTOSAT (32m) and SRTM (30m). In addition, more recent LULC improves accuracy further.

Estimation of Surface Runoff and Flood Topology in Thaukyegat Watershed, Bago Region, Myanmar

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An attempt has been made to explore the flood area and predict the flash flood area, to conduct the effects of flood and to provide the baseline data to mitigate for the flood period in the lower part of Thaukyegat Watershed in Bago Region, Myanmar. Surface runoff for the Thaukyegat Watershed can be calculated by using the SCS TR-55 Model equation. For the simulation of flood area, Landsat 7 ETM (Enhance of Thematic Mapper) for preparing digital elevation model (DEM) and peak water levels are used with the help of Remote Sensing (RS) and Geographic Information Systems (GIS). Total surface runoff volume is 6354265321.64 m^3 for 1990, and 6462730567.98 m^3 for 2017 respectively. A long-term average increase of 108465246.34 m^3 which is 4017231.34 m^3/year water runoff volumes occurs when the watershed is converted from pre-development with Closed Forest conditions to a low-density residential area with agriculture conditions. Typology of flooding can be divided into two categories in this watershed such as flash flood and combined flood. Possible causes of floods over these areas are (1) inundated periods are coincided with flood periods of Sittoung River, (2) relatively low and flat surface level of the area than others, (3) the elongated shape of the basin, (4) the nature of relief, and (5) the seasonal fluctuation of water level of Thaukyegat Creek. These studies are very useful for planning of flood mitigation and watershed management.

Keywords: Thaukyegat Watershed, SCS TR-55 Model, flood topology, surface runoff volume, land cover changes

Assessment of some severe cyclones of Odisha coast and study of relationship of cyclone with global warming

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Odisha has 485 kilometres (301 mi) of coastline along the Bay of Bengal on its east, from Balasore to Ganjam. It is the 9th largest state by area and the 11th largest by population. When we made a study on cyclone among the states from 1891-2017, it was found that most of the time, Odisha is attacked by the cyclone and huge loss of lives and property occurs. In the 19th century, due to lack of forecasting technology, severe loss of lives and property occurred as we take an example of Odisha super cyclone (1999), in which 9885 people died. But now in any cyclone, the causality rate has been decreased as we take the example of cyclone Phailin and Fani the causality rate was 44 and 38(only in Odisha) respectively. Now the forecasting accuracy rate(landfall forecast, track forecast, intensity forecast) of IMD has also increased when we compare from 2003 to 2017.

Nowadays, the severity of cyclone has been increased, It is mainly due to the effect of global warming. An aspect of climate change shown by temperature measurements and by multiple effects of the warming. Continuous increase in average air and ocean temperatures since 1900 caused mainly by emissions of greenhouse gases (GHGs) is the effect of global warming. Keeping view on that when we make a study on air temperature (1901-2017), sea surface temperature and height (1891-2018), greenhouse gases like CH_4, N_2O, CO_2 etc. (1970-2012), it is found that all factors are in increasing trends. These are also one of the parameters which help in the formation of a cyclone or can make cyclonic storm to severe cyclonic storms. On the other hand, when we study about the cyclonic storms and severe cyclonic storms from 1891-2017 in Bay of Bengal and Arabian sea region using IMD data, we found that compared to 1891-1932 and 1933-1975, the number of severe cyclonic storms more in 1976-2017 duration. By taking IMD data when we made another study on the probability of converting cyclonic storms to severe cyclonic storms, the period of 1976-2017 was showing highest value compared to 1891-1932 and 1933-1975. As a result, we conclude that if we will not take any action regarding global warming, the future scenario is furious.

Keywords: cyclones, Global warming, forecasting accuracy, increasing trends of cyclones severity

Vulnerable indicators and their impacts on forests a case study of northwestern Himalaya, India

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The forests of Himachal Pradesh are the storehouses of rich flora, which form the outstanding vegetation cover. This essential life supporting system is under great stress due to increasing anthropogenic pressure, modern civilization, growth in population and variety of hazards. Deforestation causes ecological degradation at a rapid pace in some important patches of the Indian Himalayan Region. The Himalayan region, with its young folded and unstable topography, is one of the most fragile ecosystems on the earth. The present case study is taken from Kinnaur district of the northwestern Himalaya. It is an area known for its very important forest cover for the species like *Pinus gerardiana* (Chilgoza). The total geographical area of Kinnaur is 6401 km^2, out of which forests constitute 9.8% (630.54 km^2) of the total area. However, the rest of the area falls under the non-forest category. The Kinnaur region has a long history of physical hazards like landslides, floods, avalanches, earthquakes, etc. Total 49.64 km^2 area got affected and has become vulnerable due to landslides and soil erosion among forest and non-forest land use land cover classes. The most disastrous floods were experienced in 1993, 1995, 1997, 2000, 2005, 2007 and 2013. Climatic variability was also found high in the study area. In the past, this region has a total forest dependent economy which influences alternative livelihood options of the local communities. However, this region after the 1990s has noticed the developmental phase of hydropower projects which showed both the negative as well as positive impacts.

Keywords: Forests, hazards, ecological degradation, Kinnaur, Indian Himalayan Region

Forest Management from Wildfires through Evapotranspiration Mapping in Western Himalayas

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Forest management for fuel treatments and other fuel buildups in the forests is regarded as a necessary step to check the forest fire incidences & forest mortality rate and restoration of forest health more sustainably. The aim of the research reported is to assess the response of mountain forests with annual water deficit through evapotranspiration across the region. Its' seasonal and annual magnitudes during dry periods and what future vulnerabilities do the spatial patterns reveal. The results revealed that Wildfires in the 2007-2018 period resulted in significant forest area burned. The evapotranspiration was accessed for this period using both ground based observations and spatiotemporal mapping. Non-parametric statistical indices were applied coupled with advance GIS based land cover classes to delineate the monotonic trend of gridded and observed data. Evapotranspiration was assessed using Thornthwaite model (1955) and FAO-56 for four different locations in high fire prone areas of Himachal Pradesh. The results revealed that the time series trend resulted in a reduction in evapotranspiration by as much as 3.154 mm year-1 and 2.258 mm season-1 Thus, the rates of recovery confirm the need for follow-up the forest fuel management at an interval of 5 years to sustain the lower evapotranspiration as per the inter-annual climate and landscape vegetation. However, the drought periods will push some lower elevation forests towards thresholds associated with widespread forest fires in the western Himalayas.

Keywords: Evapotranspiration, wildfire, M-K trend, GIS mapping and Western-Himalayas

Estimation of Maximum Daily rainfall for different Return periods over Kerala using Generalised Extreme Value (GEV) Analysis

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The State of Kerala has witnessed episodes of extreme rainfall in years of 2018 and 2019, which caused significant damage to life and property. The present study is focused on the estimation of rainfall amounts for different return periods over Kerala using the IMD gridded rainfall data of 117 years (1901-2017). Estimation of Maximum Probable Rainfall for different return periods is of greater importance for the proper planning and Disaster management in a particular region. Extreme Value Analysis (EVA) is just one statistical technique that enables us to predict the likelihood of extreme values appearing in ant data set, for example, an exceptionally cold spell or extremely heavy rainfall event in place. In practical terms, it helps us to characterize the risk of any given natural hazard, and ultimately make sure that infrastructures are built to withstand their impact. The Generalised extreme value analysis is carried out using daily gridded rainfall over Kerala. The parameters are estimated using the maximum likelihood estimation method. The location specific rainfall maps were prepared for different return periods from 1,2,10, 25, 50 and 100 years. The return levels are estimated for the extreme rainfall of 2018, which is in agreement with earlier studies. The study further demonstrates how these results can be used alongside the NCMRWF Unified Model (NCUM) real time forecasts for early warning of extreme rainfall events.

Keywords: Extreme Value Analysis, Maximum Likelihood estimation, Return periods, Extreme Rainfall

River Flood Inundation Area and Monitoring Maps in the Bago River Basin, Myanmar

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Bago River is originated from the Bago Yoma or Central Mountain in Myanmar. It is located between latitudes 16°43′15″N and 18°26′17″N and longitudes 95°53′30″E and 96°43′30″E in the southern part of Myanmar. The Bago River Basin is a flood prone area in Myanmar. The Bago River Basin has a catchment area of 5348 km^2. Bago River is flood in heavy rainfall in the rainy season. Lower Bago River Basin has populated areas as Bago City. The total population was increased 101893 persons in 2014 and 4,867,373 persons in 2019. Not only the built-up area was increased in the lower river basin but also the upper river basin was decreased by vegetation cover. These reasons, flooding is essentially an annual problem. Bago River Watershed and Stream Order from a Digital Elevation Model (DEM) by using QGIS. Normalized Difference of Vegetation Index (NDVI) and River flood inundation areas were calculated by Landsat 5, Landsat 8 and Sentinel 2 satellite images in 2010, 2015 and 2019. Open data and DEM with high-

resolution data were subsequently used to make inundation maps and flood risking mapping. It is an interpolation of a new DEM from download contours and "blue lines" captured from conventional topographic maps. Estimate the flood monitoring maps were increased by water level from 1 meter to 5 meters by using water body in STRM and open street map.

Keywords: Flood Inundation Area, Digital Elevation Model (DEM), Normalized Difference of Vegetation Index (NDVI), Landsat7, Landsat, Sentinel 2 and flood monitoring maps

THEME 12

Artificial Intelligence, Machine Learning, & Deep Learning in Weather & Climate Research and Services

Integration of Machine Learning Technique in Short-Term Precipitation Forecast using Radar Data

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The short-term precipitation forecasting using radar data is a crucial part of meteorology which can be used for many purposes, such as monitoring natural disasters; identify the pattern of crops for agriculture fields etc. The main aim of short-term precipitation forecasting using radar data is to forecast the depth of rainfall for a local sector over a short period. Here, we define precipitation as a forecasting problem in spatiotemporal sequence, i.e., the input data for the model and prediction goal is in a spatiotemporal arrangement. With many scientific tools, models are built for experimental observation of precipitation forecasting using radar data, LSTM with convolutional layers was found one of the promising ways. As the experiments show that Long Short Term Memory (LSTM) with Convolutional layers is better for capturing spatiotemporal correlations for precipitation forecasting for a short period. Convolutional structures are needed for the transitions, for this purpose, Convolutional layers are used with LSTM. By using Convolutional layers with LSTM, it is possible to construct a proper trainable model for the precipitation forecasting problem for a short period. This paper implements a method to predict precipitation over a short period at a destination- place in the future established on historical radar data. The main purpose of this project is to build a prediction model for rainfall solely using radar data.

Keywords: Short-term precipitation forecasting, Radar data, Rainfall depth, Spatiotemporal, Convolutional, LSTM

Forecasting of time series of geophysical parameters using GPR and LSTM models

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In the last few decades, the frequency of abnormal weather such as heavy rain, the number of depressions, and cyclones has increased and it can have serious implications in the rocket launch activities over Sriharikota (SHAR), India's primary spaceport. Geophysical variables, such as wind speed and direction, relative humidity (RH), temperature, and rainfall play a key role during the launch operations. Therefore, accurate prediction of these parameters is of paramount importance.

In this project, we have used historical time-series (1900-2016) data of rainfall and 16 years (1994-2009) data temperature, pressure wind speed and direction to predict the weather at SHAR using Artificial Intelligence (AI)/ Machine Learning (Ml) models. After necessary quality checks, we have explored univariate (Gaussian Process Regression-GPR) and multivariate models (GRU, LSTM, simple RNN) for the feasibility of the weather prediction. The GPR model is able to predict the time-series of geophysical variables for normal weather conditions but fails in providing reliable predictions during the disturbed periods such as tropical cyclones. Subsequently, we propose multivariate Long-Short Term Memory (LSTM) base model - a kind of recurrent neural network to predict the weather parameters for SHAR region. For this purpose, we have used a sliding window approach to transform the problem of time-series forecasting into a supervised learning problem, which enables the prediction in a more efficient way. The proposed LSTM base model is able to predict the weather parameters at four time-steps 12, 24, 36 and 48 hr, respectively. The performance of the proposed model is assessed by estimation of root-mean-square error (RMSE). Results obtained from the present study indicate that the LSTM model's performance is good for the prediction of temperature, pressure, RH and wind speed; however, the rainfall occurrence is not reproduced in an effective manner. Efforts are on to improve and fine-tune the proposed model to predict the rainfall in an appreciable way.

Keywords: Artificial Intelligence, GPR, LSTM, RNN, geophysical parameters

Tropical Cyclone Category using adaptive Neuro-computing over North Indian Ocean

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Prediction of cyclogenesis, track and landfall of Tropical Cyclone (TC) is the most important issue nowadays. The present study has tried to forecast the category of the cyclonic system in well advance using Artificial Neural network. For that study has considered two parameters: central pressure drop (PD) and maximum sustained wind speed (MSWS). To prepare the input matrix for ANN factor analysis has been implemented on a number of predictors. The present study has considered 57 cyclonic systems over the Bay of Bengal and 33 cyclonic systems over the Arabian Sea during pre-monsoon and post-monsoon season from IMD best track data. That cyclonic system includes systems from Deep depression (DD) to Extreme Severe cyclonic system (ESCS). To make a target, study has divided each cyclonic system into two parts: pre-mature stage and mature stage. The mature stage of the cyclonic system has been identified when a particular system attained its peak wind speed and this has been set as "0" hour of this system. Several synoptic parameters have been considered and then principal component analysis at "0" hour has been implemented to get significant parameters. Using those parameters, Artificial neural network has been implemented to predict central pressure drop and wind speed separately. Minimum Prediction error (RMSE) in MSWS is 4.62 knot for 60 hour lead time and in PD is 1.5 hPa for 6 hour lead time over BOB. Over the Arabian Sea, minimum prediction error in MSWS is about 8.45 knots and in PD is 2.2hPa. Study shows that over BOB the prediction is quite good.

Meteorological Drought Prediction by Genetic Programming Approach with Uncertainty Analysis using Copula

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The Drought prediction plays a substantial role in water resources planning of a region and determining drought mitigation plans. Predicting of droughts is a challenging task due to the complicated nature of climatic systems. The lack of rainfall results in meteorological drought. It further leads to agricultural drought and hydrologic drought. Large-scale atmospheric circulation patterns show a noticeable influence on Indian Summer Monsoon Rainfall. Hence, signals obtained from the large-scale atmospheric circulation patterns in the form of their indices are used for the development of drought prediction models in this work.

The signals of atmospheric circulation patterns viz. El Nino Southern Oscillation (ENSO), Equatorial Indian Ocean Oscillation (EQUINOO), Atlantic Multidecadal oscillations (AMO), Indian Ocean Dipole (IOD) and Multivariate ENSO Index (MEI) are used for prediction of meteorological drought over 'North West' and 'West Central'' Homogeneous Monsoon regions' of India. The analysis of the wet period and dry period is carried out by using 'SPI Index' (Mckee et al.1993). The SPI index is a statistical assessment of rainfall. It gives dry period and wet period along with intensity, duration, and frequency in various time scales as 3, 6, 9, 12 and 24 months. The droughts are classified suitably based on SPI Index.

AI tool 'Genetic Programming' (GP) is advantageously used to establish the complex nonlinear relationship between Standardized Precipitation Index (SPI-6) as drought index and aforesaid atmospheric indices along with monthly anomaly rainfall. Koza (1992) defines GP as a domain-independent problem-solving approach, in which computer programs are evolved to solve problems based on the Darwinian principles of reproduction and 'survival of the fittest'. Genetic Programming generates millions of programmes by combining input data and algebraic operators.

The work shows that GP derived SPI-6 drought index forecasting models, using monthly rainfall anomaly and large-scale climatic inputs are able to predict SPI-6 drought indices. Out of 14 models of one month lead time prediction, the combinations of ENSO and EQUINOO gives good correlation coefficients 0.851 and 0.734 for training and testing respectively for West-Central India. The correlation coefficients are 0.797and 0.690 for training and testing respectively for North-West India.

The prediction uncertainty is assessed by the multivariate probability distribution tool 'Copula', with Markov Chain Monte Carlo (MCMC) posterior distribution simulation. Total of five copulas is used for uncertainty analysis. For the North-West region of India, 't' copula is found most suitable. The values of 'Copula parameter 1' and 'Copula parameter 2', for Markov Chain Monte Carlo (MCMC) simulation, are 0.7631 and 6.784 respectively. For 'Parameter 1', uncertainty ranges between 0.7592 to 0.7685 and for the 'Parameter 2', it ranges between4.876 to14.923. The goodness of fit is assessed using RMSE and NSE as 0.0987 and 0.996, respectively. For West Central region, Gaussian copula is found to be the best with MCMC parameter value 0.8256 and uncertainty range in between 0.8211 to 0.8304. The goodness of fit was assessed in the form of RMSE and NSE as 0.1338 and 0.993respectively, indicating the best fitted copula for predicting uncertainty.

Keywords: Standardized Precipitation Index (SPI), EL Nino-Southern Oscillation (ENSO), Equatorial Indian Ocean Oscillation (EQUINOO), Genetic Programming (GP), Markov Chain Monte Carlo simulation (MCMC)

A simple multilayer Convolution Neural Network (CNN) model for classification of clouds from INSAT cloud imageries

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Cloud classification is one of the fundamental applications of satellite cloud image processing. Real Time Analysis of Products and Information Dissemination (RAPID) website of IMD/ISRO provides images with 4-Dimensional analysis capabilities. In this paper, it is experimented with an image processing Deep Neural Network (DNN) model called Convolution Neural Network (CNN) to train on 6-channel INSAT cloud imagery data sets ['IR1','IR2','SWIR','MIR','VIS','WV'] to recognize cloud patterns as reported from manned IMD surface observatories and test it with unknown INSAT images. A standard set of 5 stages of processing is followed with every picture: a) Image downloading, b) Image geo-referencing, c) Creating a model, d) Learning the model parameters and e) Evaluating (a.k.a. testing/prediction) the model. Insat cloud imagery corresponding to 06 UTC was used both for training and testing of the model to ensure availability of both visible and swir channels and also synoptic observations reporting observed clouds types at the departmental observatories of IMD. Input data is formatted in the form of text files. Each line of these text files takes the form: |labels 0 0 0 0 |features 0 0 0 0 ... (9 x 9 x 6 integers each representing a pixel). Image pixels corresponding to the integer stream named "features "are used for training as well as testing of the model. Thus the number of features is equal to 486 (= 9 x 9 x 6 pixels), 1 per pixel. This simple model is configured to detect four cloud types (ground, low, medium and high) in the INSAT picture representing 4 labels in the input data. Microsoft Cognitive Toolkit (CNTK) framework in Python is used for data reading and to experiment with Convolution Neural Network model to predict the unknown class of the cloud from processed pictures of the INSAT cloud imagery. Three convolutional layers comprising 8, 32 and 128 filters respectively each having a weight and bias followed by a dropout layer (0.2) are used to prevent over-fitting. This adds up to 6 parameter tensors. Additionally, the dense layer has weight and bias tensors. Thus, the model trains with 8 parameter tensors. A total of 81244 parameters are trained in 8 parameter tensors. The learning rate was kept to below at 0.14. The softmax function is used to map the accumulated evidence or activations to a probability distribution over the classes. Cross-entropy is minimized between the label and predicted probability by the network. The trainer strives to reduce the loss function by different optimization approaches, Stochastic Gradient Descent (sgd) being one of the most popular. Typically, one would start with random initialization of the model parameters. The "sgd" optimizer would calculate the loss or error between the predicted label against the corresponding ground-truth label and using gradient-descent generate a new set of model parameters in a single iteration. It trains with 6 x 9 x 9 size pixels located over latitude and longitude of a surface observatory reporting synoptic cloud types and tests and evaluates unknown INSAT images with an average accuracy of more than 60 per cent, which is quite encouraging considering the limited number of convolution layers in the model architecture and limited computational power of a laptop/desktop. There are scopes for improvement of the model by (1) varying feature size (2) varying the label size (3) varying number of convolution layers and (4) varying the learning rate. With a large number of INSAT images and higher computational power, it is envisaged that CNN model can train and predict with good accuracy to classify clouds in all types of images including INSAT and Doppler Weather Radar (DWR) images.

Forecasting pressure drop and maximum sustained wind speed associated with cyclonic systems over Bay of Bengal with Neuro – Computing

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Tropical cyclones are possibly the most detrimental of all meteorological hazards and are the most frequent causes of natural disasters. The assessment of the highest central pressure drop and maximum sustained wind speed of the tropical cyclones is very important for estimating the strength of the cyclones. The present research proposed a neuro-computing based adaptive intelligent model to forecast the central pressure drop and maximum sustained wind speed associated with cyclonic systems at the stage of the highest intensity over the Bay of Bengal of North Indian Ocean. The cyclonic systems considered in this study include the phases from deep depression to extreme severe cyclone. The low level vorticity (LLV), mid-tropospheric relative humidity (MRH), vertical wind velocity at 850, 500 and 200 hPa pressure levels are obtained as the most suitable input parameters through factor analysis. The adaptive neural network models with different architectures are trained with the data from 1990 to 2015 to select the best forecast model over the Bay of Bengal. The result reveals that the multilayer perceptron (MLP) model provides considerably less error in forecasting the pressure drop and maximum sustained wind speed of cyclonic systems than radial basis function network or generalized regression neural network model. The multilayer perceptron (MLP) model provides good accuracy at 6 and 30 hour lead time in forecasting the pressure drop of tropical cyclones at their highest intensity. Though the minimum error is obtained at 6 h lead time in forecasting the pressure drop at the highest intensity stage of cyclonic systems. The result further shows that the MLP model is the best model for forecasting the maximum sustained wind speed with 91% accuracy at 60 hour lead time. The result is compared with the existing conventional models to evaluate the skill of the present model and subsequently, the results are validated with observations from 2016 to 2019.

Keywords: Cyclonic systems, artificial intelligence, forecast, pressure drop, wind speed

Use of Machine Learning in Drought Prediction in Indian Scenario

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Drought is a complex phenomenon characterized by slow onset. Careful monitoring of the symptoms of drought and early warning is key to the effective management of the calamity as it has many economic, social and environmental effects. Since the Indian economy is significantly based on Agriculture, it is very important to monitor and predict drought situation. Any early warning about drought will significantly improve the implementation of drought proofing and contingency plans. Ministry of Agriculture published Drought Manual during 2016, which describes the procedure for declaration of Drought in India. It has made the procedure of Drought Declaration objective based on various parameters. Currently, only drought monitoring and assessment is done in India. This

research work has attempted to explore the use of machine learning techniques to predict the drought at any given area which can be turned into an early warning system. There has been previous research also on Drought Prediction using Machine Learning and Artificial Neural Networks on other parts of the world. In this work, the authors have attempted to use Machine Learning tools for Drought forecasting in Indian Scenario.

Few areas of the country have been chosen for the development of models for Drought prediction based on the aridity of the region. The parameters affecting drought viz. Rainfall and Normalized Differential Vegetation Index (NDVI) has been used. The data for rainfall is obtained from IMD, whereas data for NDVI has been obtained from the centre (MNCFC) where the work has been carried out. The Drought information for the study areas has been collected from the portal www.farmer.gov.in.

Different Machine Learning techniques viz. Logistic Regression (LR), Random Forest (RF), KNN, Decision Tree, Gradient Booster, Support Vector Classifier (SVC), Multilayer Perceptron (MLP) based Neural network has been analyzed to predict the occurrence of Drought. It has been observed that RF, LR, SVC and MLP classifiers perform well while predicting drought. The future value of features viz. Rainfall and NDVI is predicted using Time Series Forecasting using the ARIMA model and then Drought occurrence is predicted using the forecasting values.

Keywords: Drought Prediction, Machine Learning, Support Vector Machine, Logistic Regression

Assessment of Ground-level Fine Particulate Matter (PM2.5) from Artificial Neural Networks Using Satellite Data

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Air pollution has adversely affected the environment and human health. Nowadays, the use of aerosol products derived from a wide range of satellites has improved ground based air quality monitoring. Although, satellite based products are measured by the entire aerosol column, not only near the surface, the present study aimed to integrated satellite based and ground station observations to derive$PM_{2.5}$ by using bi-variant (BV), multiple variant linear regression (MVLR) and artificial neural networks (ANN) methods. In this study, Moderate Resolution Imaging Spectroradiometer (MODIS), Indian National Satellite System (INSAT) and AERONET derived Aerosol Optical Depth (AOD) and meteorological parameters from the ground station at four different cities of India which is Jaipur, Delhi, Kanpur and Patna were during January 2017–December 2019. The MLR and ANN models were trained using the AOD, meteorological parameters and measured $PM_{2.5}$ dataset of the previous two years (2017-2018), and one year (2019) used for validation. The BV method uses AOD and $PM_{2.5}$, MVLR and ANN use AOD, NVDI, PBLH, AT, RH, WS, BP and $PM_{2.5}$ for training and validation. The INSAT-derived $PM_{2.5}$ shows the lowest correlation with ground measured $PM_{2.5}$ in ANN. High correlation values were obtained during the training of ANN models ($R \geq 0.7$ for each group). The value of Pearson R is found highest to lowest in ANN >MVLR> BV. The AERONET derived AOD_{625} give highest Pearson R (0.91) at Kanpur by ANN. The best validation of model also finds in Kanpur by ANN. The correlation value Pearson R of aqua (0.87), terra (0.84), means (0.83), INSAT (0.80) and AERONET (0.91) at Kanpur. The other location such as Jaipur,

Delhi and Patna highest value of Pearson R is observed by aqua ANN 0.44, 0.75 and 0.87, respectively. Although the degree of correlation varies for different sites, this study demonstrates the potential of ANN in air quality monitoring.

Keywords: $PM_{2.5}$, AOD and metrological, ANN

LULC classification using Convolutional Neural Network

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Use of deep learning techniques to improve the accuracy for LULC classification from multispectral remote sensing data has become quite popular. This study is carried out to test the sensitivity of tuning hyperparameters in improving the overall accuracy of the image classification. Deep learning based convolutional neural network (CNN) algorithm is used to classify multispectral images in this study. The labelled Eurosat data acquired using Sentinel-2 satellite images which contains 27000 images in total having 10 classes were given in the form of RGB composite images. Experiments were conducted for RGB composite and the experimental design deployed basic 5 layer CNN with activation function Rectified Linear Unit (ReLU), 27 learning rates which ranges from 0.0001 to 0.01 with 10% increment and 8 optimizers (Adam, Stochastic Gradient Descent(SGD), Rmsprop, Adadelta, Adagrad, Adamax, Nadam, ftrl). The overall classification accuracy achieved is 96.37% for RGB composite. The best accuracies are in the learning rate range of 0.0001 to 0.000358318 with Nadam, SGD, Adamax and Adagrad as the best optimizers. In summary, this paper provides a systematic methodology to identify the best combination of hyperparameters for image classification using CNN.

Keywords: Convolutional Neural Network (CNN), Hyperparameters, Land Cover Land Use (LULC), Multispectral images

Deep LSTM model for Indian Summer Monsoon Rainfall prediction using indices

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Abstract: Predicting the monsoon rainfall temporally is a major scientific issue in the field of monsoon meteorology. Machine learning and deep learning methods have significantly contributed to modelling and prediction of time series for achieving higher accuracy, efficiency, robustness, and overall model performance. In this study, we have used Long-Short Term Memory (LSTM), a deep learning algorithm, and attempted to improve the seasonal forecast skill of the Indian Summer Monsoon Rainfall (ISMR). Unlike simple recurrent neural networks, LSTM supports time steps of arbitrary sizes and without the vanishing gradient problem. A multivariate model is developed

using the indices NAO, SOI, Nino 3.4, and DIM to prepare the input matrix while the output is ISMR. Multicollinearity analysis was carried to check the collinearity among the indices and removed the trans-Nino Index (TNI), Global mean Lan/ Ocean Temperature Index, and North Pacific pattern whose VIF value is more than 10. The data used were collected over the period of 1901 to 2018. Both standard and bidirectional LSTM predictive models in this study, with 70 per cent of the available data were used to train the model and 30 per cent used to validate. LSTM hyperparameters were optimized and the models were built with the parameters that resulted in minimum errors and the same was used to predict. The model prediction accuracy is evaluated using the error measures, RMSE, MAE, and MASE. Standard LSTM was found to be superior to the Bi-directional model with a minimum MAPE of 8.90 and 13.08 respectively and with around 30% lesser MASE value.

Keywords: Long Short-Term Memory (LSTM), ISMR, NAO, SOI, Nino 3.4, and MASE

On the Deep Learning based Multi-Model Ensemble

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Although Deep-learning (DL) has been used extensively in weather and climate forecast since the mid-1990s, recently there is a strong interest to explore the use of DL for multi-model ensemble (MME) to improve the seasonal forecast. This talk will explore the question: whether DL-based multi-model ensemble methods add value over existing methods to improve the skill of the seasonal predictions where the sample size is a big constraint to train the DL network? The primary goal of the current study is to create guidelines for the proper usage of DL in the multi-model ensemble and identify potential value-added over regular methods. A state-of-art single-hidden-layer feed-forward neural network (SLFN) based non-linear regression method viz., Extreme learning machine (ELM) employed on the coupled GCMs of the North American Multi-Model Ensemble (NMME) to make the multi-model ensemble. The skill and interpretability of the proposed method compared other regular MME methods, including simple arithmetic mean and singular value decomposition-based multiple linear regressions. The results will be discussed for the South Asian monsoon.

Downscaling CMIP5Model Outputs by Genetic Programming Approach to Capture Spatiotemporal Variations of Future Precipitation over Homogeneous Monsoon Regions of India

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Climate Change studies focus on downscaling precipitation as one of the important parameters using Global Circulation Models (GCM) outputs. This study deals with the assessment of probable future precipitation and trends of spatiotemporal variability of precipitation over six homogeneous monsoon regions of India.

Global Circulation Models (GCMs) are considered as effective tools to generate climatic conditions for many decades in the past and the future. GCM play a key role in generating future projections of climate change using different emission scenarios. GCM output is not used directly. However, it is necessary to downscale the GCM outputs at the regional level by using statistical and dynamical downscaling techniques. The present study includes statistical downscaling of CanESM2 model outputs by K means- clustering and Classification and Regression Tree (CART) as Artificial Intelligence techniques.

The study includes analysis of IMD daily gridded rainfall data set at a high spatial resolution (0.25° lat X 0.25° long) for the period of 58 years (1961-2019). The study region covers the spatial domain of the from 6.5°N to 38.5°N in latitude and from 66.5°E to 100°E in longitude which covers six homogeneous monsoon regions of India viz. Central India (CI), Northeast India (NEI) and the West Coast (WC). The analysis of daily gridded rainfall data is done for obtaining the rainfall states(dry/medium/heavy) by K-means clustering techniques on Homogeneous Monsoon Regions of India. Cluster validity indices are applied to the clustered data to get the optimum number of clusters. This AI technique is simple and easy-to-use for grouping the rainfall data to identify rainfall states. These rainfall states are used as input data to train classification and regression tree-based model for prediction of future rainfall.

Similarly, K-means clustering technique coupled with a supervised data classification technique, (CART) is applied for CMIP5 model outputs to determine rainfall states from large scale atmospheric variables over the study area. The CART model is then trained to establish a relationship between the daily rainfall state of the study area and the standardized, dimensionally-reduced National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data. The relationship thus developed is applied to the General Circulation Model (GCM)-simulated, standardized, bias-free large-scale climate variables for prediction of rainfall states in future.

The analysis shows that the spatial rainfall distribution over the west coast of India and northeast India shows an increased number of heavy rainfall events. Whereas, on the leeward side of the Western Ghats low rainfall events are found more in numbers.

Comparisons of the number of days falling under different rainfall states for the observed period and the future indicate that the changes are due to global warming projections with two RCPs RCP4.5 and RCP8.5 respectively. These results obtained through analysis are further used for downscaling the rainfall by regression method to generate future scenarios. The results obtained by the regression are compared with multi-site rainfall predicted by using AI tool, Genetic Programming. The results obtained by Genetic Programming Approach are found to be better than regression. The study highlights the usefulness of proper water resources planning and management in the future.

Keywords: Climate change, Downscaling, NCEP/NCAR, CMIP5, Genetic Programming

Seasonal Prediction of River Basin Yield using Global Climate Parameters by Genetic Programming Approach

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The distribution of rainfall over a continent is influenced by Global and local climatic parameters. The variation in areal distribution and depth of rainfall over a catchment of river basin influences the river basin yield. This study aims to predict the seasonal basin yield of Upper Bhima river basin, situated in the Maharashtra state of India.

The Bhima river is one of the major tributaries of the Krishna river. The Upper Bhima basin includes 26 Major dams, 39 Medium dams and 480 Minor projects along various tributaries to trap and store water and utilize it for various purposes such as drinking, irrigation, industrial development etc. Ujjani dam is the highest capacity dam in this basin with a capacity of 3320 million cubic meter (MCM). The minimum, maximum and average seasonal yield over the period of 1972 to 2014 are found to be 1000 MCM, 15000 MCM and 5728 MCM respectively.

The net yield from a basin is calculated as the summation of inflow in all the reservoirs, loss of surface water due to evaporation from all the reservoirs, use of water for different purposes from all the reservoirs, and the spill from the last reservoir of the basin. After the cross-check, and cautious scrutiny of all data, the basin yield values for month, season and a water year are confirmed.

El Nino-Southern Oscillation (ENSO) index and Equatorial Indian Ocean Oscillation (EQUINOO) index and Historical average seasonal yield (climatological value) are used to predict the river basin scale yield. The novel Artificial Intelligence (AI) tool –'Genetic Programming (GP)' is adopted for developing prediction models.

Three different combinations of input parameters are attempted for the development of seasonal river basin yield models to arrive at the best input variable combination for prediction with different lead times before the onset of monsoon. The best combination of input variables is found to be of ENSO indices of the previous three monthly time steps and EQUINOO indices of the previous two monthly time steps. For deciding the best combination Correlation coefficient (r), Nash–Sutcliffe model efficiency coefficient (NSE) and Root mean square error (RMSE) is used as a selection criterion.

The prediction models developed by genetic programming approach are found to capture the complex relationship between the river basin scale seasonal yield and the various climate inputs quite nicely. The correlation coefficient between observed and predicted seasonal yield for the best model was found to be 0.85 during the training phase and 0.75 during the testing phase. The NSE for the same combination during the training phase was 0.93 and during the testing phase was 0.86, which appears very fine for such a complex water resources system.

Keywords: River Basin-scale yield, ENSO, EQUINOO, Genetic Programming

Solar Radiation estimation based on Artificial Neural Network approach for Agricultural Decision Support System

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Improving Agriculture efficiency in terms of productivity is an issue which needs to be addressed at most for sustainable agriculture in the country. There are various knowledge pools and domains have been created to help the farmers in their decision making in farm operations and increase farm productivity. Weather information based decision support system is one of them which require meteorological data as an input, but data availability is limiting the efforts. Solar radiation is one of the important parameters in defining the yield of the crop, therefore, availability of solar radiation data helps in crop simulation modelers and further decision-makers and planners, but the availability of solar radiation information is very limited. The current study is carried out with an objective to calculate the solar radiation with available significant weather parameters using Artificial Neural Network (ANN) based approach. 30 station historical observation data over India are normalized and used for training and testing of the model. The Backpropagation algorithm used for training of different configuration of multi-layered feed-forward neural network. The best ANN algorithm and model are identified based on Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Linear Correlation Coefficient (R) and NSE (Nash Sutcliffe Efficiency). It is found that the proposed approach estimates daily solar radiation with an error of 2.35% to 14.64 %, which ascertain the accuracy and reliability of the model to estimate radiation.

There is a further comparison made between the NASA's Worldwide Energy Resource (NASA/POWER; power.larc.nasa.gov) project estimated Daily Solar Radiation which is based on satellite observation and assimilation models and available at .5 × .5 coordinate grid. The comparison is performed for individual grid cell where the ANN estimated radiation values shows a higher correlation (Typically 0.85-0.95) than the NASA power values. Provided daily estimates could be very useful to use in various crop simulation models based decision support system.

Keywords: Daily Global Radiation, Artificial Neural Network, Back Propagation Algorithm

An application of Machine Learning algorithm in the Aviation-weather forecasting

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Accurate weather is critical to aviation, and it can have a profound impact on the aircraft from the moment an aircraft starts its engine until it arrives at its destination, it can have a major impact on the flight – both economically and physical safety, especially commercial airlines. The precipitations such as rain, snow or ice are not the only weather factors that impact flights, cloud levels, turbulence, thunderstorms and snowstorms, to wind and fog as well as temperature and pressure extremes can

also impact operations and potentially cause costly delays. This is the reason that access to accurate and timely weather forecasting and routing information is critical to those planning and operating these flights. Machine Learning (ML) applications are surely spread all over the weather forecasting applications as well as data processing and assimilation systems on real time operation. In this study, the state of machine learning algorithm has been employed to predict weather parameters (temperature, relative humidity, wind velocity, visibility) using the METAR weather report at Delhi Airport (VIDP), one of the busiest airports in India. The SciKit Learn, the most popular python machine learning library, is used for predicting the weather condition at Delhi airport. Algorithms such as Linear Regression and Random Forest were used to predict the weather condition. The analysis of results shows that the Random forest regression technique performs better than the linear regression. It is also found that parameter selection in the Random Forest model has a significant effect on the prediction.

Keywords: Machine Learning, Aviation, Weather Forecasting, Python

Statistical downscaling of daily precipitation estimates in Narmada river basin using machine learning approaches

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Indian Summer monsoon precipitation is a large-scale atmospheric phenomenon dependent on multiple variables. Statistical downscaling of precipitation is a challenging task because of the complex relationship with other local and large scale atmospheric and meteorological variables. Analysing the interdependency of these variables is statistically difficult. This task has been made easy by a popular machine learning approach called Artificial Neural Networks (ANN). In this study, different types of ANN techniques such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) are applied to downscale precipitation using multiple dependent variables.

The precipitation data used for downscaling is taken from ERA-interim atmospheric reanalysis dataset. Upper Narmada basin in central India is taken as the study area and precipitation data along with 8 other covariates at 500, 850, and 1000 hpa pressure level is extracted for 11 weather stations at 0.5°× 0.5°spatial scales. The observation data is provided at 0.25°× 0.25° spatial scale from the Indian Meteorological Department (IMD) for 39 years, from 1980 to 2018. The downscaling approach is applied on monsoon season rainfall (from June to September) for each weather stations separately for better handling of the big data. The first 30 years of data is used for training the CNN and RNN models and the next 8 years of the data for validating the models. Both the ANN models are built in regression setting for generating the time series of last one year data which can be tested with the existing IMD dataset at 0.25°× 0.25° scale. The error metrics like mean-squared error and mean absolute error is used to evaluate the models.

The analysis is currently in progress and the preliminary results show that the CNN method is effective in reducing the mean squared error to 0.01. The final results and the comparison of the results from both the approaches will be presented at the conference.

Machine-Learning based prediction of fog occurrence over Indian region using NWP forecasts

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Machine Learning (ML) techniques have been shown to be highly effective at solving classification problems. The use of ML techniques in atmospheric science and satellite meteorology applications is also fairly extensive. Neural Networks have been used in the estimation of precipitation from satellites and in retrieving ocean wind speeds from scatterometers among other applications. Naïve Bayes Classifier has been used to detect ground clutter in weather radars. The current study evaluates the efficacy of ML techniques in predicting fog occurrence.

There have been numerous studies related to the prediction of fog globally over the past decades. For example, Zhou et al. (2012) derive a set of simple rules based on NCEP model meteorological fields to suggest likely conditions for fog. Barokova et al. (2015) predict fog events over Dubai based on a Machine Learning approach (decision trees) using the 1-dimensional WRFPAFOG model parameters as input. Cornejo-Bueno et al. (2017) study the performance of various machine learning techniques in predicting fog at the Valladolid airport in Spain. On a related note, Singh et al. (2018) compares the visibility forecasts provided by the NCUM model with INSAT-3D fog images and airport visibility observations and finds that the model exhibits reasonable skill.

In the current study, we use NCEP GFS 24-hour forecasts at 0.25^0 resolution to forecast fog occurrence with 24-hour lead time. The 2-metre temperature, 2-metre dew point temperature, wind speed, surface pressure, and the specific humidity at the surface are used as the predictor variables. The visibility from the GFS analysis at 00h UTC is used as the training reference. The relationship between the predictor variables and the fog occurrence binary variable was modelled using a neural network (NN) with sequential stacks of layers. The NN architecture contained two hidden layers with 9 and 5 nodes respectively, followed by an output layer with 1 node. The binary cross-entropy loss function was used in the training process.

The deep learning model was trained using data over land in the grid 5N – 45N, 50E – 110E for the month of January 2019, and validated using data for the month December 2018. Fog occurrence is defined to consist of pixels where visibility is less than 1 km. Figure 1 shows the daily accuracy of 24-h fog occurrence forecasts from the ML model compared with 24-h GFS forecasts of visibility. We find that both the NWP and the ML models have high binary accuracy, though the accuracies are somewhat inflated due to the fact that fog occurrence is a relatively infrequent phenomenon; the vast majority of pixels in the images are non-fog pixels. The preliminary results suggest that it is possible to create ML models for forecasting fog occurrence that have similar accuracy to NWP model accuracy. However, further analysis is required to verify the robustness of the preliminary results.

Shoreline Variability and Change along the Andhra Pradesh Coast using Deep Learning

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Currently, 14.2% of India's population lives in the coastal region and that percentage is likely to be doubled by 2025 which will eventually lead to the change in size, composition and distribution of human affect the coastal region by changing land use land cover. In addition to population, wave energy, wind currents, seasonal changes due to both south-west monsoon and north-east monsoon causes variability in the shoreline. Therefore, it is necessary to evaluate the reasonable causes in order to predict what the shore might look like in the future and to understand how the land loss will impact coastal communities. As a result, the shoreline varies over the seasons and there is a need to identify the factors responsible for the estimated changes over the period of 30+ years along the Andhra Pradesh coast. The publicly available remote sensing data from Earth Observation satellites (Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (OLI), SENTINEL-2 (MSI)) archived through Google Earth Engine enabled Python toolkit to extract the shorelines. From the estimated shorelines, we compute the total amount of coastal area that has been lost/gained during the past 30+ years. A robust and generic sub-pixel resolution shoreline detection algorithm is used to the pre-processed satellite images and then it gets classified into four different classes 'sand', 'water', 'white-water' and 'other land features'. In this Image classification, a Neural Network classifier called Multilayer Perceptron in scikit-learn is used to label each and every pixel of the image with the above mentioned four classes. And a sub-pixel resolution border segmentation is used to extract the boundary between the sand and water using the Modified Normalized Difference Water Index (MNDWI) and applied to each of the classified images. At the sub-pixel level, a deep learning algorithm referred to as Marching squares is used to compute the iso-valued contour on the MNDWI image for a level equal to the 'sand'/'water' threshold. Extracted shorelines are intersected with shore-normal transects and extract the time-series of cross-shore shoreline change along the transects. South-west and North-east monsoons which affect the Andhra Pradesh coast are counted. Finally, successful future coastal planning relies on an improved understanding of the links between the spatial patterns of coastal change and environmental forcing regulated by climate drivers.

Keywords: Deep Learning, Google Earth Engine, Neural Networks

Deep LSTM model for Indian Summer Monsoon Rainfall prediction using indices

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Predicting the monsoon rainfall temporally is a major scientific issue in the field of monsoon meteorology. Machine learning and deep learning methods have significantly contributed to modelling and prediction of time series for achieving higher accuracy, efficiency, robustness, and overall model performance. In this study, we have used Long-Short Term Memory (LSTM), a deep learning algorithm, and attempted to improve the seasonal forecast skill of the Indian Summer Monsoon Rainfall (ISMR). Unlike simple recurrent neural networks, LSTM supports time steps of arbitrary sizes and without the vanishing gradient problem. A multivariate model is developed using the indices NAO, SOI, Nino 3.4, and DIM to prepare the input matrix while the output is ISMR. Multicollinearity analysis was carried to check the collinearity among the indices and removed the trans-Nino Index (TNI), Global mean Lan/ Ocean Temperature Index, and North Pacific pattern whose VIF value is more than 10. The data used were collected over the period of 1901 to 2018. Both standard and bidirectional LSTM predictive models in this study, with 70 per cent of the available data were used to train the model and 30 per cent used to validate. LSTM hyperparameters were optimized and the models were built with the parameters that resulted in minimum errors and the same was used to predict. The model prediction accuracy is evaluated using the error measures, RMSE, MAE, and MASE. Standard LSTM was found to be superior to the Bi-directional model with a minimum MAPE of 8.90 and 13.08 respectively and with around 30% lesser MASE value.

Keywords: Long Short-Term Memory (LSTM), ISMR, NAO, SOI, Nino 3.4, MASE

THEME 13

Remote Sensing of Atmosphere, Geophysical Parameter Retrieval, Calibration and Validation

Spatial, Temporal, and interannual variability of Deep Convective Clouds over the Tropics using Multi-year Megha-Tropiques-SAPHIR Observations

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The multi-year seasonal mean diurnal variation of the occurrence frequency of Deep Convective Clouds (DCCs) over the tropical regions for various climatic regions including land and ocean are studied, using Level-1 brightness temperature (Tb) data from SAPHIR payload, aboard the Megha-Tropiques (MT) satellite for the period 2011-2018. The low inclination orbit of MT, which provides the measurements at different local times makes the study of the diurnal cycle of DCCs possible from a single platform over the entire tropics. The methodology takes advantage of the ability of microwave radiance to penetrate deep convective clouds and discern convective cores from anvils and employed the water vapor channels centered around 183.3 based on thresholds for brightness temperature differences between the channels. The seasonal variation of DCCs is in concurrence with the sun position with maximum occurrence frequency in the summer months of the respective hemisphere. The largest occurrence of DCCs is found over the west Pacific and the northeast Bay of Bengal with a maximum occurrence frequency of ~4% during Northern Hemispheric summer. Central African landmasses, the South Pacific Convergence Zone, and the Amazon region also marked a higher occurrence during their summer seasons. The climatological seasonal occurrence of DCCs for the period 2011-2018 is estimated. From the climatological occurrence frequency maps, different regions are identified to estimate the seasonal mean diurnal variation of those regions. Over the continental regions, convective activity peaks during 15-18 LT, and over the open ocean, it peaks during 00-06 LT. Similarly, the convective activity is minimum over the oceanic region during 12-18 LT and over the land during 06-12 LT. The specific features associated with the distribution of DCCs such as the migration of Inter-Tropical Convergence Zone (ITCZ), double ITCZ, the pool of inhibited cloudiness, the zonal variation of the diurnal cycle of DCCs over the tropics, the effect of El-Niño, and the role of surface temperature and surface wind convergence on the occurrence of DCCs are studied.

Remote Sensing of Atmospheric Aerosols Loading Using Twilight Technique

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Aerosol measurement has been carried out at Kolhapur (16°42'N, 74°14'E) by using semiautomatic twilight photometer to study the vertical distribution of the atmospheric loading in terms of Aerosol Number Density per cm3 (AND). In this ongoing study, one attempt was made to study the effect on the vertical distribution of AND due to the increased manmade activities at road construction time in Kolhapur (During October 2009 - May 2010). The height resolution of semiautomatic twilight

photometer at a tropospheric level is 30 meters. Hence, fine-scale features of atmospheric aerosol loading are visible in the vertical profiles of aerosols obtained by this instrument. There is ample evidence that road construction activities are an important source of aerosols into the atmosphere and can have a substantial temporary impact on air quality. Emissions of aerosols during the construction of road are associated with land clearing, ground excavation, cutting and filling operations and the construction of a particular facility itself. Aerosol emissions from construction are largely in the coarse fraction, but they are also a source of airborne ultrafine particles. Dust emissions often vary substantially from day to day depending on the level of activity, the specific operations and the prevailing meteorological conditions making it difficult to assess the total contribution of such emissions to the air pollution levels of a city or region. Aerosol vertical profiles obtained during the period 1 January 2009 to 15 May 2011 were studied. The observations reveal that many types of aerosols introduced in the atmosphere at the road construction time remained suspended in the atmosphere for some hours to days. Therefore, one new tropospheric aerosol layer (in between ~6 and ~9 km) was observed on the vertical profiles of aerosols. The calculations showed that the minimum increase in AND was ~55% and the maximum was ~210% due to the road construction activities. This layer was the result of enhanced aerosol generation due to the primary production (bulk-to-particle conversion) and photochemical processes (secondary production) at the time of road construction activities. No such aerosol layer was observed before or after this period. The AND of the newly observed tropospheric aerosol layer at road construction time and its altitudes for clear sky days showed day to day, monthly and seasonal variations with the highest height in the month of October and lowest in the middle of March was observed. The considerable difference was observed in the morning and evening altitudes of this layer. At evening this aerosol layer was observed at higher altitudes than morning for all the months. The aerosols introduced in the atmosphere due to road construction work were heat-absorbing aerosols. Hence, an increase in temperature at this period was observed. The atmospheric pressure was also increased. Relative humidity in the atmosphere was decreased. It is clear that manmade activities affect the tropospheric aerosol loading and thereby affects the local climate.

Keywords: troposphere, aerosol, temperature, humidity

Application of the Satellite Consensus (SATCON) algorithm to estimate TC intensity over North Indian Ocean (NIO)

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Tropical cyclonic Storms (TCs) are one of the most devastating weather systems. At the same time, Early warning and forecasting of TCs is also very important. In North Indian Ocean (NIO) many TCs have also developed in recent past. Forecasting of TCs has improved significantly in recent decades (especially after Satellite era). In this paper, an attempt has been made to develop a method for an accurate estimate of current intensity (CI). Operational forecasting of Consensus-based algorithm for estimating the current intensity (CI) of global TCs combines infrared and microwave-based intensity estimates to generate a consensus TC intensity estimate that is more skilful than individual participants. The method known as SATCON can also be applied to TCs over the North Indian Ocean (NIO) and the Bay of Bengal on a near-real-time basis. Examination of the efficiency of the Satellite Consensus algorithm compared to the individual TC members and other operating TC estimates (Best Track CI / Manual T number) during 2018-20 is presented. It is found that it reduces the time spent for calculating the manual intensity and demonstrates a higher efficiency in calculating the TC intensity over the NIO and Bay of Bengal. An accurate estimate of CI may have potential applications for operational TC forecast and initialization of TC forecast models.

Keywords: Tropical Cyclone, Intensity, SATCON, NIO

Study of ionospheric parametric variation through Remote sensing and satellites navigation: a revolutionary measure in forecast of hazards

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Parametric signals generated by satellites and GPS receiver monitoring at different height of atmosphere namely D, E F and Fo-fe layer reveal remarkable anomaly and significant trend in variation of EM data working through Madriganal and IRI model2016, IGS network and ESA CEA calculating site present mysterious and remarkable anomalous variation in parameters like electron density, ions temperature, plasma drift velocity and magnetic, electric field trend in specific magnitude and direction. They present significant change prior to various natural hazards like earthquakes, tsunamis, typhoon and storms etc. Continuous monitoring of satellite data through NOAA and NCEI and IGS network GPS receiver stations provide amazing anomaly in TEC, plasma drift and electron flux variation. Nature is not uniform but specific to a certain event in a proportionate amount as TECV rises continuously seven days prior and declines suddenly one day prior to the event. Exact two to three hours prior to the event electron flux exponentially decreases against solar X-ray flux. Findings are observant even in quiet space weather condition. The 3D plot of TECV against the magnetic field (H and z Components) have positive coefficient .7-.9 for Nepal Pokhra Nepal lat and long during and prior the 25 April 2015 event. Least Square error for significance α=.5 and confidence level z=1.87 determines 10-15 %SD.

Keywords: TECV, Magnetic field, Electron density, plasma drift, seismicity

Radiance inter-calibration of INSAT-3D ozone channel with MSG-SEVIRI and successive improvements in ozone retrieval and validations

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Among various trace gases, ozone has a unique vertical distribution and plays different roles at different altitudes. The useful stratosphere ozone absorbs harmful UV radiations, while tropospheric ozone, a powerful greenhouse gas adversely affects living beings and vegetation. Its role in atmospheric chemistry, radiative transfer, and the processes that regulate its variation are distinct at a different altitude. Ozone concentration is influenced by various parameters, like dynamical variability, ambient meteorology, non-linear photochemical reactions, and climate variables. In the Asian countries the increasing anthropogenic emissions, higher solar radiation and water vapour further intensifying ozone photochemistry in the troposphere. The split in the tropopause rather than continuous transition over the Himalayan region adding ozone rich stratospheric air to the troposphere. Additionally, the Himalayas provides conducive conditions to confining pollutants those are emitted from the northern/ central Indian region. Thus the continuous monitoring of the vertical ozone profile is necessary. Thought one of the most important and reliable instruments for measuring the vertical profile of ozone is the ozonesonde, however they provided a small snapshot scenario of ozone profile at a particular location. Nowadays, ozone monitoring via satellite based remote sensing has gained wide importance due to its near global and higher temporal coverage. The Indian geostationary satellite INSAT-3D/3DR is accomplishing this need for India. Apart from the meteorological sounding INSAT-3D/3DR sounder is also incorporated with a 9.6 µm strong ozone absorption channel, which can provide very high spatio-temporal data of ozone over India. We have assessed the INSAT-3D retrieved total ozone and ozone profiles with respect to the ozonesonde observations from Nainital, in the central Himalayas. Apart from some minor deviations, INSAT-3D is able to capture the observed features with a smaller bias in the stratosphere and somewhat larger bias in the troposphere. Total ozone column from INSAT-3D showed a maximum difference of 8% with ozonesonde-derived total ozone column. To mitigate these deviations or errors, we have checked the radiance biases in INSAT-3D/3DR observations by inter-calibration with MSG-SEVIRI for collocated pixels. Although the RTTOVV12.3 simulated brightness temperature for these two instruments has shown one to one observation for ozone channel, but the actual observation has shown biases in INSAT by more than 4 K. Further in the new retrieval algorithm based on feed forward neural network and the optimal estimation method we have inculcated these biases and found very significant improvements in the INSAT-3D/3DR ozone retrievals and the more details on techniques and the improvements will be presented.

Deep Convective Cloud Cores: Radiative flux, Upper tropospheric humidity and Latent heat

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Deep convective cloud cores are significantly different from the anvil part of a deep convective system in different ways. Radiative flux in the core region, upper tropospheric humidity, latent heat and surface wind convergence are significantly higher in the core region. Conventionally, the Infrared (IR) brightness temperature (Tb) thresholds are being used to identify the deep convective clouds. However, since the IR brightness temperatures map the cloud top temperatures, the convective cloud core regions cannot be delineated from the convective anvils. SAPHIR payload aboard Megha-Tropiques satellite has 6 channels centred around 183.31 GHz. A method has been developed to identify the deep convective cloud cores using these channels. Different thermo-physical parameters are studied over the deep convective cloud core regions utilizing concurrent and collocated measurements from other payloads aboard Megha-Tropiques and also other satellites such as ScaRaB, TRMM and CloudSat. The presentation covers the data set and the methodology used in this study and also the results of the evaluation of different thermo-physical parameters.

INSAT-3D observation on Aerosols during COVID-19 Lockdown period over India

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The lockdown period in India due to COVID-19 came into effect from 25 March 2020 onwards. The present study analyses the changes and trends in Aerosol Optical Depth (AOD) and derived Particulate Matter (PM10 & PM2.5) levels during the last few months and particularly during the lockdown period. INSAT-3D AOD observation shows an average reduction of 20-36% across the country during the lockdown period (DLD) (25 March-31 May 2020). INSAT-3D observations also show an average reduction of 25-40% in PM2.5 and PM10 concentration levels across the country during DLD. INSAT-3D AOD comparison DLD (25 March-31 May 2020) with the same period of 2019 shows decrease by 34 - 46% whereas 30-40% in particulate concentration (PM10 & PM2.5) in 2020. Ground observation (CPCB monitoring stations) on air pollutants for some selected stations show around 40-50% reduction in surface concentration during DLP as compared to Pre- lockdown period (PLD). The satellite observations showing a reduction in air pollution are supported by ground observation monitoring stations. The maximum decrease in AOD was seen during 25 March to 30 April 2020 with values as low as 0.24–0.26, which is 45-60% lower than the February–March 2020 level. AOD then slightly increased in the first week of May due to stubble burning and then fell subsequently. The maximum decrease in PM10 & PM2.5 was seen during 25 March to 30 April 2020 with values as low as 11-21 μgm^{-3}, which are 71-87% lower than the February–March 2020 level. PM10 & PM2.5 then slightly increased in the first week of May due to stubble burning. The AOD anomaly map of 2020

(25 March–31 May) from the average of 2019-2020 shows a distinct reduction in aerosol levels between 0.01 and 0.3 over North India and IGP, and between 0.01 and 0.12 over peninsular India with a nominal increase of 0.01–0.08 over the central and central-eastern regions. The analysis shows a distinct and drastic reduction in Aerosol Optical Depth which include both PM2.5 & PM10 and is observed at many places across India, in particular Indo-Gangetic Plain (IGP) region.

Vicarious calibration of INSAT-3D, -3DR visible and SWIR channels over Desert site

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The post-launch sensor calibration is an important project element to understand the data products generated at various levels. In failing to the onboard calibration exercises, the vicarious calibration methods are adopted to meet the mission demand. The visible and SWIR channels of INSAT-3D and -3DR satellite sensors are calibrated vicarious by conducting a special calibration campaign over Greater Rann of Kutch during the past and the latest campaign was conducted on 4-8th January 2020. Synchronous measurements of surface reflectance and other atmospheric variables like aerosol optical depth, integrated water vapor and columnar ozone were done in order to carry out the post launch radiometric performance assessment of visible and SWIR channels. The top-of-the-atmosphere (TOA) radiance are simulated using 6SV2.1 radiative transfer model along with measured atmospheric variables. The vicarious radiometric calibration results of the ground reflectance-based approach show a slightly larger difference when comparing the predicted and observed VIS band TOA radiance values for INSAT-3D/3DR imager. The relative errors of the VIS bands of INSAT-3D and INSAT-3DR imager are within 44% and 23% respectively when compared with the simulated RT TOA radiance values. However, the relative errors for SWIR channels show 5.6% and 14.3% respectively. The correlation coefficient between INSAT-3D/-3DR derived TOA radiance and 6SV simulated radiance is 0.79/0.83 (visible) and 0.76/0.87 (SWIR). Vicarious calibration gain coefficient is computed based on the ratio between model simulated and sensors measured radiance at TOA level for correcting the sensor degradation. The mean vicarious calibration coefficient of the visible channel of INSAT-3D/-3DR is 1.78/1.3 and SWIR channel is 1.07/1.18 respectively. These coefficients are proposed to be implemented in data product generation to compensate for the observed differences in radiometric performance.

On the Calibration of INSAT-3D Imager Visible Channel Data using Deep Convective Clouds

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Deep Convective Clouds (DCCs) are optimal solar reflectors and behave as an isotropic target under the different sun and satellite illumination and viewing conditions. They are located near the tropopause

where the effects of surface albedo, aerosols and water vapour absorption are at their minimum. They are very common in the tropical regions and are the brightest targets available naturally. They can be identified by simple satellite imager infrared brightness temperature data threshold techniques. Thus, DCCs have good potential to calibrate visible channel satellite imager data. The possibility of using Deep Convective Clouds (DCCs) to calibrate INSAT-3D imager visible channel data is explored in the present study. The first step for calibration is the identification of DCC pixels in the INSAT-3D imager data. The second step involves the processing of the identified DCC pixels for visible channel albedo for further statistical analysis to access the performance of the visible channel data. INSAT-3D imager data for 2019 is taken from the MOSDAC website and processed to get the radiances, albedo and water vapour (WV) & thermal infrared (TIR1) brightness temperature (BT). Detection of DCCs is done using Brightness Temperature Difference (BTD) of WV and TIR1 channel data, the threshold of TIR1 BT, the spatial homogeneity of DCCs, spatiotemporal-geographical criterion and solar geometrical-illumination conditions. After detection of DCC pixels, Probability Density Function (PDF) were generated for all identified DCC pixel level albedo values. It is a well-known fact, based on the Radiative Transfer Model (RTM) simulations and satellite observations, that for the visible channel, PDFs of DCC pixel level albedo usually peaks around 78% to 85%. This simulation observation is then compared to the PDFs of the INSAT-3D to obtain calibration coefficient. PDF of INSAT-3D DCC albedo peaks around 47.83%. The DCCs calibration gain coefficients are calculated using the mean value of RTM simulated DCC albedo reported in the literature.

Examining the cloud microphysical properties from surface observations

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This study investigates the cloud characteristics, Rain Drop Size Distribution (DSD), and Z-R relationship obtained from co-located Micro Rain Radar (MRR), Ceilometer, and Laser Precipitation Monitor (LPM) for the 2018 monsoon season over Argul, Odisha (85.70°E, 20.17°N). This study will focus on rainy as well as non-rainy days for cloud occurrence and cloud base characteristics from ceilometer data at a high temporal frequency of 16 seconds. The ceilometer data will help us in understanding the nature of clouds before the occurrence of rainfall and can lead to the classification of clouds and their associated convective processes. The rainfall data is collected at 1 min for LPM at the surface and 10 sec for MRR with 31 vertical levels up to 6km vertically. The analysis will be carried out using LPM, which will illustrate the drop size distribution, size, and fall velocity. The preliminary result suggests the rainfall intensity recorded by MRR underestimates the amount at 200m (lowest level) than surface rainfall estimates. A good agreement is found for rain rate and radar reflectivity data between both instruments. Further, DSD vertical profiles segregated based on rainfall intensity indicate the higher drop concentration at lower (<2km) altitude proposing the dominant role of the drop coalescence process for intense rain rate. Besides, vertical distribution of rain DSD and Z-R relation will be examined for all the heavy rainfall events of the season. The DSD, along with the Z-R relationship, will help us in understanding the dominant processes (evaporation, drop coalescence, and drop breakup mechanism) for classified rainfall categories. This study will further look into gamma distribution function and the nature of various parameters (intercept, shape, and slope) for

two rainfall types classified along with the vertical levels. This study will benefit us in understanding the cloud characteristics, raindrop distribution (both areal and volumetric), and formulation of rainfall DSD over a tropical climate location.

On Understanding satellite perceived North-South gradient of atmospheric methane distribution over India

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Methane has been on the tremendous rise since the last decade after the stallation in its growth rate it has seen worldwide around the year 2000-2007. Due to the complex nature of source and sink of methane, proper estimates of methane growth and studies are associated with high uncertainties hence are the variation seen in different estimates and different approaches. Presence of methane near to the earth's surface has got an adverse effect on human health. In the troposphere, it has got a vital role to play due to its high radiative forcing capacity among all greenhouse gases. Atmospheric Infra-Red Sounder (AIRS) retrieved methane concentrations has been reliable and extensively used data to understand the variability of methane in the troposphere. In this study, we have tried to understand the gradient in the concentration of atmospheric methane as higher in North India and lower in South India as observed by AIRS satellite near to surface and in mid-troposphere and the possible sources causing it with the help of emission inventory available to us. CH_4 concentrations used in this study are used from aboard AQUA Earth Observing Satellite. Anthropogenic emission inventory used in this study is provided by IIT-Bombay. It is available for a long period of 15 years for all the anthropogenic parameters of CH_4 emission. Meteorological parameters are also used in this study, like temperature and winds, are obtained from NCEP-NCAR reanalysis data product. AIRS CH_4 data is analyzed at near surface (925 hPa) and mid-troposphere (500 hPa). To study the north-south (N-S) gradient over the country, the two boxes; one from north India and other is selected over south India. Satellite retrievals show the presence of a gradient in the concentration of methane between northern and southern parts of Indian region which also has got a seasonality in the middle troposphere. Our study suggests the observed gradient and the seasonal variation in it can be a resultant of anthropogenic emission patterns acted upon by prevailing meteorological conditions. Emissions from some of the sectors play a dominant role in maintaining the observed gradient in the troposphere. Broadly these sectors are agriculture and industrial emissions. These sectors are known to be the major contributors in total anthropogenic CH4 emissions however, their contribution in influencing the tropospheric gradient is not yet studied over Indian region. The understanding from this study may be further implemented for quantifying the role of a particular emission sector and developing policies relevant to mitigation efforts giving attention sector wise.

Simulation of all-sky radiance using multiple scattering radiative transfer model of Megha-Tropiques SAPHIR sensor for data assimilation applications

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Ingestion of cloud- and precipitation-affected radiances from microwave satellite sensors in data assimilation system has a great potential in improving the accuracy of numerical model forecasts over the regions of high impact weather. By employing the multiple scattering radiative transfer model RTTOVSCATT, all-sky radiance (clear sky and cloudy sky) simulation has been performed for six channel microwave SAPHIR (Sounder for Atmospheric Profiling of Humidity in the Inter-tropics by Radiometry) sensors of Megha-Tropiques (MT) satellite. To investigate the importance of cloud-affected radiance data in severe weather conditions, all-sky radiance simulation is carried out for the severe cyclonic storm 'Hudhud' formed over the Bay of Bengal. Hydrometeors from NCMRWF unified model (NCUM) forecasts are used as input to the RTTOV model to simulate cloud affected SAPHIR radiances. Horizontal and vertical distribution of all-sky simulated radiances agrees reasonably well with the SAPHIR observed radiances over cloudy regions during different stages of cyclone development. Simulated brightness temperatures of six SAPHIR channels indicate that the three-dimensional humidity structure of tropical cyclone is well represented in all-sky computations. Improved correlation and reduced bias and root mean square error against SAPHIR observations are apparent. Probability distribution functions reveal that all-sky simulations are able to produce the cloud-affected lower brightness temperatures associated with cloudy regions. The density scatter plots infer that all-sky radiances are more consistent with observed radiances. Correlation between different types of hydrometeors and simulated brightness temperatures at respective atmospheric levels highlights the significance of the inclusion of scattering effects from different hydrometeors in simulating the cloud-affected radiances in all-sky simulations. The results are promising and suggest that the inclusion of multiple scattering radiative transfer models into data assimilation system can simulate the cloud-affected microwave radiance data which provide detailed information on three dimensional humidity structure of the atmosphere in the presence of cloud hydrometeors.

Wind Speed Evaluation of RISAT-1 SAR over the Indian Ocean with Numerical Model generated Wind Speed

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Global ocean surface winds are being monitored by the onboard Scatterometer observations with a nominal coarse grid spacing in the range 6.25 km to 12.5 km as well as with the wider data gap in the coastal regions, particularly over the Indian Ocean. Apart from this, scatterometer winds are not realistic near the coastal region due to land contamination and interferences. In order

to overcome these drawbacks near the Indian coastal regions, the Indian Space Agency, ISRO (Indian Space Research Organisation) successfully launched a SAR (Synthetic Aperture Radar) onboard Radar Imaging Satellite-1 (RISAT-1) on Apr 26, 2012 for a mission of five years. RISAT-1 successfully filled the data gap near the coastal region of India during July 2012 to Sept 2017. In this study, a comparative study has been done to evaluate the accuracy of RISAT-1 wind speed with the Global Forecasting System (GFS) model which is operationally run at 25 km during the above mentioned period and is currently being run at 12.5 km at India Meteorological Department, Ministry of Earth Sciences. The RISAT-1 wind speed was retrieved using the wind retrieval algorithm developed at Space Applications Centre (SAC), ISRO. The high resolution (approximately 1 km) wind speed was retrieved using an empirical C-band Geophysical Model Function (GMF), CMOD5.N. A GMF is a mathematical equation that relates the SAR observed backscattering coefficient to wind speed at 10 m height. The GMF provide the neutrally stable wind speed at 10 m height and therefore GFS wind speed is converted to neutral wind speed at 10 m height. The separate comparative study has been made for different seasons like Pre-monsoon, Monsoon and Post-monsoon over the Indian Ocean. The statistical comparison results for RISAT-1 wind speed shows -0.7 m/s, -1.8 m/s and -0.5 m/s bias with corresponding Root Mean Square Error (RMSE) 2.2 m/s, 3.0 m/s and 1.9 m/s, respectively for pre-monsoon, monsoon and post-monsoon seasons. The comparison results are in agreement with the earlier study carried out for wind speed validation using satellite observation (ASCAT, the Advanced Scatterometer of European Space Agency) and buoy observations. Hence, the retrieved wind speed can be used to assimilate in the numerical model to improve the forecasting, particularly over the coastal region of India.

Study of Depolarization Phenomenon in Clouds Using Polarimetric Weather Radar to Differentiate Among Different Hydrometeors

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Depolarization is a stochastic process where energy is coupled from deterministic to random modes of fields. It is a common phenomenon with radar which occurs when the scatterers possess asymmetry. Depolarization is usually seen as the loss of information since it is a measure of randomness in the scattering behavior of the targets. That is why it is also considered as the process that causes noise generation. Even the phenomenon describes the randomness in determining the types of scatterers, it can be used to analyze the anisotropic behavior of the scatterers as well as the media in weather observations. The anisotropic behavior of clouds indicates a mixture of liquid and solid hydrometeors. However, the anisotropic behavior of clouds' layers at different elevations can be viewed as the presence of different hydrometeors in those layers. Therefore, in this paper, the depolarization processes in clouds are analyzed through variations in the behavior of different polarimetric weather radar products. In addition to this, the effect of wind in depolarization process has also been analyzed. Since the wind causes the canting of the water particles, the reflected energy partially switches from the incident horizontal polarization to vertical polarization. The analyses showed in this paper demonstrated that the study of depolarization processes can be used to differentiate among different types of hydrometeors present in the clouds.

GPS Meteorology: Ever Recorded Extreme Integrated Water Vapour associated with Extreme Rainfall – A case study

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Although water vapor accounts for only about 0.25% of the total mass of the atmosphere, this critical and fundamental tropospheric component affects cloud distributions, storm initiation, and heat transport from the surface to upper layers. Therefore, knowledge of the spatial and temporal distribution of water vapor is very important for a variety of applications. Conventional observations of moisture profiles have been possible thanks to the GPS sonde twice in a day and today a variety of instruments monitor water vapor at various temporal and spatial scales. Among these techniques, global navigational satellite system (GNSS) observations are of high relevance, and there has been a fast growth of ground network receivers, making GNSS crucial for water vapor monitoring. In this work, we are presenting the extreme value of integrated precipitable water vapour estimated from CORS network in real time over Dwarka and New Delhi GNSS site during this south-west monsoon season 2020. The two GNSS site reported extreme value of 84.5 mm and 85.5 mm respectively at least much earlier to the extreme rainfall of more than 21 cm. This extreme value of IPWV is ever recorded by GNSS or any other remote sensing or GPS sonde instruments. Most of the remote sensing technique becomes saturate when IPWV exceeds more than 65 mm. This limits the numerical models to capture the extreme rainfall events, mainly in the tropical regions. In this paper, we are presenting the extreme IPWV measured with high temporal resolution along with synoptic condition and various thermodynamic conditions responsible for the extreme value.

Keywords: Integrated precipitable Water Vapour, Global Navigational Satellite system, Zenith Total Delay, mapping function, Zenith Wet Delay

Physical characteristics of atmospheric aerosols over central Indo-Gangetic Basin

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The Indo-Gangetic Basin (IGB) in northern India is one of the densely populated, most polluted including being a region of the world heavily loaded with airborne particulate matter (PM). This region includes more than 50 % of the country population. It is a region of interest because it demonstrates meteorological condition control by the dynamic behaviour of the atmospheric aerosol. With its high population density and related energy demands, the aerosol concentration over IGB increases, mainly through fossil fuel and biomass fuel combustion resulting in high spatial-temporal variability Atmospheric aerosol plays a crucial role in the Earth's radiation budget and climate studies. The present study reports the variability of the physical and optical properties of columnar aerosol over Varanasi (25.2°N, 82.9°E), located in the middle of the Indo-Gangetic Basin

for the year 2018. The study is carried out using MICROTOPS-II for measuring AOD and two high volume samplers (PM2.5 and PM10) for measurement of both coarse and fine particulates. AOD was found to be enhanced during pre-monsoon and winter season. AODs value at shorter wavelength observed maximum in June and November while at longer wavelength maximum AOD is observed in June only. PM2.5 particles were found to be dominant during winters whereas PM10 were dominant during pre-monsoon season. A large variation in aerosol optical depth and Ångström exponent indicate towards the highly turbid atmospheric environment with significant heterogeneity in aerosol sources, types and optical properties. Five days air mass back trajectories were computed. They suggest different patterns of particle transport during different seasons.

Heavy rainfall monitoring from Indian GNSS Network

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Heavy rainfall events are parts of severe weather events and have both spatial and temporal variability in GNSS derived Integrated Precipitable Water Vapour. This study was carried out for heavy rainfall episodes on 8 places of Indian GNSS Sites. The results show a mean increase in IPWV of around 25-30 mm occurring about 6 hours prior to the occurrence of heavy precipitation. The other meteorological parameters such as pressure, temperature and humidity retrieved from Met sensor at GNSS also play an important role in monitoring the heavy rainfall occurrences. Fluctuations in IPWV fields correlate well with rainfall occurrence and a combined rise in IPWV and a drop in atmospheric pressure may well be used as a precursor to heavy precipitation.

Keywords: Global Navigation Satellite System (GNSS), Heavy rainfall and Integrated Precipitable Water Vapour (IPWV)

Evaluation of Aerosol Optical Thickness and Columnar Water Vapour using space-borne remote sensing

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The aim of this study is to validate the Aerosol Optical Thickness (AOT) and Total Columnar Water Vapour (TCWV) retrieved as a bi-product of atmospheric correction strategy adopted for multi-spectral Instrument (MSI) onboard Sentinel-2 series. Here, we implement the Sensor Invariant Atmospheric Correction (SIAC) approach, which exploits the coarse resolution MODIS spectral surface bi-directional reflectance distribution function (BRDF) to derive the surface reflectance and atmospheric composition products from Copernicus Atmospheric Monitoring Service (CAMS) as a priori information to invert the atmospheric composition parameters using efficient Gaussian process emulator that approximates the

Second Simulation of a Satellite Signal in the Solar Spectrum (6s) Radiative Transfer Codes. Figure. 1 displays the AOT and TCWV estimated over the region of interest (ROI) in between India-Bangladesh border. Further, the estimated AOT and TCWV are compared with products derived from Sentinel-2 sen2corr atmospheric correction algorithm, MODIS and ground-based Aerosol Robotic Network (AERONET) data over North-eastern region (NER) of India over a different time span.

Evaluation of GPM-IMERG precipitation product in Heavy Rainfall event during Northeast monsoon season in 2015 over Tamil Nadu, India

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This study focuses on the estimation of extreme precipitation event from satellite-based Integrated Multi-satellite Retrievals for GPM (IMERG) for the period of October to December in the year of 2015. Statistical information viz., CC, RMSE, NRMSE, and Agreement were computed to study the monthly mean precipitation from rain-gauge datasets as a ground reference. The results showed that IMERG captured the maximum amount of seasonal precipitation was observed by 1453.63 mm as against 1755.31 mm of ground reference. The correlation coefficient, RMSE, and NRMSE at individual monthly precipitation of IMERG ranged from 0.55 to 0.86, 28.51 to 71.18 mm/month/ and 17.75 to 20.40 mm/ month, respectively. Although the agreement per cent ranged from 79.60 to 82.25. It is clear that GPM-IMERG captured a good amount of rainfall against observed rain-gauge datasets during heavy rainfall activity in 2015.

Keywords: GPM-IMERG, North-East Monsoon, Statistical; Comparisons, Tamil Nadu

Spatio-temporal assessment of drought severity maps using agricultural drought severity index for seven agro-climatic zones of Tamil Nadu, India

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In this study, spatial and temporal variations of drought severity maps were generated using agricultural drought severity index (ADSI) for seven agro-climatic zones over Tamil Nadu during the two seasons of the northeast monsoon (October – December) for the year of 2015 and 2016. For

ADSI mapping purpose reclassification was done and a new set of severity classes has been assigned viz., Severe (less than 0), High (0.0 to 0.2), Medium (0.21 to 0.4), Low (0.41 to 0.6), Very Low (more than 0.61) each of which comprises of different consecutive ranges of values. The results indicated that the agricultural land in Northwestern zone was under high severity in both the periods and the severe risk has been found to be more during the period of 2016. This was very well related to the fact that 2016 was the worst drought year in Tamil Nadu in the last 140 years due to rainfall deficiency.

Keywords: ADSI, North-East Monsoon, Agriculture Drought, Tamil Nadu

Integrating weather model & Remote Sensing indices for wheat yield prediction in Haryana, India

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Wheat is a major food grain crop of the main agricultural region, i.e. northern plain of India. Haryana state holds a premium position in wheat production (Rabi Season) in the country. Pre-harvest yield estimation of wheat has a key role in policy framing. In Haryana, Agriculture is a big support to its economy which continues to occupy a prominent position in State GDP. In the present research, Agromet-Spectrals models have been developed for this purpose, i.e. yield estimation in Haryana with the help of input data such as meteorological indices and satellite based NDVI (NASA's-MODIS) from 2000-2017. Empirical models were developed for predicting wheat yield for Hisar and Karnal districts representation the two agro-climatic zone of state in Haryana, India. The models were developed used weather variable (Temperature (Minimum and Maximum), Relative Humidity (Morning and Evening) and Rainfall) and spectral indices Normalized Difference Vegetative Index viz. Agromet- model (weather model) and Agromet-spectral model (MODIS-NDVI). Weather or Agromet model was integrated with NDVI values for both locations to enhance the accuracy of models. Regression models were developed using significant weather variables and NDVI data for wheat yield prediction at both locations. The result revealed that the models, when integrated with remote sensing data (NDVI) gave better prediction as compared to agromet model that depends only on weather variables. Agromet-models (adjusted R2 = 0.38 to 0.78) whereas satellite data based NDVI i.e. MODIS-NDVI for both station gave the best result (Adjusted R2 = 0.61-0.86) as compared to weather models. MODIS-NDVI pixel based values observed to be more effective for wheat yield predication in integrated with weather parameters. This study could help the provincial government of Haryana as well as in northern plains in the estimation of yield prior harvest at the first week of April by using weather spectral (NDVI-MODIS) models.

Keywords: Agromet-Spectral model, MODIS, NDVI, Remote sensing, Weather parameter

Land Use Land Cover Changes in Bhubaneswar Urban Area Post-Tropical Cyclone 'Fani'

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Tropical cyclone (TC) landfalls are among the dangerous and devastating natural disasters affecting life, property, and ecosystem throughout the world. The North Indian Ocean region experiences about 6-7% of the global annual cyclone count, out of which 2-3 are extremely severe. Post landfall, the intensity of cyclones decay due to land interference, although the associated high wind speed and precipitation cause havoc in the inland socio-economic state of civilization. Destruction in the affected area is often quantified in terms of mortality and economic loss. TCs contribute to the changes in Land Use Land Cover (LULC). Consequently, the LULC, directly and indirectly, affect the post-cyclone landfall local meteorology. In this present work, LULC changes in Bhubaneswar urban area are analyzed post the severe destruction caused by TC "Fani" in May 2019. TC "Fani" is the only pre-monsoon cyclone till 2019 in the last 30 years (IMD), with landfall on 3rd May 2019 near Puri coast, Odisha, with a peak wind speed of 200 kmph. The category-4 cyclone (extremely severe cyclonic storm as per IMD classification) with an unusual track eradicated three cities even after high preparedness. The devastation caused by this TC in Bhubaneswar and its surroundings in the state of Odisha, India, was hence analyzed considering the corresponding changes in LULC using remote sensing and GIS techniques. Also, the present study investigated the meteorological changes associated with post land cover changes. The Sentinel-2 data set is acquired before the cyclone landfall and date after the cyclone landfall. The Normalized Vegetation Difference Index (NDVI) has been calculated using the Sentinel-2 data to see the vegetation change. It is found that the NDVI value has decreased after the cyclone landfall from the city center as the green cover inside the city is demolished. The satellite image is classified into seven different classes to calculate the percentage of area that is transformed from one type to another. The supervised classification is performed on the sentinel-2 satellite image pre and post-cyclone Fani landfall using the maximum likelihood classifier. It is found from the results that the vegetation cover inside the city of Bhubaneswar has been completely removed, leaving the land cover into barren land. Around 3.124% decrease in dense vegetation inside the city boundary is noteworthy. The loss of vegetation is reflected from the 10% increase in barren land type inside the city center. Changes in the LULC are correlated with the city meteorology, and significant alteration is noticed. The MODIS land surface temperature is compared to pre and post-cyclone landfall. The land surface temperature is increased by 1.5 degrees kelvin after the vegetation loss due to cyclone Fani. The near-surface wind after the cyclone changed its direction as a result of vegetation loss. The directional spread of wind is affected by the vegetation loss; wind direction became a more unidirectional post-cyclone event. This case study proves the changes in LULC due to the inland devastation of tropical cyclones and the corresponding changes in local meteorology. Conversely, LULC changes are prone to extreme short-term events, which can significantly alter the urban landforms. High-resolution multi-spectral Remote Sensing observations are an effective means to study such changes.

Land use and land cover classification over the West Coast of India using Landsat imagery

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The optical land imager (OLI) onboard Landsat 8 provides high-resolution data of Earth's surface. This data has been used to map the land use and land cover of the West Coast region of India, which also includes the Western Ghats. Cloud free data for the months of December-January during 2017-18 were procured and supervised classification was done to generate the land use and land cover. This study relies on the use of ground truth information from the high-resolution Google Earth images. The imagery was classified into 10 classes based on the International Geosphere-Biosphere Programme (IGBP) classification scheme. This study forms the basis for a long-term study of change in the land use land cover over the West Coast and their link to precipitation and temperature changes over the region. The classification accuracy would be ascertained from known reference images from Google Earth.

Estimation of Atmospheric Particulate Pollution over Kashmir Himalaya Using Remote Sensing

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Satellite measurements of particulate pollution, boundary layer dynamics and meteorology play an important role in determining the aerosol optical depth (AOD)-particulate pollutant relationship. In this study, 1377 satellite-derived AOD observations from the Moderate Resolution Imaging Spectrometer (MODIS) from 2013-2017 were used alongside the ground based PM_{10}, $PM_{2.5}$ measurements and meteorological parameters to develop two variate linear model (TVM) (AOD versus PM_{10} or $PM_{2.5}$) and multi-variate regression models (MVMs) (AOD + meteorological parameters versus PM_{10} or $PM_{2.5}$) for estimating the ground level PM_{10} and $PM_{2.5}$ in the Kashmir Himalaya, India. The model performance evaluation showed that PM prediction estimates are significant at 99% confidence level for all the models. The TVM predicts daily PM_{10} concentration better than $PM_{2.5}$, explaining 82% and 74% variance in the observed data, respectively. By adding meteorological data to the regression analysis, there is an improvement of 5% and 11% in R^2 for PM_{10} and $PM_{2.5}$ estimates which inter alia reduced the RMSE by 11.8% and 20.47% respectively. The best agreement between AOD, meteorology and PM concentration were found during the clear sky days only. Estimation of the particulate pollution utilizing the easily available time series of satellite measurements of AOD, ground-based observations of the PM, meteorological parameters and model-based PBL data would boost the satellite-based air quality monitoring in the data-scarce Himalayan region. However, it is suggested that more studies are required to improve the operational prediction of particulate pollution by incorporating satellite observations of other pollutants in the model using advanced approaches.

Study of Melting Layer Characteristics Using Polarimetric Weather Radar Products

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Melting layer has its own crucial role in weather forecasting and nowcasting systems since it describes the phase transition of hydrometeors. In the melting layer, the radar signal interacts with the both solid and liquid phase of hydrometeors, thus, samples both types of precipitations. The increase in dielectric constant due to the melting of the ice has been observed as the high reflectivity in radar. However, the same phenomenon can also be observed for the other precipitation conditions. Since the detection of the melting layer is highly desirable for accurate quantitative precipitation estimation, the ambiguity problem due to similar reflectivity weather conditions should be addressed. In this paper, to avoid the aforementioned ambiguity issue, the variations of different polarimetric weather radar products in the melting layer have been presented. The mixture of solid and liquid precipitations response differently to horizontal and vertical polarizations. This results in low correlation values. Moreover, the moderate differential phase values for the melting layer empower it to separate from the pure solid or liquid forms of precipitations. The behavior of different combinations of polarimetric features has also been analyzed to correctly estimate the location of melting layers which can be further used for hydrometeor classification algorithms.

Quantitative variations of Aerosol Optical Depth (AOD) over some places of China and India

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AERONET data was used for comparison of AOD (675nm) over India and China during the period of COVID-19 pandemic to see an impact of anthropogenic aerosols in the variation of AOD. The Indian mean AOD for COVID-19 (Feb-May, 2020) period is 0.43, i.e. a decrease of 6.52% in comparison to the same period of 2019. But in China, there is a 9.09% increase. The variation of columnar AOD depends on various factors including natural and manmade factors with this there comes a wide range of meteorological parameters which requires thorough and extensive study. A long-term observation is usually required to follow AOD trends, but since COVID-19 pandemic has a history of only three months now, it has been difficult to get accurate results which leaves room for further study.

Keywords: AERONET, AOD

A study of the variations of aerosol optical depth (AOD) retrieved from MODIS satellite data products over North Eastern regions of India

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A long term study for the period (2001-2010) was conducted to investigate the spatial and temporal variations in aerosol particles over North Eastern region of India retrieved from upgraded version 5.3 of Moderate Resolution Imaging Spectroradiometer (MODIS) data retrieved from Terra satellite. During the decadal period of 2001-2010, an increase of >15% was observed in AOD values across the North Eastern Region. High AOD values (0.65±0.03) were observed during the summer season, whereas low mean AOD values (0.07±0.02) were estimated for the post-monsoon season. It was found that Guwahati of North Eastern region observed the highest annual mean increase of AOD (> 79 %). These studies are highly significant so as to provide a better understanding of aerosol-cloud interaction.

Keywords: AOD, NE region, MODIS, Clouds

The impact of signal-to-noise ratio during the process of data analytics in Satellite Imagery

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The signal-to-noise ratio (SNR) is used for the validity and usefulness of a selected particular band in satellite imaging to characterize image quality. The sensitivity of satellite imagery is characterized in terms of the signal level that yields a threshold level of SNR. The signal-to-noise ratio(SNR) plays an important role in the acquisition of data from the sensors is affected by the signal strength, heat, distortion, lenses, and atmospheric conditions are creating a different noise from the satellite sensors. The information on data acquired by Earth observation depends on the acquisition of the datasets for image features. The higher the SNR ratios reflects higher the quality of information that influences the accuracy with anti-noise interference in the imaging system. The cost-cutting of satellite for designing the sensors is challenging today's technology and SNR is still not supported by the desired constraints in the available Technology. The SNR result depends on the atmosphere correction, sensor design, mathematical models, and atmospheric conditions like aerosol, cloud formations, and other noise effects. The objective of this research paper is to improve the features of satellite imagery and increase the signal-to-noise ratio in the case study of Multispectral and Hyperspectral imagery of Landsat sensors. The dataset of Landsat-8 sensors is processed using Machine Learning, wavelet algorithms, and the ratio of the average value of the standard deviations. The results showed improvement of the SNR on each advanced algorithm visualization effect on the imagery application areas on a wide range of water quality, land cover, and forestry given with low SNRs datasets imagery for the case study.

Investigation on relation between TCO and AOD using Microtops-II Ozonometer

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The highly advanced, compact and portable photometer called as Microtops-II ozonometer is used to measure the total column ozone (TCO) and aerosol optical depth (AOD) during April 2019 to 15th March, 2020 at Aigre village (16.74° N, 74.37° E, 604 meters above sea level, masl), located on the southeastern slope of Indian western Ghats. We have been carried out the measurements on an hourly basis on a day from 9:00 to 17:00 LT. The AOD shows a distinctive diurnal variation in post-monsoon season compare to winter and summer season. In the post-monsoon season, AOD remains constant due to the scavenging effect. However, it shows high concentration in winter and summer season. The daily mean variations in TCO was higher in the morning at ~9:00 to 10:00 am and it decreases in the noontime in between 12:00 to 13:00 pm then it increases up to 17:00 pm. The daily pattern of variations in TCO was same in seasonal variations. It is found that the concentration of TCO was high in the post-monsoon season compared to winter and summer season. The AOD varies with changes in weather conditions as well as local activities such as biomass burning. The TCO is highly depending on the intensity of the incoming solar UV irradiance. Therefore, the daily mean TCO shows a particular pattern, while the daily mean AOD didn't depict any significant trend. However, our results show a significant relationship between TCO and AOD in the winter and summer season.

Keywords: Ozone, TCO, aerosol, AOD

High-resolution Land Surface Temperature estimation over Kosi river basin through multispectral data from Landsat-8

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Land Surface temperature is an important aspect of the land surface in many areas, such as hydrological, agriculture, urban land use land cover etc. Rapid changes in land use and land cover of the area have become a major concern for the environment in recent times. This has contributed to unsustainable growth with a reduction in green spaces and also to changes in the environment Local climate and the development of urban heat islands. The aim of this study is to estimate the changes in the land surface temperature and consequent changes in land cover over the Kosi river

basin in Uttarakhand. Retrieval of land surface temperature from Landsat-8 Band 10 TIR (μm) which is 100 m resolution, initially Band 10 is converted to top of atmosphere radiance and then convert TOA radiance to brightness temperature. Emissivity (ε) is the proportion of vegetation, which is derived from the band constants. The seasonal and annual variability of land surface temperature over the Kosi river basin is estimated. This will provide us with base information for land use monitoring and management dynamics and developing mitigating environmental strategies.

Keywords: Land surface temperature, landsat8, land use, land cover, NDVI

THEME 14

Aerosol-Cloud-Precipitation Interactions

Aerosols and Monsoon Rainfall

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Atmospheric aerosols can exert a cooling and warming on the Earth's climate through direct (scattering and absorption of solar and long wave radiation), semi-direct (evaporation of cloud droplets due to solar absorption), and indirect (modify the cloud optical properties, lifetime and albedo) effects. The concentration, size and composition of aerosols that can act as cloud condensation nuclei determine the cloud properties, evolution and development of precipitation. The indirect radiative effects of aerosols are more uncertain than the direct radiative effects of aerosols. The combined effects of aerosols produced by local and non-local (long-range transport) sources may alter the large-scale heating and induce changes in the general circulation of the atmosphere, thereby affecting the processes of cloud formation and rainfall. The inter-annual and spatial variations in aerosols and cloud characteristics, and their relation to rainfall in summer monsoon over India and the surrounding oceanic regions (Arabian Sea and Bay of Bengal) during the last decade which witnessed normal, drought and excess rainfall will be presented. Recent results obtained on the aerosol-cloud-rainfall linkages and observational evidence for aerosol indirect radiative effects will be discussed.

Elevated aerosol layer over South Asia worsens the Indian droughts

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Droughts have become more severe and recurrent over the Indian sub-continent during the second half of the twentieth century, leading to more severe hydro-climatic and socio-economic impacts over one of the most densely populated parts of the world. So far, droughts have mostly been connected to circulation changes concomitant with the abnormal warming over the Pacific Ocean, prevalently known as "El Niño". Here, exploiting observational data sets and a series of dedicated sensitivity experiments, we show that the severity of droughts during El Niño is amplified (17%) by changes in aerosols. The model experiments simulate the transport of boundary layer aerosols from South Asian countries to higher altitudes (12 – 18 km) where they form the Asian Tropopause Aerosol Layer (ATAL) (~ 60 – 120 °E, 20 – 40 °N). During El Niño, the anomalous overturning circulation from the East Asian region further enriches the thickness of aerosol layers in the ATAL over the northern part of South Asia. The anomalous aerosol loading in the ATAL reduces insolation over the monsoon region, thereby exacerbating the severity of drought by further weakening the monsoon circulation. Future increases in industrial emissions from both East and South Asia will lead to a wider and thicker elevated aerosol layer in the upper troposphere, potentially amplifying the severity of droughts.

Aerosol types induced changes in precipitation patterns over a tropical station Pune, India

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Economic development is often accompanied by increases in aerosol emissions, especially in developing countries but the implications of the increased emissions are largely unknown. Aerosols, solid and liquid particles in the atmosphere induced by both natural processes and anthropogenic activities, affect the Earth's climate by altering its energy balance and lead to changes in cloud microphysics. These changes can result in either suppression or the enhancement of the development of clouds and precipitation. In the present work, we demonstrate the aerosol's induced changes on heavy precipitation events and changes to raindrop size distributions over a tropical station Pune, India. CALIPSO data is used to identify the aerosol type (e.g. dust or elevated smoke). We have analyzed 5 different cases for data when the convective precipitation with rain intensity was varying from 50->150 mm/hr and lasted from 10 minutes to > 1 hour. One such case of convective precipitation, with rain intensity greater than 100 mm/hr, lasting for more than one hour had dust aerosols present which caused invigoration and high precipitation. The drop size distribution obtained from disdrometer data shows an increased number of larger droplets with a broad spectrum of drops varying from 0.5 to 3 mm diameter. Another case study of the convective precipitation lasted for 10 minutes with average rain intensity of 50 mm/hr with peak in small size raindrops observed in the disdrometer data. This case occurred when an excess of elevated smoke aerosols was present, indicating the potential suppression of convective precipitation due to a large number of small size rain droplets. Back trajectory analysis is used to confirm the source regions for the air masses were advancing from inland or oceanic regions. An additional analysis investigated the moisture content for both cases with comparable moisture content observed for both the smoke and dust cases.

Effect of Pollution on North-East Monsoon Clouds

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Aircraft measurements of aerosols and clouds made during the onset of northeast monsoon are presented in this study. Aerosol measurements from a biomass plume near to the east coast showed

the dominance of Aitken mode aerosols. High concentrations of Aitken mode aerosol and black carbon particles were observed in the free troposphere and are attributed to the convectively transported smoke and aerosols from the boundary layer. CCN closure study indicated a drastic reduction in the effective hygroscopicity of marine aerosols due to the presence of biomass burning aerosols. The effect of this pollution was also noticed in the cloud microphysics as well. Continued aerosol activation up to 2 km above cloud base and dominance of supercooled droplets above freezing level was observed. Heavy loading of aerosols near the cloud base leads to enhanced mixed-phase processes in these clouds. This study attempts in detailing the sequence of events in the lifetime of such heavily polluted clouds from the cloud base aerosol activation to the precipitation in the anvils.

Optical properties and radiative effects of aerosols in the Eastern Himalayas

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First of its kind extensive study of the optical properties of aerosols were carried out over a remote site-Lachung (27.4°N, 88.4°E, ~ 2700 m a.s.l) in the eastern part of Himalayas during August 2018 to February 2020 to elucidate the role of distinct sources and types of aerosols on radiative implications. The observed intra-annual variability in aerosol scattering coefficients (σ_{sca}) at 550 nm in three distinct particle size regimes: <10 µm, <1 µm and between 1 and 10 µm (coarse mode) showed a very wide variability (4 Mm^{-1} to 360 Mm^{-1} for aerosols < 10 µm) during the entire period of study, mostly dominated by sub-micron mode aerosols (> 80%). Despite this, a clear seasonality is seen in the monthly variation of the σ_{sca} due to coarse mode aerosols, having pronounced effect during winter. Aerosol absorption coefficient (σ_{abs}) also showed significant seasonality with the highest monthly mean values (~ 29 ± 21 Mm^{-1} at 550 nm) in March (spring) and lowest (~ 9.5 ± 13 Mm^{-1} at 550 nm) in August (summer). Occurrences of the various high values of σ_{abs} (> 30 Mm^{-1}) are also seen, though less in percentile, indicating the impact of local source and dynamical processes in modulating the absorption properties of aerosols over the observational site. The monthly variation of aerosol single scattering albedo (SSA) derived from the simultaneous measurements of σ_{sca} and σabs also indicated large annual fluctuations with dominant role of scattering above total aerosol extinction during winter (highest SSA in February ~ 0.82 ± 0.1), while the effect of aerosol absorption was found to be dominant in summer, resulting in SSA as low as ~ 0.64, which is quite unique owing to the remote nature of the site. The seasonal variation of aerosol optical depth (AOD) showed an enhancement during spring (0.13 ± 0.01) followed by winter (0.12 ± 0.02), post-monsoon (0.08 ± 0.01) and summer (0.07± 0.01). Corresponding to this, aerosol direct radiative forcing (DRF) also showed higher radiative perturbation in spring (~ -4.3 ± 0.8 Wm-2 at the top of the atmosphere). On the other hand, despite lower SSA in summer, atmospheric forcing was highest in spring (~ 13.4 ± 4.4 Wm^{-2}), which translated to an atmospheric heating rate of 0.38 ± 0.12 K day^{-1}. Air mass back trajectories indicated that heavily polluted eastern part of IGP act as a potential anthropogenic source region to this eastern Himalayan region.

Sensitivity of convection intensity to vertical velocity and buoyancy representation in cloud microphysical parameterization

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Understanding of the formation, growth, and dissipation of deep convective clouds and the formulation of their impacts on weather are challenging tasks. The multiscale phenomena from microscale to synoptic scales contribute to the evolution of the cloud systems. At the global scales, convective/microphysics parameterization plays an important role in the global energy and radiation balance while influencing the larger-scale atmospheric circulations' strength. The cloud-resolving scale models to global climate models cannot resolve appropriately cloud microphysical properties due to limited representation of vertical updraft and downdraft velocity of hydrometeors due to various approximations used in the parameterization. The coarse resolution of vertical velocity and buoyancy calculation underestimates the intensity of convections in the models. Further, most of the microphysical schemes follow equilibrium thermodynamics for phase change of different hydrometeors based on the conventional rule of statistical averaging, which does not hold good for the extreme rainfall events. Therefore, in the present study, the vertical velocity's sensitivity on the cloud microphysical processes and hydrometeors concentrations based on the concept of non-equilibrium thermodynamics is evaluated for the extreme precipitation events. The study revealed that the convection intensity is sensitive to vertical velocity and buoyancy representation in the cloud microphysics parameterization. The inappropriate representation of convective intensity influences the rainfall intensity in two ways. First, it underestimates convective updrafts/downdrafts and number concentration and mass mixing ratio of ice nuclei, simulating warm cloud processes and underestimating the cloud top height and cold microphysical processes. Second, it underestimates the melting (freezing) processes and corresponding heat absorption (release) inside the cloud. Thus it underestimates the convective intensity as well as rain intensity during extreme convection and rainfall. The results of the study will be presented at the conference.

WRF Microphysics Sensitivity study to Rainfall estimation during Fukushima Dai-ichi release

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Atmospheric dispersion and radiological impact estimates during nuclear accidents require accurate prediction of weather parameters. Apart from winds, the height of the mixed layer and stability condition, rainfall is a crucial parameter that determines the area of deposited activity by the wet scavenging effect when rainfall is present. Accurate rainfall prediction is thus highly crucial for the realistic radiological assessment using atmospheric dispersion models. The Fukushima Dai-ichi Nuclear Power Plant accident was one of the severe nuclear accidents in the history of nuclear

technology. Large quantities of radioactivity were released to the environment over a long period. During the release period, the wind flow was mainly westerly, which transported the releases over the Pacific Ocean. However, two low pressure systems which developed during 16-23 March 2011 over the east Pacific changed the flow to west-northwest and also produced moderate to heavy rainfall leading to significant wet deposition over land. In this work, the sensitivity of rainfall prediction and consequent atmospheric deposition due to cloud microphysics in high-resolution cloud resolving simulations in WRF-FLEXPART modelling system is studied. Four bulk microphysics schemes WSM3, Thompson, Goddard and Lin scheme based on different hydrometeors types and distribution moments (single/double moment) are used to analyze their efficiency in rainfall simulations. Data from TRMM and Raingaugue stations are used for model rainfall comparison in terms of rain rates and the spatial distribution during the Fukushima release event.

Insights from intensive long-term observations of carbon aerosols and trace gases at the Central Himalayas

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Aerosols act as cloud condensation nuclei and alter cloud properties like reflectivity, lifetimes and can sometimes even cause cloud burn-offs. The ability of these particles to form cloud droplets varies according to their type, size and hygroscopic properties. Carbonaceous aerosols (black/elemental carbon and organic carbon-BC/EC, OC) are particularly important in this aspect because of their high abundance (20-70%) in less than 2.5micron size range and contrasting optical and hygroscopic properties (i.e. BC is absorbing and hydrophobic while OC is scattering and hydrophilic). Mountain ranges of the Himalayas have complex terrains which complicate understanding the cloud processes due to orographic effects. In addition to this complexity, Himalayas are now also experiencing the adverse impact of air pollution, which includes increased emission of aerosols, rising critically with the advent of rapid industrialization and urbanization. However, extensive long-term ground-based measurements of aerosols are almost non-existent in this region due to the prevailing extreme conditions and complex terrain. In this context, we present insights from the long term (2014-2017) online, simultaneous ground based measurements of carbon aerosols and trace gases (CO, CO_2 and CH_4) carried at ARIES, (29.4°N, 79.5°E, 1958 m a.m.s.l), a high altitude site in the Central Himalayas. We also used satellite observations, transport and radiative transfer models with these extensive observations to understand the variability, sources and radiative impact of these aerosols, which can, in turn, impact cloud properties. The higher temporal resolution of online measurements revealed that daytime concentrations of OC, EC, CH_4 and CO were twice that of the night-time. It is shown that the swiftly varying meteorological parameters along with higher boundary layer in the daytime, especially in spring is responsible for these changes at diurnal scales. The diurnal observations of EC are used to estimate radiative forcing (RF) and it is shown that atmospheric RF during the afternoon is about 70% higher than the forenoon RF. We applied EC tracer method to find the Secondary Organic Carbon (SOC) content. It is found that SOC is about 60% of the total OC content and

dominate the site throughout the period. Such high SOC and OC signify the abundance of potential cloud condensation nuclei. We also used offline sampling and their chemical characterization for a year and we found increased crustal elements in the samples showing enhanced dust aerosol emissions. The average concentrations of PM10, OC, EC, WSOC and SOC were recorded as 44±13 µg m^{-3}, 3.66±1.26 µg m^{-3}, 1.29±0.61 µg m^{-3}, 7.15±1.96 µg m^{-3} and 1.45±0.73 µg m^{-3}, respectively during the study period. High WSOC observed in the offline samples shows the abundance of hygroscopic organic particles suitable for cloud formation. In order to trace the sources of these species, the effect of long-range transport was studied using derived species residence time and Concentration Weighted Trajectory analysis along with OC/EC ratio and fire estimates from MODIS. Our results show high concentrations of aerosols from the biomass burning during pre-monsoon (MAM) from the Northern Indian low lying Indo-Gangetic Plain regions even at these high altitudes. Aerosol concentration, however, attains a seasonal minimum in the monsoon (JJA) due to extensive wet scavenging at the site. It is shown that during winter (DJF), aerosol concentrations are due to the local burning activities for heating and cooking, to aide in lower temperatures. These results were further substantiated with aerosol optical depth (AOD) observations from Multi wavelength radiometer and used for validation of MODIS derived AOD at the site. Wavelength dependent source apportionment model shows the dominance of fossil fuel emissions in both BC and CO, in general. Further, long term aerosol properties acquired from the CALIPSO is used to study the vertical structure of aerosols and their subtypes and it is shown that the fine mode aerosols with particle depolarization ratio < 0.2 dominate the site. The study thus utilizes the long term dataset to precisely segregate the role of local meteorological conditions, transport, fossil fuel burning, biomass burning and local emissions impacting the study site in different seasons and shows its particular importance in terms of radiation budget, cloud condensation nuclei and constraining emission sources.

Characterization of raindrop size distributions and its response to cloud microphysical properties

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The raindrop size distribution (DSD) reflects the characteristics of cloud microphysical and dynamical processes during the rain formation. The interseasonal variation of DSD is attributed to the cloud and meteorological parameters. This study attempts to analyse the instantaneous response of cloud properties and meteorological conditions on the DSD using ground-based DSD, satellite-derived cloud properties, and meteorological reanalysis data during monsoon season (June-October, 2013-2015). The DSD measurements were conducted at a tropical sub-urban site, Indian Institute of Tropical Meteorology (IITM), Pune using a Joss Waldvogeldisdrometer. The derived rain rate varied from 0.50 to 40.68 mm/hour, which was segregated into stratiform rain (mean and standard deviation of 2.12 ± 1.24 mm/hour) and convective rain (13.10 ± 14.45 mm/hour). The stratiform rainfall was more frequent than convective rainfall, but the derived rain rate was much higher for convective rain compared to stratiform rain. The high cloud effective radius (CER) resulted in skewed DSD

towards larger raindrop size in stratiform rain, and convective rain showed a decrease in large raindrop concentration with CER. Similarly, the high cloud droplet number concentration (CDNC) resulted in a narrower DSD during convective rainfall and a broader DSD in stratiform rain. The low wind shear and high convective available potential energy for convective rain highlighted the persistent convective cores during the monsoon that leads to the formation of large size raindrops in the convective systems. Such a distinct response of DSD to different rain regimes could help in the short-term prediction of extreme rainfall events.

Aerosol properties and radiative effects over Western Trans Himalayan Region

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The optical and microphysical properties of aerosols were analyzed over two high-altitude locations at Hanle (4500 m amsl) and Merak (4310 m amsl) sites located in the remote western trans-Himalayan region using direct and diffuse Sun Sky Radiometer (POM-01, Prede) observations during 2008 to 2018. Since, both the sites have similar topography, atmospheric conditions and very far from any anthropogenic activities, and the absolute difference between them were in the order of measurement uncertainties, the two sites were studied as a single point. We found that the average aerosol optical depth (AOD) at 500 nm is 0.04 ± 0.03, however the seasonal AOD peak is around 0.07 which happens during May (0.07) and lower (~0.03) in winter. The study observed influenced by long-range transported aerosols with high AOD (~0.1 to 0.2) which dominantly occurs during the pre-monsoon period (March to May). De-convolution of AOD at 500nm into fine and coarse mode aerosols were performed and justified the aerosol seasonality and sources. The marginal diurnal variation in aerosol properties indicates the weak influence from local sources except for some episodes. Further, the aerosol classification via fine-mode fraction vs single scattering albedo indicates the dominance of mixed type aerosols (~39%) followed by fine aerosols with very high scattering efficiency (26%), dust (21%) and low fractions of fine absorbing (~13%) aerosols. The estimated aerosol radiative forcing at the top of the atmosphere is -1.3 Wm^{-2}, while at the surface it ranges from -2 to -6 Wm^{-2} on a monthly basis. Further, the monthly mean atmospheric radiative forcing is about 1 to 4 Wm^{-2} leads a heating rate of 0.04 to 0.13 K day^{-1}. The estimated radiative forcing is higher than the global averages and may cause climate implications over the trans-Himalayan region.

Aerosol classification over a high altitude location in Central Himalayas during GVAX campaign

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We used the in-situ measurements of aerosol optical and microphysical properties obtained during the Ganges Valley Aerosol Experiment (GVAX; https://www.arm.gov/research/campaigns/amf2011gvax) at a high altitude remote location, Nainital, India over the period from June 2011 to March 2012, aiming to identify the aerosol types and mixing state of two different particle sizes ($PM_{1.0}$ and $PM_{10.0}$). Using a classification matrix based on scattering vs absorption angstrom exponent, seven different aerosol types were identified and which are highly dependent on size. In $PM_{1.0}$, "large/BC mix" is most dominated aerosol type with 45.4% contribution, followed by "small/LA" (31 .6%) and "BC- dom." (14.8%). In case of PM_{10} also, "large/BC mix" dominates (46.9%) and "Large/LA" and " BC- dom." accounted for 39% and 3.9% respectively. PM_{10} size group was dominated by weakly spectral-absorbing aerosols, while in PM_1 most of the particles with AAE<1 and SAE>1 refer to fine aerosols with the anthropogenic origin. This study is very helpful for the chemical transport model and better optimum result in aerosol radiative forcing over the Himalayan region.

Long term (2003-2019) spatio-temporal MODIS (Aqua level 3) derived climatic variations of aerosol optical depth and cloud properties over Tibetan Plateau

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The Tibetan Plateau located at the south-west of China affects the general circulation and regional monsoon system, causing the earliest monsoon onset over the eastern Bay of Bengal. The present work aims to provide prototype research of how MODIS observations can help to understand the spatial and temporal variations in aerosols over Tibetan Plateau. A scientific climatologically database on aerosol optical depths at 550 nm from the passive MODIS sensor is utilized in the present study. The main focus of the study is the analysis of long term (2003-2019) spatio-temporal variation of AOD at 550 nm over Tibetan Plateau derived from the MODIS (Aqua version 6.1 level3) sensor. The study also presents seasonal, interannual and spatial variations in AOD. Aerosol optical depth (AOD) data at 550 nm used in the present work is Aqua MYD08_D3, Version 6.1) level 3 $1^0 x 1^0$ Collection 6 (C006) daily and monthly gridded atmospheric data product. The data for AOD from terra/Aqua is globally available and monthly area averaged values are used in this study during Jan 2003- December 2019.

Observation of sub-3nm particles and new particle formation in an urban location in Peninsular India

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The formation and growth of ultrafine particles (usually less than 100 nm size) has been a topic of immense attention in the past two decades. In the global atmosphere, a larger fraction of the particle number concentration originates from atmospheric new particle formation (NPF) compared to primary particle emissions. NPF begins with the production of nanometer-sized clusters from gaseous vapours. These clusters grow to detectable sizes or get removed by coagulation with the pre-existing aerosols. The key steps of NPF occur in the sub-3nm size range, in which size-segregated observations have not been possible until recently. Here, we present observations of ultrafine particles down to the size of 1 nm in a polluted environment, Hyderabad. Particle number size distributions (PNSD) in size range from 1.1 nm to 514 nm were measured from 29 March 2019 to 25 June 2019 using a combination of Airmodusnano condensation nucleus counter (nCNC) and long-DMA scanning mobility particle sizer (SMPS). The nCNC system is capable of measuring PNSD in size range from 1 to 4 nm size and number concentrations of particles greater than 1 nm. nCNC observations provide better reliability to develop a process-level understanding of NPF than results from SMPS, which gives PNSD in the range 10 – 514 nm. NPF events were classified into three types based on the characteristics of the events observed. Out of a total of 87 days, 46% of the days had a sustained occurrence of sub-3 nm particle concentration more than 10×103particles cm-3.Analysis of the data revealed that 14% of days had NPF events with the particles growing up to 70 nm in diameter (Type-I). Another 32% of the days had NPF without any growth in particles over 30 nm (Type-II). 12% of the total days were identified as non-NPF (Type III) days. Average nucleation rates ($J_{1.4}$) for Type I events were found to be 30±50cm^{-3} s^{-1} and 50±60 cm^{-3} s^{-1} for Type II events. We will also present a critical analysis of different types of events occurring at the site.

Ubiquity of quasi-aerosol layers in the free troposphere: Results from multiyear satellite- and balloon-bone observations

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Vertical distribution of aerosols and their composition in the lower troposphere is critically important for assessing the Earth's radiation budget and their impact on monsoon circulation. We combine the data obtained from balloon-borne in-situ measurements together with space-borne LIDAR profiling along

with (Goddard Earth Observing System) GEOS-Chem simulations to provide an unprecedented climatological overview of the physical and optical characteristics of quasi-aerosol layers and their source and formation mechanism throughout its annual life cycle in the free troposphere. Persistent aerosol layers existing between 4 and 6 km exhibit much larger extinction coefficients than those observed near the surface and distinct aerosol components for different seasons. Depolarization ratios generally increase with height, suggesting that the irregularity of aerosol shape increases with altitude. Detailed results shall be presented in the meeting.

Keywords: Ubiquity, quasi-aerosol layers, CALIPSO, GOES

Covid-19 Pandemic related lockdown: Impact on aerosol radiative forcing at Varanasi

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Reduced anthropogenic activities and associated decreases in aerosol emission during COVID-19 pandemic have resulted in decreased aerosol loading and associated aerosol optical depth (AOD) across all parts of the world. The lockdown has resulted in a considerable improvement in air quality and resulted in the clear blue sky and improved visibility. The present study aims to assess the changes in Aerosol Optical properties, Aerosol Radiative Forcing and resulting Heating Rates at a representative Central Indo-Gangetic Plains (IGP) station in ISRO-ARFI Network, Varanasi, for the entire lockdown period (i.e., March 25th – May 31st, 2020) during COVID- 19 pandemic. During the lockdown phases 1 to 4, MICROTOP II observed AOD_{500}, $PM_{2.5}$ and Black Carbon was found to be varying from 0.22 to 1.27, 8.57 µg/ m^3 to 70.33 µg/ m^3 and 0.1 µg/ m^3 to 3.52 µg/ m^3, respectively.

Analysis of new particle formation events with PCA method using air mobility measurement at Pune, India

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Simultaneous measurements of ion-mobility of both polarities with a Neutral Cluster and Air Ion Spectrometer operating in the mobility range 3.16 – 0.00133 cm^2 V^{-1}s^{-1} (diameter range 0.36 - 47.1 nm) and concentration of Radon (222Rn) and its progenies with a Radon detector, RTM 2200 during the period January 2012 to December 2012 were analysed to study various features of new particle formation (NPF) events. NPF events mostly occurred in the morning hours of the pre-monsoon season during the hottest months (April and May) of the year. The results are explained in terms of

evaluation of the atmospheric boundary layer and morning wind blowing along the mountain slope due to the topography of the measurement site. The computed ion production rate correlates (CC, R = 0.67) well with the observed small cluster ions. Also, the role of temperature and humidity on the ion concentration both for the event and non-event days are discussed. The principal component analysis (PCA) method was used to investigate the dominant pattern of the ion-mobility and mobility boundaries between different groups of atmospheric air ions. It was found that the first five principal components could report more than 98 % of the total variance on event and non-event days. Even the first principal component explained about ~ 86% (65 %) of the total variance on non-event (event) days. The statistical analysis also confirms that the small and large – ions on non-event days originated from a similar physical/chemical background.

Quantification of carbonaceous aerosols over a semi-urban location in the central Indo-Gangetic Plain

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Black Carbon (BC) mass concentration within the planetary atmospheric boundary layer was measured at Gorakhpur, a semi-urban city located in the eastern part of the central Indo-Gangetic Plain (IGP). The present study aims to access temporal variation of BC aerosols over a different time scales due to seasonal changes in the emission sources, boundary-layer dynamics and changeable meteorological conditions of this region. The annual-mean BC concentration at 880 nm is observed to be 12.6±8.2 μg m^{-3} in the range of 0.03 – 58.6 μg m^{-3}. Winter season is characterized by extremely high BC concentration of 19.5±15.8 μg m^{-3} comparable to those seen in urban environments of IGP region, dropping off to 4.6±3.4 μg m^{-3} during the monsoon. In the period of study, spectral dependence of absorption coefficient reveals that dominant source of BC is biomass burning during the post-monsoon season while there is mixed contribution from biomass, biofuel burning and fossil fuel combustion in other seasons. Diurnal variation in the absorption angstrom exponent indicates that the morning and evening peaks are contributed by the biomass combustion with values above the threshold of 1.3. However, angstrom exponent values are found low during noontime of pre-monsoon and monsoon season, suggesting fossil fuel contribution. Concentration weighted trajectory (CWT) analysis reveals that the potential sources for the carbonaceous aerosols and pollutants are due to local emissions within the urban environment and transported smoke from agricultural residue burning in North-West India during post-monsoon. The high BC during winter is mostly associated with the advection from West and North-West side of the station, while during monsoon the air mass pattern is constricted to the oceanic region making BC aloft due to local pollution only. Aerosol cross-sectional vertical profile using CALIPSO observation showed a strong intra-seasonal variability with the dominance of smoke and polluted continental aerosols over the central IGP.

Study of Aerosol Optical depth (AOD) using satellite approach over Indian region

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Aerosol Optical Depth (AOD) was observed in a different region of India. We have used MODIS Satellite data for Aerosol Optical Depth (AOD) variation over selected regions. This study presents the inter-comparison of Aqua and Terra satellite data. Moreover, the annual and diurnal trend of AOD over the different region of India was also studied. The data for the five years (January to December 2015-2019) have been discussed here. Analyses were performed considering MODIS-based AOD with meteorological parameters like temperature, relative humidity, and wind speed. The result shows that the variation of Aerosol Optical Depth throughout the year, which are mostly related to the changes in the local boundary layer.

Keywords: Aerosols Optical Depth, MODIS, Aqua, Annual variation

Global variation in aerosol burden during COVID-19 imposed lockdown

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The global aerosol hotspots are identified using climatological as well as empirical orthogonal function (EOF) analysis for two decades of the continuous satellite observations. Principle component (PC) analysis corresponding to leading modes of the aerosols indicate an upward trend. The upward trend in aerosol loadings over most of the global aerosol hotspots is attributed to the anthropogenic emissions. In the backdrop of an upward trend in anthropogenic aerosol loadings over global aerosol hotspots, the air quality has significantly improved worldwide post declaration of the Coronavirus disease-2019 (COVID-19) as a global pandemic by World Health Organisation (WHO) in mid-March-2020. The present study using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite derived aerosol optical depth (AOD) and the Modern-Era Retrospective analysis for Research and Applications (MERRA) version-2 estimated aerosol radiative forcing (ARF) however, demonstrates the regional variation in aerosol loading during peak of the lockdown period. Significant reduction of aerosol loading is observed in China from the month of January (-9 %) in the milieu of high aerosol loading over other global aerosol hotspots (with reduction of -26% in the month of May). Reduction in aerosol loading over Indian, SE Asian and Middle East region is seen from mid-March/April-2020 with highest percentage reduction in the month of May (-27%, -3%, -16% respectively). The decline in aerosol loading is comparatively high(less) over North African region (South African region). Reduction in aerosol loading over global hotspots resulted in positive surface ARF up to +6 Wm-2 during the peak of the lockdown period. In the background of reduction in aerosol loading worldwide, the considerable above normal aerosol loading is identified during April-May-2020 over the Amazon river basin and northern areas of South America (32%, 25%) and Mexico region (47%, 1%).

Comparative study of Aerosol Optical Depth and Black Carbon in two different sites of Indian Himalayan Region

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Atmospheric aerosols are a suspension of liquid, solid, or mixed particles with extremely variable chemical composition with different size distribution. Aerosols are contemplated as the major air pollutants responsible for the worst impacts on human health and climate. Among all other constituents present in aerosols, Black Carbon (BC) is the main anthropogenic light-absorbing constituent. Hence, BC is gaining its research significance because of its ability to influence air quality and climate on local, regional, and global scales. To make the ground measurements and to collect the field data, we selected two different regions of the Himalayan region with varied climatic responses. Therefore, the present study aims to analyze the ground based measurements of Aerosol Optical Depth (AOD) and Black Carbon (BC) over Katarmal-Almora (Uttarakhand) and Mohal-Kullu (Himachal Pradesh) during July 2019 to June 2020 to make the comparative interpretation over it. In this, diurnal variation of BC showed a significant rise in the morning hours between 6 AM to 10 AM IST and in the evening from 7 PM to 10 PM IST, while low concentration was determined throughout the day. At Katarmal, BC concentration was increasingly accumulated two times during morning and evening hours as compared to afternoon and night hours while remained more than three times at Mohal. Seasonal variations of BC showed high concentration during winter dry season associated with the air masses primarily coming from the Indo-Gangetic Plain and minimum throughout the monsoon season due to significant precipitation at each of the sites. In addition, these sites further compared with each other with different parameters. AOD was found to be greater at smaller wavelength while smaller in greater wavelength at both sides.

Keywords: Aerosol Optical Depth, Black Carbon, Seasonal variations, Air masses

Aerosol Optical Properties over Jaipur during 2017-2020

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The optical and physical characteristics of the aerosol are analyzed over Jaipur, a semi-arid region in the northwestern part of India using sky-radiometer data for the period 2017- 2020. The observational site is located at Amity University Rajasthan, 45 km away from the main city of Jaipur. The results reveal that a maximum daily Alpha value noticed during winter monsoon and minimum Alpha value during summer months. The AOD is observed maximum in July and minimum during the winter period. During July season, Alpha and AOD show a seasonal trend, which gives the changes in aerosols during the season to season. The highest AOD in November 2019 is may be due to the anthropogenic burning or

crackers burning during Diwali events. SSA values are higher in winter monsoon suggests that less absorption by aerosols and more reflection except for October 2017 where SSA values are lower suggests more absorbing aerosols present at that time. Aerosol size drops from pre-monsoon up to mid of monsoon period & from the mid of monsoon aerosol size observed to increasing till the winter period as confirm with Angstrom Exponent. To understand the aerosol transport and its origin, meteorological parameters of temperature, wind and relative humidity derived from ERA interim data are analyzed during pre-monsoon, summer monsoon, post-monsoon and winter monsoon season. At 925 hPa, the Surface wind speed may enhance continental aerosol production from the dry surface and the high temperature along with the favorable convective conditions, may penetrate aerosols at higher altitude levels. Anthropogenic and continental aerosols long range transports are may dominant in this region along with the wind speed and direction may contribute to the significant variability in Alpha and AOD.

Aerosol Characteristics over High Altitude Western Ghats Location, Ooty, Tamil Nadu

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Atmospheric aerosols can affect the earth's climate through both direct and indirect effects and play important roles in atmospheric radiation and climate change. Among all of the anthropogenic aerosols, black carbon (BC) aerosols can effectively absorb solar radiation in the visible and infrared bands to heat the atmosphere and affect the climate and air quality and therefore play a unique and important role in the climate systems. The Intergovernmental Panel on Climate Change (IPCC) report indicates that the average direct radiative forcing of global BC aerosols is 0.4 $W \cdot m^{-2}$. BC aerosols make an important contribution to global warming and have become the second major warming factor after CO_2. In order to observe the occurrence of atmospheric aerosols level, the continuous monitoring of Black carbon was carried out from 2010 to 2019 at high altitude region of Nilgiris mountains (11.25°N, 76.43°E, 2520 meters mean sea level), the Western Ghats in southern India. Observed trends in Black carbon level were showed diurnal and seasonal variations. Almost an identical diurnal variation for all the months and also for different seasons, except winter months can be noticed and there is a gradual increase of BC mass concentration at 09.00 h and as the day advances, it starts to show a steady decrease and reaches the diurnal minimum around 13.00 h. Moreover, an evening peak (during 17:00 to 22:00 h) during Feb to May was noticed decrease gradually towards morning and become lowest during the early morning hours (05:00 h).and thereafter it slowly tends to increase to reach the secondary maximum after 20.00 h. With the advent of monsoon, diurnal variation is less pronounced as much the shallower boundary layer isolates the measurement site from the surrounding valley region. The monthly variation of BC loading shows the larger concentration of BC (1.287 $\mu g\ m^{-3}$) during the months of March, April and May followed by those in December, January and February and low concentration (0.417 $\mu g\ m^{-3}$) during September, October and November. The HYSPLIT back - trajectory analysis indicates the dominant easterly advection contributing to the seasonal high value of trace gases during the summer season.

THEME 15

Weather and Climate for Human Health

Carbon sequestration process of a semi-deciduous forest in Northeast India

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Tropical forest ecosystems play a significant role in controlling the global carbon cycle. The carbon balance processes of a forest ecosystem are controlled by several biometeorological parameters. North-East India (NEI) harbors rich forest ecosystem and is characterized by a unique climate system compared to the rest of the country. Despite its vast carbon sequestration potentials, no systematic study has been done until recently to quantify its atmosphere-biosphere carbon exchange processes. To fill this gap, an eddy-covariance technique based observational system was established in Kaziranga National Park in 2015. Under this activity, CO_2 and water vapor concentrations are measured using an infra-red gas analyzer. The wind components are measured using a 3D sonic anemometer. The gas concentrations and the vertical wind component provide the CO_2 and water vapor fluxes between the atmosphere and the biosphere. Additionally, weather sensors capable of measuring temperature, humidity, rainfall, and wind have also been installed at multiple levels. Soil parameters are measured using soil sensors. We studied the bio-meteorological processes in this tropical semi-deciduous forest to quantify the net ecosystem exchange (NEE), defined as the net amount of carbon exchanged through the photosynthesis and respiration processes by the land biosphere. It was observed that the pre-monsoon season is the most preferred, while the winter season is the least favourite time for carbon uptake by this forest. The diurnal rainfall pattern plays a vital role in determining the photosynthetic process. The respiration component of this forest ecosystem is found to be relatively higher compared to the other similar ecosystems in India. The annual NEE of the forest is estimated as +177 and -31 gC m^{-2} yr^{-1} for the year 2016 and 2018 respectively. The yearly gross primary productivity (GPP) of the forest for 2016 and 2018 is estimated as 2693 and 2564 gC m^{-2} yr^{-1} respectively.

Impact of Climate Change on Transmission Dynamics of Malaria in the KSA region using the Dynamical Model

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Malaria is the most notorious tropical disease existent in more than 100 countries globally. Over the last decade, the incidence of confirmed malaria has declined significantly in Saudi Arabia. The kingdom of Saudi Arabia has always strived for being a malaria free region, but the changing climate has interfered with its intervention policies. The recent trend due to climate change depicts a rise in malaria cases over the Saudi region. This work aims to assess the spatio-temporal distribution of malaria and its association with climatic factors in Saudi Arabia. VECTRI, a malaria model is simulated from 1981 to 2017 (37 years) over Saudi Arabia to assess the association of malaria incidence with climatic variables. The model dynamics of *Plasmodium falciparum* parasite transmitted by the *An. culicifacies* vector is verified over the Saudi regions. The four model output parameters such as rainfall, surface mean temperature, mosquito density and entomological inoculation rate (EIR) are analysed. Results indicate that the trends of malaria incidence are observed in three high-risk malaria provinces of Saudi Arabia. Analysis reveals that the malaria vector abundance is higher during April, May, and June. The intensity of malaria transmission is found to be higher in the Asir, Jizan, Najran, Makkah, Medina province of Saudi Arabia. It is also found that the peak of the malaria transmission occurs at the mean temperature of 29 to 34 °C and the mean averaged rainfall of 0.4 to 1.0 mm during the winter monsoon season. The favorable conditions for the malaria parasite to develop in the Saudi Arabia region begins with a lag period of one month after rainfall with optimum temperature. A significant decreasing trend of malaria cases was found in regions other than Asir, Jizan, Najran, Makkah, Medina provinces. This information may be useful for the planning of elimination of malaria in Saudi Arabia.

Keywords: VECTRI, Malaria, Transmission dynamics, Saudi Arabia

Affect of Weather, Environment and Wastes on Human Health

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Weather and climate have a great effect on human health. With the increase in the human population, there have been modifications in the environment of the earth and it has further made changes in weather and climate. Increase in human population and the development of civilization results in an increase in production of various types of wastes. It has been an ignorant practice of unplanned disposal of various types of wastes. These wastes have a very serious impact on human health. Weather has an immense influence on human health owing to outdoor debris and waste materials which are vulnerable to weather conditions. Release of volatile organic compounds, particulate matter and carbon monoxide are common from the debris of waste materials. VOCs and PM have both short and long-term effects on health. In case of availability of the abundant amount of sunshine and warm temperature, such debris undergoes chemical reactions and gives rise to even more harmful pollutants. There are various types of wastes which are being produced like organic wastes, dry waste, horticulture solid waste, construction and demolition waste, sanitary waste, street sweeping, drain silt, domestic hazardous wastes etc. Wind patterns, temperature and solar radiation all influence air pollution. Air pollutants can be carried by the wind to different places. Temperature also has an impact on air pollution by influencing the rate at which chemical reactions occur. Ozone available in the upper atmosphere blocks harmful Ultraviolet radiations but is considered a pollutant at ground-level. At ground-level, ozone is rarely emitted directly, but it is formed from chemical reactions involving VOCs and nitrogen oxides. Over the last 50 years, a huge quantity of CO_2, greenhouse gases and other pollutants have been continuously produced due

to human activities by improper disposal of wastes, burning of fossil fuels etc., leading to change in global climate. The weather has an immense influence on the spread of air pollution from waste management operations. Strong winds are a risk factor for site personals like it can disrupt dust and fine particles, irritating the eyes and respiratory system. In the last 130 years, the world has warmed by approximately 0.85°C. High temperatures lead to a rise in the levels of ozone and other pollutants in the air, which increase the number of patients suffering from cardiovascular and respiratory disease. Variability in rainfall patterns is likely to affect the supply of fresh water. Clean and safe drinking water leads to compromise in hygiene and increase in the risk of getting the diarrheal disease. This disease kills over More than 5,00,000 children aged under 5 years die every year due to water-borne diseases, drought and famine. Extreme weather events are becoming more intense and frequent. Climate change affects social and environmental determinants of health like clean air, safe drinking water and food. World Health Organization is emphasizing a reduction in the production of the greenhouse effect, availability of clean air and safe drinking water to save precious human lives from various diseases. In this paper, a detailed description of weather parameters and various types of waste materials affecting human health will be discussed.

Keywords: Weather, Climate, World Meteorological Organization (WMO), World Health Organization (WHO), Wastes, Pollutants, Health

Inter-Spatial Vulnerability Assessment of Heat Hazards in Summer-2018 over Madhya Pradesh using Wind-chill and Discomfort (Thermal) Indices

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Due to global warming, an increase in air temperature is a growing concern at present. This rise in temperature may cause mild to severe thermal discomfort and heat related hazards mostly for the people who are engaged in outside activities throughout the day. The present study shows the inter-spatial monthly distribution of thermal patches over major stations of Madhya Pradesh viz. Bhopal, Gwalior, Indore, Jabalpur, Hoshangabad, Rewa, Ratlam, Ujjain, Dhar etc. To carry on the study in the areas mentioned above, following dataset of primary and derived parameters were collected from respective sources, i.e. Weather Normal of all districts in Madhya Pradesh was collected from National Data Center (NDC), IMD, Pune, Hourly/ 3-hourly/ 6-hourly meteorological (synoptic/ autographic) observations were collected from Meteorological Centre, IMD, Bhopal for the months of March, April and May in the year 2018 for 33 districts of Madhya Pradesh, Statistical Tools used: Excel for data analytics, Visual Tools: Pie-chart for infographic analytics. In this study, various Heat Indices applicable for tropical climate including Wet Bulb Globe Temperature (WBGT) are used to estimate the thermal stress by analysing the meteorological data of Summer-2018 in Madhya Pradesh. The study was carried out for computing indoor, shady and outdoor heat stress separately and heat transfer rates to identify the places vulnerable to severe heatstroke in the month of March, April and May in 2018. It is observed that declaration of heatwave alone at any station is not sufficient for the administration and health organizations to take precautionary actions; also, discomfort indices should be referred for impact based monitoring and making work schedules. It is found that March

and April fall in the Partial discomfort category for at least half of the districts in Madhya Pradesh. It is interesting to note that several districts fall in discomfort category in outdoor conditions but not in indoor or shady conditions in May month. Severe stresses are observed mainly in the West and Central Madhya Pradesh during April and May months. Comparison of various Heat Indices is too performed along with computing Tropical Summer Index (TSI) and Apparent Temperature (AT) to indicate real feel-like temperatures in Madhya Pradesh during extreme temperature events.

Keywords: Summer-2018, Wind-chill factor, HI (Heat Index), WBGT, TSI, Discomfort Index

Warm-season human biometeorological index over Northern India: Climatology, Trends and Variability

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Climate change shows a noticeable increase in the average global temperature, mainly due to natural and anthropogenic activities (i.e., industrial and vehicular emissions, deforestation,etc.). In the current scenario, the frequency of extreme events such as heatwaves is increasing day by day due to a considerable rise in air temperature. Therefore, it becomes crucial to investigate the impact of heat stress on human health. Universal Thermal Comfort Index (UTCI) is one of the bio-meteorological indices used to analyze northern India's comfort level. The present study has utilized the 39-years (from 1981-2019) UTCI data at a spatial grid of 0.25° x 0.25° during the warm season (April-May-June-July). The highest seasonal average thermal discomfort (310 K) is noticed over northwest (NW) India compared to other Indian regions during the warm-season. Further, the sub-seasonal climatology of UTCI exhibits a maximum (312 K) UTCI during June compared to other months over NW India. The long-term spatial trend analysis of UTCI depicts that the rising trend (0.04 K year-1)over NW India compared to other Indian sub-regions during the warm season. Furthermore, extreme UTCI days (>32 to <38), which indicates the strong heat stress, have been increasing since 1981, which could further increase human stress leading to more detrimental effects on humans. Under this scenario, when humans are exposed to extreme thermal environments, which generally leads to the failure of humans' thermoregulatory mechanism, this phenomenon has many detrimental effects causing discomfort, making us more prone to cardiovascular disease, and direct exposure for many hours could even cause death. Therefore, this study is crucial as it will give an essential input in making different policies and strategies to mitigate and adapt to global warming.

Keywords: Climate change, Global warming, UTCI

Development of a probabilistic early health warning system based on meteorological parameters

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Among the other diseases, malaria and diarrhoea have a large disease burden in India, especially among children. Changes in rainfall and temperature patterns likely play a major role in the increased incidence of these diseases across geographical locations. This study proposes a method for probabilistic forecasting of the disease incidences in extended range time scale (2-3 weeks in advance) over India based on an unsupervised pattern recognition technique that uses meteorological parameters as inputs and which can be applied to any geographical location over India. To verify the robustness of this newly developed early warning system, detailed analysis has been made in the incidence of malaria and diarrhoea over two districts of the State of Maharashtra. It is found that the increased probabilities of high (less) rainfall, high (low) minimum temperature and low (moderate) maximum temperature are more (less) conducive for both diseases over these locations, but have different thresholds. With the categorical probabilistic forecasts of disease incidences, this early health warning system is found to be a useful tool with the reasonable skill to provide the climate-health outlook about possible disease incidence at least 2 weeks in advance for any location or grid over India.

Keywords: Extended range prediction, Malaria, Acute Diarrheal Diseases, Self-Organizing Map, Early Health Warning System

A comparative study of Antarctic Ozone Hole and related parameters before and during lockdown

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The aim of our study is to observe whether there is any variation in Antarctic Ozone Hole area and stratospheric Ozone density in 2020, during the COVID-19 pandemic or lockdown period in comparison to these trend in 2018 and 2019, because greenhouse gas emissions from industry and transport sector were much less throughout the world. Greenhouse gases like Nitrous Oxide and Carbon monoxide oxide play important roles to deplete Ozone. Though this is a tropospheric event, but when troposphere becomes cool, stratosphere becomes comparatively warm and hence much density of endothermic Ozone favors which implies less Ozone Hole area. The linear trend of Antarctic Ozone Hole area and Ozone density are presented for 2018,2019 and 2020 in two phases, i)January to July (non-spring period) and ii) August to December (spring). Moreover, average tropospheric Ozone level in each month of 2018 and 2019 are plotted and a linear trend of the same has been observed. The correlation coefficient between i) stratospheric Ozone density and Ozone Hole area, ii) stratospheric and tropospheric Ozone density has been calculated. The trends and values of the parameters have been compared during the COVID-19 pandemic period and of 2018, 2019.

Impact of COVID-19 lockdown on air quality over India with emphasis on the North East region of India

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The outbreak of highly contagious 'COVID 19' affected a huge population all over the globe and claimed many lives in a very short span of time. Worldwide, almost all countries introduced measures to restrict movements as part of their efforts to contain its spread which in turn has shaken humanity in all aspects of life including economy, education, environment, and physical and mental health etc. A nationwide restriction of public movement and industrial activities ('Lockdown' in common term) was also imposed by the Government of India from 25th March of 2020 in multiple phases successively with varied stringency. This lockdown significantly reduced all anthropogenic activities, including industrial activities and vehicular movements. This work aims to investigate the impact of this lockdown on the air quality over India with emphasis on northeastern India (NEI). To study the changes in concentrations of pollutants which have a critical impact on human health, satellite observations of aerosol optical depth (AOD), angstrom exponent, black carbon (BC) concentration, and fire count, are considered before and during the pandemic period and are compared with respect to the decadal (2010-2019) mean. It has been observed that the air quality improved during the period of first fifteen days after lockdown (Period 2) but bounced back during the next fifteen days (Period 3) as compared to before lockdown period of fifteen days (Period 1). AOD at 550 nm over the Gangetic valley reduced by 0.2 to 0.3 during Period 2 while the same increased by 0.1 during Period 3. The BC concentration also showed a similar trend but with a distinct reduction of more than 3 μgm^{-3} over parts of the NEI. The AOD decreased during period 2 over most part of the NEI with the highest decrease of 33.2% over the region closer to the Indo-Gangetic plains, whereas BC decreased more prominently during period 3 due to reduced forest fire activities with maximum BC reduction of 50.6% over eastern Assam. Over NEI, it has been observed that places that are closer to the source of pollution showed a drastic reduction in pollutants than remote locations.

Keywords: COVID-19, air quality, North East India, Aerosol, Trace gases, lockdown

Heat stress over the Indian Himalayan region

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The recent accelerated global warming and the associated global climate change is a worldwide concern. This negatively impacts various sectors and systems. The findings from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) reveals that the increasing greenhouse

forcing escalate the warming of the Earth, which leads to the increase in the magnitude and duration of the extreme events. Further, the rise in the temperature extremes has a direct influence on the health, economic activity, working efficiency and comfort of the global population. The rising global temperature increases the water holding capacity of the atmosphere following the Clausius–Clapeyron. The increase in the moisture or humidity of the atmosphere is one of the major reason for human discomfort. Therefore, a thermal discomfort index which integrates the combined impact temperature and moisture would better represent the human discomfort or heat stress as compared to the indices prepared using temperature alone. Therefore, the examination of heat stress becomes utmost important in the framework of work efficiency, health impact and deaths due to the extreme heat. Comparing the impact of climate change at different parts of the world, the mountainous regions are reported to be more susceptible to climatic changes as compared to other land features lying under the same latitudinal belt. The present work examines the heat-stress over the Indian Himalayas region in recent time. The eastern Himalayan region is dominated by the Indian monsoon rainfall while the western Himalayas receives most of its rainfall due to the activities of the western disturbances. This reflects that the different parts of Himalayas are dominated by different climate regimes. Therefore, the study mainly aims to examine the heat stress over different parts of Himalayas and its impacts on society.

Possible influence of radon and meteorological parameters during COVID-19

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Radon being a radioactive noble gas occurs everywhere in the environment and leads to high-level radioactivity. Its global average for outdoor level ranges from 5 to 15 Bq/m3. The annual worldwide average radiation dose due to naturally occurring radiation sources is 2.4 mSv. The radon air concentration varies greatly, and concentration enhances depending upon the ventilation conditions in the dwellings. The Covid-19 has impacted in the behaviour and lifestyle of human beings. The scientific community throughout the globe are working to minimise the spreading of COVID-19. The lockdown recommended by WHO to limit the spread of Covid-19 has increased the residence time inside the homes. Lockdown had the direct consequence by increasing exposure to radon 222 and a possible increase in health risks due to its inhalation. Lockdown as a measure to limit the spread of Covid-19 forces people sometimes to breathe low air quality that does not meet environmental criteria. If the air quality of gaseous and particulate pollutants is improved during the lockdown; however, radon exposure may influence the risk of developing lung cancer in radon enriched areas. For a person confined during the incubation period of the virus has a more significant exposure time and of relatively more risk of issues related to lung cancer. Although covid-19 recovery rate is entirely satisfactory when compared with the mortality rate, the mortality rate continuing its increasing phase all over the globe. Hence, this study aims to analyse the impact of weather and radon on covid-19 mortality rate in India. This study made with secondary data analysis of surveillance data of covid-19 from the Ministry of Health and Family Welfare Government of India computed levels of radon and weather-related parameters from weather stations. An effort is made to study the statistical variability and influence of meteorology during this period from January to October 2020. It is observed that there exists a correlation with humidity and anti-correlation with temperature and possibility of reasonable correlation with radon enriched areas.

Citizen Science for Weather over Mountainous Regions

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Mountainous regions show wide spatial climatic and weather variability primarily driven by the topography. Mountains modulate the climate and create micro-climates, induce different types of thermally and dynamically driven circulations, generate atmospheric waves of various scales, and affect the boundary layer characteristics and the dispersion of pollutants. At the local scale, strong downslope winds linked with mountain waves (such as the Foehn and Bora) can cause severe damage. Mountain wave breaking in the high atmosphere is a source of Clear Air Turbulence, and lee wave rotors are a major near-surface aviation hazard. Mountains also act to block strongly-stratified air layers, leading to the formation of valley cold-air pools and gap flows. Presently, neither the fine-scale structure of orographic precipitation nor the initiation of deep convection by mountainous terrain can be resolved adequately by regional-to global-scale models, requiring appropriate downscaling or parameterization. Additionally, the shortest mountain waves need to be parameterized in global weather and climate prediction models, because they exert a drag on the atmosphere. The study of weather and climate is primarily hampered by lack of observations. This is because of the difficulty of physical access, inhibiting the installation and maintenance of weather stations. The problem is compounded by the variety of the local weather conditions resulting in the weather station to be representative of only a limited range of sites. In the mountains, we are dealing with at least three types of situation – summit, slope and valley bottom – apart from considerations of slope orientation, slope angle, topographic screen and irregularities of small scale relief. These factors necessitate a very dense network. It is a universal problem but acute in India, which has a vast and complex mountainous region in the world. In India, weather observations in the most mountainous regions are sparse. To meets its operational requirement, Snow and Avalanche Study Establishment (SASE) has set up its own network of Automatic Weather Stations in Western Himalayas. However, even today, many of the mountainous regions do not have weather observatories. It poses great difficulty in understanding and prediction of weather over the mountains. In developed countries, many field Experiments have been conducted to study mountain weather, whereas not a single field experiment has been carried out in India. Ministry of Earth Sciences/India Meteorological Department (IMD) has plans to augment weather observations in the Himalayas, but because of peculiarities of the mountainous region, the IMD network needs to be complimented by a denser local network of volunteers through Citizen Science initiative.

Heat Stress and UTCI Variations in North-Western India

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Climate change shows a prominent increase in the average global temperature (Global Warming), which is mainly due to natural as well as anthropogenic activities (i.e. industrial and vehicular emissions, deforestation etc.). In the current scenario, the frequency of occurrences of extreme natural events such as heatwaves is increasing day by day due to the considerable rise in temperature. Therefore, it becomes important to study the impact of heat stress on human life. Whenever our body overheats, it tries to maintain its normal temperature through many thermoregulation methods such as sweating, which is not just dependent on air temperature. Humidity also plays a significant role in it, as the process of evaporation also depends on the saturation level of air around us. When the surrounding air is saturated (extreme case), no evaporation of sweat can take place. Therefore, researchers around the globe are now focussing more on indices that include several other parameters (e.g. humidity, insolation etc. along with air temperature (dry)). These indices increase with increasing temperature and humidity, and basically shows the discomfort and tolerance level for human beings. This increase leads to many biological issues on human's health such as extreme dehydration, making humans more prone to cardiovascular disease, increase in both morbidity and mortality etc. It also has many socio-economic issues such as a decrease in the efficiency of labour (especially the ones working under the direct exposure of sun), reduction in crop yield etc. Universal Thermal Comfort Index (UTCI) is one of the indices which we used to analyse the comfort level over the northwestern Indian region. Our spatial analysis of UTCI for the duration (1981-2019) shows the highest increase in amplitude (0.04 K per year) over northwestern Indian region compared to the rest part of India. The spatially averaged UTCI for whole Indian lat/longitude grid during AMJJ season also shows the increasing trend. This study is very crucial as it will give an important input in making different policies and strategies for both the purpose of mitigation and adaption against global warming. We are now planning to look for other parameters and natural synoptic events that can be associated with it.

Heat index trends and climate change implications over some smart cities in India

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Climate change causes significant temperature fluctuations leading to extreme heat or cold events in the urban areas. Smart cities make life more effective and efficient, which is necessary, given the projected rapid growth in urban populations over the next few decades. Extreme heat and cold may affect the health of those living in such cities. Since the climatic characteristics play a vital role in sustaining the livelihood of the residents in these areas, it is necessary to study the long term climate of these regions. Smart cities need to adopt comprehensive climate responsive development to ensure the health and well-being of residents. This study uses heat index (HI) and wind chill (WC) index, a measure of the combined effects of temperature, humidity and wind speed, to assess the variability of heat and cold exposure. The data is sourced from Surface Meteorological Stations, operated by the India Meteorological Department (IMD), located in the smart cities Agra, Varanasi, Madurai and Amritsar, Bareilly, Udaipur which experience heat waves and cold waves during the hot season (March-June) and cold season (December-February), respectively. Long term data from selected weather stations is used to estimate the variability of heat and wind chill indices at various time- scales, viz., monthly, weekly. The statistical estimates such as mean, standard deviation and coefficient of variation, at various time scales, have been derived from the weather observations over a period of 31 years (01 January 1980 – 31 December 2010). It is observed that between 1980 and 2010, for Varanasi, Agra and Madurai average days in a year, where HI was greater than equal to 32°C is ~ 150 to 200 days. Also for the season as a whole, it is observed that the HI is approximately 1° to 1.8°C warmer than the ambient temperature. However, seasonal maximum ambient temperatures are increasing at an average rate of ~ 0.4°C per decade during the season (March-June).

The HI shows an increasing trend over Varanasi, Agra and Madurai in March and April. The wind chill index shows a decreasing trend over Amritsar, Bareilly and Udaipur. The daily data shows a significant increase in the frequency of HI for the summer season, which depicts the recent increase in temperature anomalies over the whole of India.

Keywords: Smart cities, regional impact, Heat Index, Wind Chill index

Reducing lightning injuries, deaths and property damage

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Lightning causes not only property damage but also deaths and injuries to people and animals across tropical countries. The African Centres for Lightning and Electromagnetics Network, Inc (https://ACLENet.org), a nonprofit organization operating in Uganda, Africa, works in sub-Saharan Africa to decrease these effects. ACLENet has been active with public education on lightning science, safety and protection using television broadcasts, newspaper inserts, and public service announcements, teaching at schools and providing lightning protection (LP) to model schools throughout Uganda. ACLENet maintains a database of lightning injury reports for over 30 African countries and works with governments to adopt internationally recognized lightning protection standards with LP education for engineers, architects, and LP installers. Additionally, ACLENet investigates lightning deaths and injuries to learn more about mechanisms of injury in tropical areas and supports research on effective personal lightning safety practices.

Variability and change in human thermal comfort during heat waves over India

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During recent years heatwaves have become one of the major natural hazards taking lots of lives. Studies have shown that the increasing trend in the frequency of heatwaves and also exhibits high spatial variability in its distribution of over India. There are limited studies focused on the weather related human thermal comfort over India due to non-availability of high resolution (HR) climate data. Here we develop dynamically downscaled HR (4x4 km) daily climate information for the months of April to June during 2001-2016 using a regional climate model, which are validated with station observations. Heat stress is due to the combined effect of high temperature and high relative humidity. The human thermal comfort and its variability are quantified in terms of indices like Excessive Heat Factor (EHF), Heat Index (HI), Humidex, Apparent Temperature (AT) and Wet Bulb Globe Temperature (WBGT). The daily surface temperature and thermal comfort indices of HR are in accordance with the station observations. The distributions of indices have spatial and temporal variability. Climatologically the extremes are over the south-east coast of India, Indo-Gangetic plains, northwest India and adjoining areas of Pakistan. The results show that the days with

persistent heat stress are moreover the Indo-Gangetic plain and comparatively less over south-west coast of India. Frequent days which gets dangerous discomfort are generally moreover South India than North India, but the trend of the extreme category of indices are significantly increasing (99% significance level) over North India during the study period. The days with hazardous discomfort are significantly increasing (99% significance level) over north India. The occurrence of long days with extremes of indices indicate the chances of heat cramps, heat stroke or even death to those who are more prone to sunlight. Adverse health impacts were more over the Indian states like UP, Jharkhand, Bihar, Odisha, Telangana, Haryana, Punjab, and Rajasthan. This increasing trend of temperature extremes will adversely affect society and cause many health related diseases. These findings put forward to improve the heat or health warning system to reduce the causalities.

Seasonality analysis of relationship of PM2.5 and PM10 with micro-meteorological parameters over a complex terrain

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Regional atmospheric aerosol concentrations are intricately linked to seasonal meteorological conditions, near surface microclimatology and surface topography. From 2014-2017, an association of individual meteorological factors- air temperature (AT), wind speed (WS), relative humidity (RH) and planetary boundary layer height (PBLH) with aerosols $PM_{2.5}$ (µg/m^3) and PM_{10} (µg/m^3) concentrations are studied in Tezpur. This is a semi-urban area in the mid-Brahmaputra river valley, at the eastern Himalayan foothills of Assam. It offers an ideal microcosm of natural and anthropogenic conditions for evaluating aerosol concentrations. Initially, near surface wind patterns over Tezpur are examined to understand the orographic effect on local wind patterns. Subsequently, backward trajectory analysis exposed the sources of wind borne aerosol particles in a synoptic scale. Pearson correlation analysis elucidated the association of individual meteorological factors with $PM_{2.5}$ (µg/m^3) and PM_{10} (µg/m^3). The Wind Rose graphics exhibited significant impact of orography and complex terrain on the prevailing regional near surface wind patterns. The unique topography and hill ranges surrounding the station have shown a profound impact on the prevailing near surface wind pattern and flow direction; typically representing the orographic effect over the Brahmaputra valley. The local wind patterns are in contrast to the pattern of the synoptic winds changing from calm northeasterly in winter to calm southeasterly in pre-monsoon, which changes to moderate southwesterly in monsoon. The southwesterly winds coming from the Bay of Bengal arrive over the station after getting deflected from Arakan Hills Myanmar, from its south or southeast. Backward trajectory analysis proves that trans-boundary and regional transport of aerosols contributed to local mass loading in the mid-Brahmaputra valley. The average mass concentration of particulate matter is highest during the winter and pre-monsoon seasons in contrast to PBLH, which is observed to be highest during the pre-monsoon. Soot from agricultural residue burning and dust from the dry river bed, brick kilns and aerosol blown from Indo-Gangetic Plains could be probable aerosol sources during the seasons. Pearson correlation analysis results show that all meteorological factors, except wind speed, had both positive and negative effects on the seasonal particle mass concentration, though $PM_{2.5}$ (µg/m^3) and PM_{10} (µg/m^3) particles displayed individual seasonal profiles. Wind speed shows consistent negative correlation with particulate mass concentration which indicates the dominance of wind pattern over the region, however, degree of correlation requires further research. This report on aerosol relation to meteorological factors, surface microclimatology and topography, breaks new ground for future investigations.

THEME 16

Indigenous Instrumentation for Atmospheric Profiling (Radars, Sodars, Lidars, AWS, etc.)

A new approach to atmospheric wind profiling with radars

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The weather observation instruments that can observe the air motion of the troposphere with high degrees of accuracy and time resolution has been developed in various countries, especially in India, European countries, the US and Japan, due to the remarkable progress of the remote sensing technology in recent years. Among such instruments, wind profiler radar (WPR), which can provide the three-dimensional structures of wind velocities and wind directions of each layer of atmosphere in real time, has become indispensable to the world today.

There are different approaches for extracting the three dimensional winds of atmosphere and accordingly radar has been designed and realized. Doppler Beam Swinging and Spaced antenna techniques are being used for this purpose. The advancement of new technology in hardware and signal processing approaches has given significant advantages to extract the winds in very high temporal and spatial resolution in a highly varying wind fields. By employing Post Beam Steering (PBS) technique in radar design and observation will help in extracting the winds in most difficult atmospheric phenomena such as convection etc.

PBS includes various signal processing algorithms such as beam forming, spectral estimation, moment's estimation etc. Capon beamformer is used for beam synthesizing in the desired direction within the radar beam width. Using the synthesized beam, the power spectrum is obtained through various power spectral estimation methods such as Fourier (non-parametric), Multiple Signal Classification (MUSIC) and Eigenvector (EV) methods. This technique is used to synthesize the beams in the desired directions and so called as Post Beam Steering Technique (PBS). As these measurements typically involve reception of signals by number of independent antennae and receivers, the vertically received signals are steered along the desired line of sight (angle) by introducing systematic phase shifts in the received signals themselves. The beam steering can be optimized by weighting vectors through beamforming approach like Capon method. Then the weighted steered signals are combined linearly to produce a two-way beam pattern in the desired line of sight angle within the transmit beam volume. The beams are independently synthesized for an off zenith and equally separated 32 different azimuth angles (in principle any number of angles) within the transmit beam width. The power spectrum in the desired Angle Of Arrival (AOA) is obtained by various spectral estimation methods. The profiles derived by this method matches well with all other conventional approaches and possible to extract winds in disturbed atmospheric conditions also demonstrated.

Twilight photometer a powerful tool for study of different atmospheric events

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The Earth's atmosphere holds suspended moisture and solid particulates termed 'Aerosols'. The functions of detection, identification and quantification of atmospheric aerosols are of great value as they are able indices of atmospheric pollution. Twilight photometry is a technique involving ground based passive remote sensing of the twilight sky brightness that can be used to derive the vertical distribution of aerosols from 6 km up to 350 km. It is an effective system having a simple and inexpensive underlying principle of operations, yet exhibits extremely efficient, accurate and precise usage and can be operated by even a person of average skill. However, it can be seen that the resultant data was consistent with nearest peer technologies, such as LIDARs, balloon observations, night airglow observations etc.

Aerosol measurements were carried out at Kolhapur (16°42'N, 74°14'E) during the period 1 January 2009 to 15 May 2011 using a semiautomatic twilight photometer. The mesosphere and the lower thermosphere lies above the maximum altitude for weather balloons and below the minimum altitude for orbital spacecraft. As a result, it is the most poorly understood part of the atmosphere. In the present study, Twilight photometer was used to calculate the mesospheric and thermospheric Aerosol Number Density per cubic decimeter(AND), for the first time in India. Furthermore, some attempts were made to examine the effect of different atmospheric events such as twilight airglow, meteor showers, the existence of clouds, volcanic eruptions, wind-blown dust and anthropogenic activities (road construction work) on the vertical profiles of aerosols. Each of these activities demonstrated their effect with varying intensity and at different altitudes with their own characteristics.

The twilight airglow lines showed a large maximum at ~80 km and above with ~600% to 1000% higher intensity than that twilight glow due to aerosols. The dust particles during three types of meteor showers showed intense peaks in-between 60 km and 140 km having ~160% enhance in intensity. Due to high-level clouds, intense peaks were detected above 6 km in the troposphere having ~400% to 600% higher intensity. Due to invisible thin clouds ~ 700% to 1000%, intense thin peak lines were observed. Wind-blown dust layers overlapped with Junge layer were noticed in between 12 and 25 km, with ~165% rise in aerosol loading. During road construction work in Kolhapur, one additional aerosol layer was observed in the troposphere in between 11 to 14 km peaking at 12 km with ~400% increased aerosols. Due to volcanic eruptions of 2010, ~85% growth in aerosol loading in between 6-11km was observed.

The main aim of this paper is to demonstrate the measurement capabilities offered by the Semiautomatic Twilight Photometer. Twilight Photometer, although currently seldom used, is still a very effective and the most appropriate tool for long-term monitoring of atmospheric aerosol loading and different atmospheric parameters in a wide range of height for a day-to-day basis.

Keywords: twilight technique, aerosols, remote sensing, meteor showers, twilight airglow

Upgraded indigenously developed Digital Current Weather Instrument System for Airport Meteorological Services

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India Meteorological Department (IMD) is providing services to the Aviation sector among its various fields of service. To cater to the needs of the aviation meteorological services, IMD installs different kind of meteorological instruments at the runway. These are AWOs, DCWIS, DIWE and HAWOS. IMD has continuously improved its instrumentation over the time at par with ICAO standards.

Till 2018, IMD's DCWIS system was based on conventional data logger and data transmission on serial protocols and 7 segments LED based slave display. This system has issues like difficulty in extending multiple displays, a lot of hardware dependency and long distance communication issues over coaxial cables. In this system separate set of hardware was required on receiving side for different runways. These were causing maintenance problems and the system was very complex at big airports like Delhi where multiple runways are there.

In this paper, an improved version of DCWIS is presented, which provides a solution to conventional problems and easy troubleshooting. The new DCWIS works on Ethernet based communication protocols which makes it convenient to extend the number of client display as required. All hardware of data receiving side has been removed and data is processed and visualized on a server. The data transmitted from multiple field systems installed along the runway is received in computer in MBR/ ATC via wireless or optical fibre communication mode which acts as a server. The server can be configured to control the slave displays and the user can choose the required parameters. Contrary to the conventional system, data from upto six runways can be accommodated on a single screen and be shared with Airport authority and other users.

Server stores data of received and derived parameters with a time stamp in real time. 1-min, 2-min and 10-min average data along with instantaneous data and metadata are stored in a suitable relational database. The archived data is available to PC based data display software for real time display of data in ATC and MBR. The data are displayed in both numerical and graphical form. Multiple software based generic slave displays can be provided as per requirement.

Above system has been installed at IGI Airport, New Delhi and working satisfactorily. Installation at other airports is in progress.

Keywords: DCWIS, Slave Display

Assessment of stability of atmospheric data measurement by Pisharoty GPS-RS sonde as seen from the ascent and descent phases of the sonde over Bengaluru region

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The information about the vertical profile of the atmosphere is essential for understanding atmospheric conditions and accurate weather forecasting. Considering the recommendations of WMO on precision, an attempt is made to assess the precision of upper air measurements. The upper air observations were made for more than one hundred ascents of indigenously developed Pisharoty GPS-RS instrument by Indian Space Research Organisation (ISRO) at Department of Physics, Bangalore University during multiple campaigns of week-long duration with daily twice ascents at 00GMT and 12GMT. Every ascent was tracked for the entire duration from the time of balloon release through balloon burst altitude and till the loss of GPS signal during the descent phase of burst balloon with GPS-RS instrument.

The accuracy is a closeness of the measurements of actual value, while precision is the closeness of the measurements to each other. Accuracy can be checked up among the sensors of different makes or models. Precision can be verified by repeating the tests under similar conditions. Depending on the sensing response of the sensors used for atmospheric pressure, temperature and relative humidity, and also ascent rate of the balloon, accuracy and precision of the measurements are defined. Periodically inter-comparison of various models of GPS-RS instruments is carried out, and accuracies of the sensors were estimated statistically.

From the ascent phase data of GPS and radiosonde, conventional profiles of altitude based atmospheric pressure, temperature, relative humidity, horizontal wind speed and directions are obtained. Temporal exposure of sensors to the ambient atmosphere during the ascent phase is almost uniform with an assumed steady ascent rate of the balloon. The rising balloon may experience unusual vertical air currents associated with turbulent pockets of air or vertical clouds embedded with updraughts and downdraughts. Following the balloon burst, the stretched rubber flop of the balloon along with attached GPS-RS instrument and thread starts with a rapid descent rate till it reaches terminal velocity with a subsequent gradual reduction in descent rate till it reaches the surface of the Earth.

Under normal conditions of battery power and sensors' health, data transmission to ground-based GPS-RS receiver remains undisturbed during the descent phase. It provides a good descent profile on par with ascent phase profile. From these ascent and descent profiles, atmospheric pressure, temperature and relative humidity data at several altitudes could be compared for the precision check. This process was carried out for all the balloon ascents, and statistical analysis on the precision of the parameters observed are presented.

Estimation of tropopause height from GPS-RS observations

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The tropopause constitutes a vertical separation in the atmosphere that segregates the lower weather active region, viz., the troposphere, from an upper, steadier region, the stratosphere. For the tropical region, the determination of lapse rate and tropopause altitude from temperature profiles of degraded altitude resolution typically leads to an underestimation of the tropopause height. Mean magnitudes of this effect range up to 500-600 m for altitude resolutions of 1 to 6 km. Considerably larger effects are found for tropopause. From the temperature profiles, wider tropopause altitude displacements were found, and the tropopause turns out to be less sensitive for vertical resolution. It infers that, while in the tropics the cold point tropopause is commonly used, in the case of coarsely resolved profiles, the lapse rate tropopause appears to be more robust, and vice versa for mid-latitudinal atmospheres. However, adaptive, resolution-dependent lapse rates can improve the tropopause determination.

In contrast, the variability of the tropopause dislocation is reasonably large in the tropics such that the recommendation of an inductively generalized correction scheme for tropical tropopause heights seems audacious and even inappropriate. Related effects on the tropopause displacement are then complicated to predict because it depends mainly on the surviving fine structure. Tropopause determination procedures do not distinguish between the a priori contribution and the measurement contribution to the final temperature profile. The large displacements, along with the large scatter found in the analysis. In consequence, it seems to be more appropriate to use smooth a priori profiles if retrieved temperature profiles are intended to be used for tropopause altitude determination. An attempt is made to analyze the possible dependence of a tropopause altitude on the vertical resolution of temperature profile and to evaluate possibilities to potentially correct tropopause altitudes inferred from coarsely resolved temperature profiles. Suppose related altitude errors can be corrected by a slight modification of the tropopause definition, which, when applied to temperature profiles of finite vertical resolution, reproduces the tropopause altitude according to the WMO definition when applied to the original data. The results are discussed in detail.

Technical implementation of first Central Himalayan VHF ST Radar at ARIES, Nainital

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The Himalayan region plays a crucial role in determining the meteorological condition of the Indian subcontinent. Hence in depth understanding of the Himalayan atmosphere needs continuous observations of the pattern of the wind over the region. Wind profiler radar has become the most efficient instrument for continuous monitoring of wind parameters of the atmosphere in all weather condition with very high temporal and spatial resolution. Aryabhatta Research Institute of Observational Sciences (ARIES), established compact VHF wind profiler radar system operating at

206.5 MHz in the foothill of the Himalayan region near Nainital, (29.4N; 79.2E; 1958m amsl). First of its kind, the entire radar system is arranged within a 30 m x 30 m two storey building for better utilization of available space on the hilly terrain. In an innovative way, 12 clusters of 49 elements are placed on the rooftop with required precision in quasi circular aperture fashion. As in VHF band, mean clutter signal strength from mountain terrain is significant; a metal fence of height 3.5 – 4 mtr was designed and installed at the perimeter of the rooftop to gain improvement in delectability of weak atmospheric signal. The design parameters of the fence were finalized after a set of experiments conducted at different places within and outside of the institute. Activation and integration of the clusters of the system progressed with the extensive calibration of each individual Transmit Receive Module (TRM) connected with each antenna.

The system is now in operation and providing potential data for frontline atmospheric research in the Himalayan region. The wind profiles obtained from the radar have been validated against collocated GPS-radiosonde. In the proposed talk, technical implementation of the system and result on validation are presented. Further, key facts experienced during stages of activation and up-keeping the system are also discussed.

Details of Weather Radar and Automatic Weather Station, Indigenous Instrumentation Indigenous Development of Passive Microwave Sensors for Atmospheric Profiling and weather Prediction

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Atmospheric Profiling requires the knowledge of Atmospheric constituents. Those Atmospheric constituents that can be monitored using Microwave Sensors are Water vapour and oxygen. Presently the Water Vapour is considered as an important Atmospheric constituent for weather prediction. Similarly, there are parameters namely liquid water content in clouds, Soil moisture in the Soil of land, the Salinity, wind speed and direction over Sea Surface also the Snow extent and depth of Snow as well as melt and freeze cycle of snow on land and on Sea ice in the Antarctica and Arctic of South and the North Pole respectively.

All these Parameters namely:-

(i) Water Vapour in Atmosphere (ii) Liquid water in clouds (iii) Wind speed and direction over oceans, (iv) snow on land and Sea ice in the North Pole (Arctic Sea and South Pole Antarctic Sea) (v) Soil Moisture (vi) Salinity of Sea Water is as an input from Soil that is a parameter in the model which is used for prediction of weather.

All these above mentioned physical parameters are/Sensitive to a certain Microwave frequency. The Microwave frequency for each parameter is given below.

(i) Water Vapour	22.235 GHz /183GHz
(ii) Liquid water in clouds	31.6 GHz
(iii) Soil moisture	1.4 GHz
(iv) Salinity of Sea Water	1.4 GHz

(v) Wind speed and Direction on Sea Surface	19.35 GHz
(vi) Snow on land and Sea ice	37.0 GHz

From the above one has to develop indigenously the Radiometers – Passive Microwave Sensor for each frequency. The frequencies are 1.4 GHz, 19.35GHz, 22.235 GHz, 31.6 GHz, 37GHz, and 183.0 GHz.

There are three types of Radiometers, namely, (i) Total Power Radiometer (ii) Dicke Radiometer (iii) Noise injection Radiometer. We will develop both Total Power and Dicke Radiometer. These Radiometers will be (i) Ground based for local Monitoring and (ii) To be placed in aircraft of DRONE and (iii) To be placed in Spacecraft. So that these Indigenous radiometers will provide localized, information and Area wise information and lastly will provide global information.

VHF Radar observations and WRF model simulations of development and structure of Tropical Mesoscale Convective System (TMCS) over Cochin, India

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Understanding the evolution and structure of convective clouds is very significant in climate studies and weather forecasting. VHF radar(205MHz) located at Cochin(10°N,76°E) provides three-dimensional wind profile data with an altitude range of 315m to 20 km. The radar beam can be tilted in angles of 0 – 30° in off-zenith direction and 0 – 360° in azimuth direction at every 1° interval, thus capturing the three-dimensional picture of the atmospheric feature. This study used profiles of signal to noise ratio, Doppler width, and wind with a vertical resolution of 45 m on May 24-25, 2019. Continuous observations were made during this period. Deep convective systems, which have vertical velocity extending in the height of ~15–16 km. Strong updraft and downdraft core have been observed and it gives the vertical structure of the deep convective system. Doppler width provides turbulence associated with deep convection.

The Advanced Research WRF (WRF-ARW) model is used for the simulation of the present convection event over Cochin. It is well captured the structure and evolution of convective clouds.

Initial results of Phased Array Doppler SODAR installed at Kolhapur region

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The Phased Array Sound Detection And Ranging (SODAR) is the simplest and most effective ground-based remote sensing device to study the atmospheric boundary layer. The SODAR system is installed by the Indian Institute of Tropical Meteorology (IITM), in the campus of Sanjay Ghodawat University at Atigre in south-west Maharashtra, in November 2019. The SODAR has a capacity to measure the three-dimensional wind structure up to the height of 2 km depending on the prevailing weather conditions. Therefore, it is a unique system to study the atmospheric boundary layer dynamics. We analyse the observations for the period of November-2019 to October-2020. In this paper, we presenting initial results on wind structure observed by the sodar system. The observed wind structure during the onset phase of south-west monsoon will be discussed. During the study period, the Nisarg cyclone was formed in the first week of June in the Arabian Sea and we capture its effect on wind profiles over the study region. Based on the current understanding, status of the on-going development activities in CSAS will be discussed for collaborations.

Keywords: Monsoon, Cyclones, Doppler SODAR, Atmospheric boundary layer

Global Lightning Occurrence and Impacts

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Over two billion lightning strokes are detected globally every year by Vaisala's Global Lightning Dataset GLD360 network. Coverage is complete over the world, such that every thunderstorm that occurs is detected with a location accuracy averaging one km. A large portion of these detections is over the Indian Subcontinent and Southeast Asia, as well as over the remote oceans. Every cloud-to-ground lightning stroke is fully capable of causing casualties and damages. For this reason, lightning data are used in forestry, utilities, aviation, weather services, military, industrial, recreation, media, and insurance applications. Recent studies in Bangladesh and Nepal are matching the occurrence of lightning with the fatalities. It is apparent that casualties often occur during labor-intensive agriculture that occurs during the daytime and in the months when lightning is most frequent. The talk will conclude with a set of updated lightning safety recommendations.

Validation of GPM rainfall over sub-Himalayan stations of Arunachal Pradesh

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This study presents an analysis of validation of Global Precipitation Measurement (GPM_3IMERGHH v06) final run products over sub-Himalayan stations of Arunachal Pradesh. The study region covers Ranganadi river basin (Red River of North East India) in Arunachal Pradesh. Ranganadi River is a northern tributary to Subansiri River which finally combined with the Brahmaputra River near Lakhimpur, Assam. The GPM_3IMERGHH v06 products were compared with 17 synoptic stations on a daily scale for the monsoon period of June 2019 to October 2019 (153 days). GPM_3IMERGHH v06 product found to overestimate daily precipitation from 1% to 13% at 5 Automatic Weather Stations (AWS) while underestimated daily precipitation in the range of 0.1% to 33% at remaining AWS stations. Majority stations where GPM products overestimate the daily precipitation lie across the boundary of Arunachal Pradesh and Assam. Highest accumulated GPM (1632.29 mm) and AWS rainfall (2188.8mm) observed at Pange station, which is present at the topmost point of Ranganadi river basin. Average accumulated GPM and AWS rainfall observed in Ranganadi river basin were 1392mm and 1554.5mm respectively during the monsoon period. Least performance of GPM model observed at Nakar station with modified Kling-Gupta efficiency (0.15) and GPM underestimated daily precipitation value with a relative bias of 0.91%. GPM model performed best at Searchgai station among all 17 stations with the highest modified Kling-Gupta efficiency (0.69) and GPM underestimated daily precipitation value with a relative bias of 3.466%. The correlation coefficient for GPM and AWS stations ranging from 0.27 to 0.73 with Root mean square error value ranging from 13.5 to 34.5, while modified Kling-Gupta efficiency value ranging from 0.15 to 0.69 across the 17 stations in Ranganadi basin during the monsoon period. More analysis will be carried out for the stations of different topography at a different season.

Keywords: Global Precipitation Measurement, Automatic Weather Stations, Ranganadi river basin

THEME 17

Severe Weather and Complex Terrains

Rainfall extremes, warnings, associated systems and related IBF during Monsoon 2020

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The Monsoon 2020 (June-September) was 109% of its LPA while State of Maharashtra received 116% of its LPA (with only 3 deficient districts). All the four meteorological sub-divisions viz. Konkan-Goa (+28%), Madhya Maharashtra (+29%), Marathwada (+30%) and Vidarbha (-10%) received normal rainfall. This year Marathwada received normal or excess rainfall in all the four months, Konkan – Goa received large excess rainfall during August while Vidarbha received deficient rainfall especially during September. The in depth study of extremes of rainfall, warnings due to associated systems and related Impact Based Forecast (IBF) during monsoon 2020 as issued by IMD is studied in the present paper indicating glimpses of progress towards forecast and relevant products generation that leads to serve the users better.

This study for Monsoon 2020 recorded various systems which were originated from Arabian Sea or Bay of Bengal and affected monsoon rainfall in different meteorological sub-divisions of the State in various ways due to complex terrain of the regions. The extremes of rainfall (viz. heavy, very heavy, extreme heavy rainfall) for different sub-divisions of the State were recorded and analyzed critically in all the four months. The associated systems which caused the extremes of rainfall were studied and analyzed. The study revealed that the upper air cyclonic circulations, mid tropospheric cyclonic circulations, trough, offshore trough, shear zone, low pressure areas, well marked low, depression etc. in different months resulted in extremes of rainfall in various parts of the State for which warnings were issued. Even strong westerlies from Arabian sea and packed isobars over Arabian sea resulted in extremes of rainfall over Konkan-Goa and Madhya Maharashtra, especially. This time India Meteorological Department (IMD), Pune and Mumbai tried for Impact Based Forecast (IBF) for the first time to facilitate the disaster managers and other users in rectification/mitigating of damages at the earliest which occurred/likely to occur due to extremes of rainfall for a number of days in succession. This paper studied critically the IBF issued for the megacities (viz. Mumbai, Pune) of the State for further improvement of the same in future. The content of IBF described chances of flooding in low lying areas, uprooting of roadside trees, major disruption of traffic flow, reduction in visibility, slippery roads during intense spells of rain, developing potholes on roads etc. The IBF issued well in advance helped common people to minimize their sufferings. Accurate forecast, warnings for extremes of rainfall and relevant IBF issued by IMD generated trust of local governance, disaster managers in the megacities of the State.

Keywords: Extremes rainfall, Warnings, Monsoon 2020, Weather systems, Impact Based

Seasonal Mean and Extreme rainfall events over Northwest India during Indian Summer Monsoon in an Indian Regional Reanalysis Framework

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The spatio-temporal variability of monsoon rainfall processes, especially the extreme rainfall events (EREs) over different geographical regions around India is quite complex due to its variable topography, distance from the moisture sources and circulation patterns. Northwest Indian region being the "breadbasket" of the country, and home to a major fraction of Indian population and intensive urbanization is extremely vulnerable to ramifications of EREs such as flash floods, landslides, agricultural and infrastructural damages along with significant loss of human and animal lives. Such events and the associated variability are in general expected to increase owing to climate change. There are limited reports on the characteristics of EREs over north-western Indian region. Therefore, this forms the main motivation to examine the EREs over Northwest India during Indian Summer Monsoon (June-September) for the period 1979 to 2015. We have used Indian Meteorological Department (IMD) and high-resolution Indian Monsoon Data Assimilation and Analysis (IMDAA) reanalysis daily precipitation datasets available at spatial grid 0.25° x 0.25° and 12 km, respectively. The state-of-the-art IMDAA reanalysis data has been compared with IMD gridded rain gauge data using standard statistical methods. In general, the IMDAA produces better spatial rainfall distribution compared to IMD data at monthly and seasonal time scales, but significant overestimation is noticed. Furthermore, EREs from IMD and IMDAA exhibit significant quantitative differences in trends. Our study will provide input for future extreme rainfall mitigation policy framework and infrastructure designing.

Keywords: Extreme rainfall, Climate change, IMD, IMDAA

A study on extremely heavy rainfall over some districts of Madhya Pradesh during 28-30 August 2020

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The study enlightens that the well-marked low pressure area moved from South West Jharkhand and its neighborhoods with associated cyclonic circulation extended upto 7.6 km above mean sea level tilting southwestwards with height to East Rajasthan and adjoining West Madhya Pradesh as low pressure area during 27-30 August 2020. The study considered the movement of a system that has given heavy to very heavy rainfall together with some exceptionally heavy rainfall along its path. During the period, on 29 August 2020, the system was over North Madhya Pradesh and adjoining South Utter Pradesh with associated cyclonic circulation tilting southwestwards with height. It was noticed that the system gave maximum rainfall on 29 August 2020 i.e. district's average of Chhindwara 250.6 mm, Betul 142.4 mm and Hoshangabad 191.1 mm with exceptionally heavy and very heavy rainfall at Chaurai (414.4 mm) and Parasia (331.0 mm) in Chhindwara district, Shahpur (193.2 mm) and Ghodadongri (182.0 mm)

in Betul district and Sohagpur (241.6 mm) &Pachmarhi (228.0 mm) in Hoshangabad district which generated floods over SE Madhya Pradesh and East Vidarbha.

From the Radar images, it is observed that average Surface Rainfall Intensity (SRI) was found between 39-73 mm per hour and Cloud Stretch was from 900 meters to 14 km (Bright Band) above ground level, and turbulence speed was between 35-55 kmph. The downpour and high reflectivity of clouds were observed over the area and satellite images also showed that a large amount of moisture was pulled over to the area on 29 August 2020. Very strong lower level convergence and upper air divergence were also seen during the period.

This study shows that the synoptic situation prevailing, dynamic conditions and orography of the area were found to be positive conditions for the extremely heavy rainfall.

Keywords: Well marked low pressure area, cyclonic circulation, surface rainfall intensity, exceptionally heavy rainfall, orography.

Spatio-Temporal distribution and Hazard Characteristics of Severe Local Convective Storms (SLCS) in Assam, India

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In Assam, Severe Local Convective Storms(hereafter SLCS) are recognized as exceptionally powerful and destructive meteorological events resulting in both death and loss of property, as well as livelihood. This study investigates the temporal, spatial and hazard characteristics of Severe Local Convective Storms(SLCS) in the state of Assam lying in the North Eastern Province of India and provides a climatology of SLCS for the state of Assam, with respect to Distribution, Frequency, Seasonality, Time of occurrence, Storm types and Storm severity. Using historical data on severe convective storms dating from 1962-2016, patterns of SLCS threat and risk to various geographic populations were investigated. A methodology for ranking the severity of the storms in the historical dataset, based on recorded damage/impact, was specifically developed for the study. Our findings in this study show that SLCS can occur throughout the state of Assam, but there are clearly demarcated areas of higher frequency and concentration. From the monthly distribution of SLCS events, as might have been expected, the most active month is April. The monthly distributions of hail, rain, and wind follow the same pattern as the total number of events. The probability of SLCS is not uniform throughout the day. Convective cells tend to reach their most vigorous development during the latter part of the evening and night hours. The observed seasonal pattern of SLCS day's distribution corresponds with the time of the year when convective heating is at its highest in the region, therefore high storm frequencies are to be anticipated. Although November, December and January show the lowest frequency during the entire year, it is still surprisingly high considering that convectional heating has decreased substantially by then. Hail and lightning do tend, however, to occur later in the day than large hail events, heavy rains, or Severe Thunderstorms. Further, SLCS data of 55 years been processed in the study to find out the annual and seasonal variability for which Mann-Kendall (MK) test has been used together with the linear regression for the determination of

trend and slope magnitude. The result infers that in the case of SLCS days no trend is noticeable for the 14 districts, however, an increasing trend is seen for the 5 districts and the decreasing trend is seen for the 11 districts of Assam. In general, there was conformity in the results obtained from the Mann-Kendall test and the linear trend line for the 24 districts. A major outcome of the study is the production of an SLCS risk map of Assam, which it is hoped will be of benefit to a number of stakeholders in the state, and assist in guiding the operational responses of authorities, especially in terms of the interventions that are designed for disaster risk reduction in the state of Assam.

Keywords: Local Severe Convective Storms (SLCS), Assam, frequency distribution, trend, convective available potential energy(CAPE)

Use of Satellite Data and Products for Monitoring and Prediction of Thunderstorms and Tropical Cyclones

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Monitoring detecting and prediction of severe weather like a thunderstorm and tropical cyclone (TC) still remain a challenge for forecasters. Objective of this study is therefore to develop suitable techniques for monitoring and short range prediction of thunderstorms and genesis of cyclones. A nowcast based algorithm ForTracc developed by Vila et al. (2008) has been examined over Indian region using Infrared Channel (10.8 µm) of INSAT-3D for prediction of Mesoscale Convective Systems (MCS) leading to thunderstorms. This validated technique can provide the nowcast of thunderstorms (upto 90 minutes) with location error of 70 Km. to 100 Km. for 30 minutes to 90 minutes lead period to forecasters. A better understanding of the role of MCS in the formative stage of tropical cyclone (TC) in terms of the role of interaction of multiple mesoscale structures has been identified which can help in better monitoring and prediction of cyclogenesis and intensification. There is a decrease in the average distance of cloud clusters from the centre of TC with respect to increase in intensity up to 2.5–3.5 (cyclonic storm / marginally severe cyclonic storm intensity). After that, the distance decreases with an increase in intensity as the cyclone pattern changes to dense central overcast or eye pattern. Microwave cloud imageries and derived products in the frequency of 85 GHz have been examined for the cyclones that occurred during FDP period (15 October- 30 November) of 2009-2011 over the Bay of Bengal. The location of centre and intensity (T number) as estimated by various operational centres like Satellite Division of India Meteorological Department (IMD), NOAA, JTWC are compared with best track data. The objective is to find out the difference in estimates of location and intensity of cyclonic disturbances over the north Indian Ocean by different operational centres and the possible causes therein. The study can be utilized in better interpretation of the satellite guidance available to cyclone forecasters for determining the location and intensity of the cyclonic disturbances.

Advanced Dvorak Technique (ADT V8.2.1) based on all the TCs (34 Knots & above) over the North Indian Ocean has been validated to utilise this technique for TC intensity monitoring. It is found that ADT (V8.2.1) overestimates by about 1 T number as compared to manually estimated T number of 1.0 to 2.5 and underestimates by about 0.5 to 1 T number as compared to manually estimated T number of 4.0 to 5.5. This is an objective method for determination of tropical cyclone intensity.

Estimation of roughness length, drag coefficient and turbulence during thunderstorms at hilly topographical region of Ranchi

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Regions with uneven terrain experience altered effects of individual thunderstorms and other climatic events in comparison to flat terrains. It is due to the fact that micrometeorological parameters are affected by the elevation, topography, vegetation type, and urban structures and the storm events. Ranchi is a hill station situated at 651 meters above the mean sea level, lying in the Eastern section of the Deccan plateau. The climate of Ranchi is of C*wa* type and prominent extreme events experienced are thunderstorms during pre-monsoon months. Eight events of pre-monsoon thunderstorm were observed in the month of May 2010, employing sonic anemometer at (height 10 m) and automatic weather station (AWS) at (8.5 m height). Coefficient of drag (*Cd*), roughness length (*Z0*), turbulent kinetic energy (TKE) and its dissipation (ε) were derived using the half hourly data obtained from the sonic anemometer and AWS installed at BIT Mesra campus, Ranchi. Roughness length was calculated by the use of Charnock relationship and the value of α taken as 0.0144. Maximum rainfall 5.9 mm occurred on 4th May, followed by 2.1 mm on 3rd, 0.8 mm on 26th and 0.6 mm on 30th at the study site. In terms of a thunderstorm and its impact on the surface parameters, it was observed that on the 30th May at 2 pm in the afternoon there was an intense storm spiking the graph upwards for roughness length (0.0023 m), drag coefficient (2.00), turbulent kinetic energy (16.80 m^2s^{-2}) and dissipation of turbulent kinetic energy (81.50 m^2s^{-3}). On 14th May at 3 pm Z_0 was 0.0017 *m, Cd* was1.31on May 15th, at 4 pm 15.40 m^2s^{-2}TKE value was recorded. Dissipation of TKE(ε) value was 47.73 m^2s^{-3} at 5.00 pm on May 4th. The lowest value for TKE was 0.037 m^2s^{-2} recorded at 1.00 am on 14th May. The lowest (ε) observed 0.00067 m^2s^{-3}, which occurred after the thunderstorm subsided at 3 pm on Maay 30th. It can be concluded that highest available turbulent energy was at 2 pm on May 30th during the storm event and therefore the rapid dissipation occurred and the highest and lowest ε value were recorded within an hour of the thunderstorm event. On days with no thunderstorm event, the lowest values for *Z0* and *Cd* were observed. Each thunderstorm event is unique and its impact on the surface parameters differ when there are alterations in the site in terms of general topography and moisture conditions. Study of individual storm events is necessary with respect to different terrain to gather information about behavior of the micrometeorological parameters in response to the storms.

Keywords: roughness length, drag coefficient, turbulence, thunderstorms

An Extensive Study on the Lightning Patterns over NEI

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Average lightning flash density values for NEI (North-East India) are analyzed for the 16-yr period

1998–2013 based on very high-resolution TRMM LIS data. These data have been examined for depicting the annual, seasonal, and spatial distribution of the lightning activity. Lightning flashes over NEI are found to exhibit a continental-type behavior. The number of lightning flash strokes varies with the period of the year: the most active period for lightning starts in March and lasts through October with the highest number of lightning strokes happening during the pr-monsoon months of April and May, with the months of June, July, August, and September having the maximum spatial density moving from the plateau to the plains area. By October, flash densities begin to decrease statewide as solar insolation decreases. The highest flash densities with a value of 4.5 flashes km^{-2} y^{r-1}, were along an escarpment in the southern parts of Meghalaya plateau lying northeast of Bangladesh plains which has considerable topographic relief, while the minimum is found in the semiarid high altitude border districts with Tibet in Arunachal Pradesh with a value of 0.001 flashes km^{-2} yr^{-1}. Our study demonstrates that CAPE and lightning activity does not decrease during the Indian summer monsoon and therefore, CAPE plays an important role in monsoon convections over this region. The environmental low-level wind flow has a significant impact on the flash density distributions during the entire year. Geographical features like the Himalayas to the North and Bay of Bengal (BoB) to the south enhance local convergence and convection and subsequently lightning. For comparison, the flash density in NEI and the center of Congo Basin is about 45.8 and 97.5 flashes km^{-2} yr^{-1}, respectively. Results of this study are intended for use in relation to hazards associated with lightning occurrence and applications such as lightning safety standards.

Study of Hail over northeast India using Significant Hail Parameter (SHIP)

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Physiography of Northeast India is unique with Khasi, Jaintia, and Garo Hill ranges spread from Assam to Myanmar. This typical demographic feature makes the region very conducive to the hailstorm phenomenon during the pre-monsoon season. These hailstorms are more violent and cause damage to the life and property of people of this region. In this study, we present a parameter that distinguishes between significant hail (with diameters ≥ 2cm and non-significant hail using 374 cases of hailstorm occurred between 1981 to 2019 during March-May months. For brevity, we present a few cases such that a large number of met. stations reported day with hail on a particular day. For this ERA5 reanalysis data is utilized and a significant hail parameter is computed on a spatial scale to identify pockets of significant hail. SHIP values greater than 1 indicate a favorable environment for significant hail. Values larger than 4 are considered very high. Values larger than 1.5 to 2 are usually linked to observed significant hail. However, the significant hail needs to be verified with observed hail size on field sites reported by various sources. The study can be useful for avoiding the damage potential of hail over the complex mountainous terrain.

Keywords: Hailstorm, hail, SHIP, complex terrain

Diurnal cycle of Rainfall over Mountainous complex terrain

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Mountainous environments are considered as sensitive indicators for weather over the globe. The Himalayan mountain region is believed to be a hotspot of Indian weather; but not much known in detail about this region. This mountain region is a character by a variety of weather conditions from tropical to alpine. Particularly the mountainous environments have a strong impact on spatial and temporal distribution of precipitation compared with the impact of plane areas.

Recently NCMRWF released unique high-resolution Indian Monsoon Data Assimilation and Analysis (IMDAA) data sets. The 40 years of reanalysis to span the era of modern space-based observations are complimentary to ground-based conventional observations for this mountain region. This study demonstrates the potential use of the IMDAA data for the study related to the diurnal cycle of rainfall.

The salient features of this study are presented here: During the summer monsoon season, the areas (i) windward side of the north-south oriented hill ranges - Western Ghats (ii) the extreme north-eastern part of the country (iii) foothills of Himalaya receives large amounts of seasonal rainfall due to the barrier effect of orography. The reanalysis showed that time of occurrence of maximum rainfall is earlier than observed, which suggest the early release of convective instability and precipitation in the model short-range forecast. Due to mesoscale wind circulations, the occurrence of maximum rainfall was predicted during the late night along the foothills of Himalaya. The study is aimed at improving our understanding of the major sources of variation and uncertainty in rainfall over mountains. An important characteristic is the relationship between precipitation amount and elevation. Information on the variation of precipitation with elevation helps in providing a realistic assessment of water resources, estimation of maximum precipitation, and hydrological modelling of mountainous regions. The phase of the diurnal cycle over inland complex terrain orography is significantly different from coastal orography.

The frequency of hourly rain increases toward the east in the windward side of the Khasi and Jaintia hills and the east–west-oriented hills separating Bangladesh from the north-eastern parts of India. This confirms the earlier observation that although total seasonal rainfall received at the windward slopes of the Western Ghats is slightly less than that over the windward slopes of the Khasi and Jaintia hills, the number of rainy days is much less along the west coast.

Heavy rainfall forecasting for Dehradun capital city during monsoon season 2020

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Dehradun city is the capital of Uttarakhand and part of the doon valley which lies between the Himalayas and the Shivaliks. India Meteorological Department has undertaken the Impact Based

Forecasting (IBF) of heavy rainfall events for capital/major cities on an experimental basis from the monsoon season 2020. The District-level severity based colour-coded weather warnings are issued upto 5 days prior to the expected severe weather events. The capital city IBF is started 24 to 48 hours prior to the occurrence of the event with the colour-coded warning

bulletins at 12 hourly intervals and at 6/3 hourly intervals on the day of the occurrence. With the improvement in meteorological observation & monitoring network of Uttarakhand and short & medium range Numerical Weather Prediction (NWP) model output, it has become possible to provide impact based forecast at very small spatial scale with good accuracy. With the help of a dense network of 7 GPRS based Automatic Weather Stations (AWS) & 3 Automatic Rain Gauges (ARG) within 20 Km radius of Dehradun city center, it has become possible to capture & monitor these events. Based on the analysis of the rainfall data from these automatic stations and manned observatories in Dehradun the scale of these heavy rainfall events is found to be very small on most of the occasions and are of the order of less than 10 Km. This suggests that the local orographic features rather than large scale synoptic features played a major role in heavy rainfall events of Dehradun city. Out of 122 days of monsoon period impact based warning was issued on 16 occasions and severe weather was observed on 8 numbers of days in Dehradun with 100% probability of detection. The presence of monsoon trough to the north of its normal position, a cyclonic circulation south of Uttarakhand over Haryana or East-Rajasthan or Uttar Pradesh and a Western disturbance around 70°E were found to be the synoptic systems favorable for the occurrence of heavy rainfall in Dehradun city. The occasional strong south-westerly wind flow from the Arabian Sea converging over foothills of Uttarakhand is also responsible for a heavy downpour.

Generation and Evaluation of Thunderstorm Potential Index using simulated instability indices and atmospheric parameters for North Eastern Region of India

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Severe weather phenomena like thunderstorms are emerging as a major problem in various parts of the world, thus a reliable prediction of thunderstorms becomes necessary to avoid heavy damages and loss of lives. Numerical Weather Prediction (NWP) models like Weather Research and Forecasting (WRF) model has been used earlier to predict features related to a thunderstorm, however, due to its small spatial and temporal scale, it has been a challenging task. With the advancement of computing facility prediction of mesoscale weather events could be achieved. For the North East Region of India during the pre-monsoon season, the frequency of thunderstorm activities increases which are often associated with heavy rainfall and lightning. In this study, we have simulated atmospheric instabilities indices and parameters related to thunderstorm using WRF. Also, here we have made an attempt to generate a Thunderstorm Potential Index (TPI) map using the instability indices and parameters. These TPI maps were made on the Arc-GIS platform and made available for whole North East region of India during Pre-monsoon season when the frequency of thunderstorms is high. With a forecast lead time of three hours, TPI maps were used to locate potential regions of a thunderstorm and severe weather events. For validation of these TPI maps, we have used INSAT-3D TIR1 derived brightness temperature data and calculated different accuracy measures like Probability of Detection, False Alarm Ration and Frequency

Bias based on contingency tables. Also, these maps were validated against DWR reflectivity data, which was made available from Cherrapunji DWR data and against lightning flash counts over this region, obtained from Earth Network Total Lightning Network (ENTLN). Overall TPI maps show good correlation with DWR and Lightning Flash counts also calculated different accuracy indicates higher forecast accuracy over many places in this region.

Role of Sea Surface Temperature on the Rapid Intensification of Super Cyclone Amphan

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Tropical cyclone is one of the major forms of severe weather events impact the east coast of India. Recently it is noted that there is an increase in the number of pre-monsoon tropical cyclones making landfall over the east coast of India. The cyclone Amphan is the second super cyclonic system in the Bay of Bengal after Odisha super cyclone-1999. The super cyclone Amphan made landfall over west-Bengal, causing enormous amounts of death and destruction. The storm has rapid intensification from Very Severe Cyclonic Storm (VSCS) on 09 UTC of May 17 to Extremely Severe Cyclonic Storm (ESCS) at 21 UTC of May 17, and into a Super Cyclonic Storm (SuCS) at 06 UTC of May 18, 2020. In this study, efforts are made to understand the role of sea surface temperature on the rapid intensification process of the SuCSAmphan. The Weather Research and Forecasting (WRF) model with 3km resolution has been used for carrying out this study. The model has been integrated using multiple sea surface temperature (SST) and standalone models to quantify its impact on the cyclone intensity, particularly during the rapid intensification phase of its life cycle. Intercomparison of results has been carried out in terms of cyclone track, intensity, translational speed, rainfall, convection, and radius of maximum wind will be presented. Further, efforts are made to elucidate the possible mechanisms responsible for storm intensity modulation in terms of air-sea interaction process and flux exchanges. Results in terms of modulation of storm structure, dynamics, and thermodynamics due to surface forcings and the complex rapid intensification process of cyclone Amphan will be examined and presented.

Keywords: Air-Sea Interaction, Super Cyclonic Storm, Simulation, Sea Surface Temperature, WRF model.

Simulating extreme rainfall over Indian region using WRF model during the presence of deep depression

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There is an increasing interest in the study of extreme rainfall events and their impact. Simulating extreme rainfall event is a big challenge as it depends on multi-scale interaction. Most of the global rainfall products are available at course resolution, but regional mesoscale models such as WRF model are frequently used to provide accurate prediction at fine grid spacing. In the present study, we will be using the WRF model to simulate extreme rainfall over Indian region during October 2020. This extreme rainfall occurred in the presence of deep depression over Bay of Bengal. The observation shows very heavy rainfall at various location.

Ila Chawla et al., 2018 The WRF model configuration with Goddard microphysics, a Mellor Yamada Janjic planetary boundary layer condition and a Betts Miller Janjic cumulus parameterization scheme is found to perform "best" in simulating an extremely heavy rain event of June 2013. The selected configuration is then verified by simulating several other heavy to extremely heavy rainfall events that occurred across different months in the monsoon season over the upstream region of the UGB. The results for the additional events indicate that the selected configuration (Goddard microphysics, Mellor Yamada Janjic planetary boundary layer condition and Betts Miller Janjic cumulus parameterization scheme) is indeed the "best" in simulating the spatial and temporal variability of the extremely heavy rainfall over the region. Thus, we will be using the same combination of schemes in WRF and will simulate the intensity and spatial variability of the heavy rainfall event.

Extreme rainfall events over Northwest India during Indian Summer Monsoon

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The spatio-temporal variability of rainfall processes over different geographical regions around India is quite complex due to its variable topography, distance from the moisture sources and circulation patterns. Northwest Indian region being the "breadbasket" of the country and home to a major fraction of Indian population and intensive urbanization is quite vulnerable to ramifications of extreme rainfall events such as flash floods, landslides, agricultural and infrastructural damages along with significant loss of human and animal lives. Such events are in general, expected to increase owing to climate change. There are limited reports on the characteristics of extreme rainfall events over the north-western Indian region. Therefore, this forms the main motivation to examine the extreme rainfall events over Northwest India during the Indian Summer Monsoon (June-September or JJAS) for the period 1979 to 2015. We have used IMD and IMDAA daily precipitation datasets available at spatial grid 0.25° x 0.25° and 12 km, respectively. The IMDAA reanalysis data has been compared with IMD gridded rain gauge data using standard statistical methods. The IMDAA overestimates rainfall during JJA compared to IMD while underestimating during September. Extreme events from IMD and IMDAA rainfall show significant quantitative differences in trends. Our study will provide input for future extreme rainfall mitigation policy framework and infrastructure designing.

Keywords: Extreme rainfall, Northwest India, climate change, IMDAA

Prognostication on Changing Tidal Environment due to Climate Change in Estuarine Parts of Sundarbans: A Geographic Approach

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Almost all the inhabited parts of the continents somehow are coping up with the issues related with Global warming and Climate change which are directly or indirectly forcing the predictable natural events to be intangible irrespectively to the uninhabited natural regions in developed and developing nations. Particularly, the tropical deltaic regions of South and South-East Asian countries like India and Bangladesh are on the threshold regarding these global issues. Steady melting of the Antarctic ice-sheets or warming up of the oceans are side by side rising the sea-level along the coasts since the last century in this part of Asia with increasing magnitude result of which can best be observed when high tides and tidal bores rampage the deltaic regions during an increasing number of severe or super tropical cyclones along the coasts of the Bay of Bengal and the Arabian Sea. Although, the recent development of weather forecasting has relieved the people of Sundarban delta to reduce the vulnerability of the climatic hazards but side by side tidal forecasting and its changing behaviour have also been overlooked since a long time which is also directly or indirectly affected by the said global issues. Hereby, the author has tried to prognosticate on the future impact of global warming and climate change on tidal dynamism in geographically as well as biologically most vulnerable natural estuarine delta, i.e. the Sundarbans, the so-called world heritage site by UNESCO and one of the most red-listed areas by IUCN.

Keywords: Global warming, Climate change, Geographic, Tides, Tidal bores, Cyclones, UNESCO, IUCN

Widespread rainfall activity with isolated heavy spells of rain over Himachal Pradesh and Uttarakhand during 15-20 July 2014

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The knowledge of weather information and awareness of weather & climate especially for disaster prone areas like mountain regions is very important for the development and safety of human life.

These states are the most natural disaster prone states in one side but are also popular for tourists as well as pilgrimage places of the country. There was a huge loss of properties and lives due to flash floods in the past. Therefore, in this paper case study have been taken up for analysis weather system of widespread rainfall activity with isolated heavy spells of rain over Himachal Pradesh and Uttarakhand occurred during 15-20 July 2014.

The present study consists of the synoptic and dynamic atmospheric situation experienced over Himachal Pradesh and Uttarakhand during 15-20, July 2014. As per the analysis of the available data, it has pointed out that the movement of low pressure from North Bay of Bengal to northeast Rajasthan across central India pulled a large amount of moisture. At the same time, the western end of monsoon trough moved northwards and remained close to the foothills of Himalayas and the eastern end of monsoon trough deepened to North Bay of Bengal. The Tibetan & Mascurene high were found above its normal position, pressure gradient & surface winds along the west coast which combine worked as a source of moisture supply over the western Himalayan region. It was also observed from the RADAR images of DWR Patiala that the heavy clouds of more than 4 km heights with higher reflectivity and positive vorticity at 850 hPa on Odisha coast which associated heavy spell of rain over the area. It is also pointed out that vertical shear and orographic uplifting leads to a short-lived, intensifying precipitation; it caused more rainfall over Uttarakhand than Himachal Pradesh.

These atmospheric situations of synoptic & dynamic as discussed above were observed for a prolonged period and it was found very conducive for widespread of rainfall with heavy spells of rain over the region. This study may be very useful to the forecasters, government planners and the general public.

Impact of SCS 'Nisarga' over parts of Maharashtra- usefulness of rainfall and wind warnings towards mitigation

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Cyclone Nisarga, a severe cyclonic storm in the Arabian Sea after 59 years, intensified from a cyclonic storm to a severe cyclonic storm which made landfall with central pressure 984 hpa with pressure drop of 20 hpa and and maximum surface wind of 60 kts over Alibaug, Maharashtra coast as a Severe Cyclonic Storm (SCS) with winds close to 60 kts to 70 kts between 0700-0900 UTC of 3rd June. In the paper, studied the affected districts of Maharashtra especially districts of North Konkan, North Maharashtra in and around landfall track. It is observed that there was damage in the total track length of the system which was around 1294 km. It was mainly steered by an anticyclonic circulation in middle and upper tropospheric levels to the east of the system centre. The hazardous cyclone was predicted by IMD effectively because of time to time Cyclone alert issued for north Maharashtra and south Gujarat coasts; the bulletins issued at 1150 hrs IST of 1st June, (about 50 hours prior to landfall of SCS NISARGA) and timely alerts well in advance helped in effective mitigative measures. Heavy rainfall and strong wind speed left the trail of destruction over Konkan and Madhya Maharashtra, leading to falling of electricity poles and many trees like coconut, Mango, Jack fruit, crops particularly grapes have suffered extensive damage in Nashik-Ahmednagar belt. Verification of extremes of rainfall forecast/ warnings indicated very good accuracy as realized rainfall. Districts of Raigad, Palghar, Ratnagiri in Konkan region affected by heavy to very heavy rain, Kolhapur, Satara, Pune, Nashik, Ahmednagar districts of Madhya

Maharashtra were affected by heavy to very heavy rain while a few districts in Marathwada and Vidarbha were also affected. The Vasai-Virar belt received heavy downpour. The strong wind created huge damage over areas of Sindhudurg, Ratnagiri, Raigad, Mumbai, Thane, Pune, Ahmednagar and Satara districts. The damage due to extremes of rainfall and strong wind were severe; death toll of human beings, domestic animals and significant damage in cropland over northern parts of the state has been discussed in the present paper. The warnings were issued by IMD for Fisherman viz. total suspension of fishing operations and evacuation from low lying areas for common people, judicious regulation of rail and road traffic. Also, people in affected areas were advised to remain indoor and other relevant advisories were issued. However, in anticipation of forecast/warnings/advisories as issued by IMD, various disaster management agencies NDRF and NDMA acted rigorously towards mitigation. The paper also discussed all the advisories for drainage of excess water from crop field, which were given to save the various types of standing crops.

Keywords: Impact, SCS, Wind speed, Heavy/ Very heavy rainfall, Warnings, Hazard mitigation

Role of convective available potential energy (CAPE) and total total index (TTI) in the genesis of lightning during convective weather

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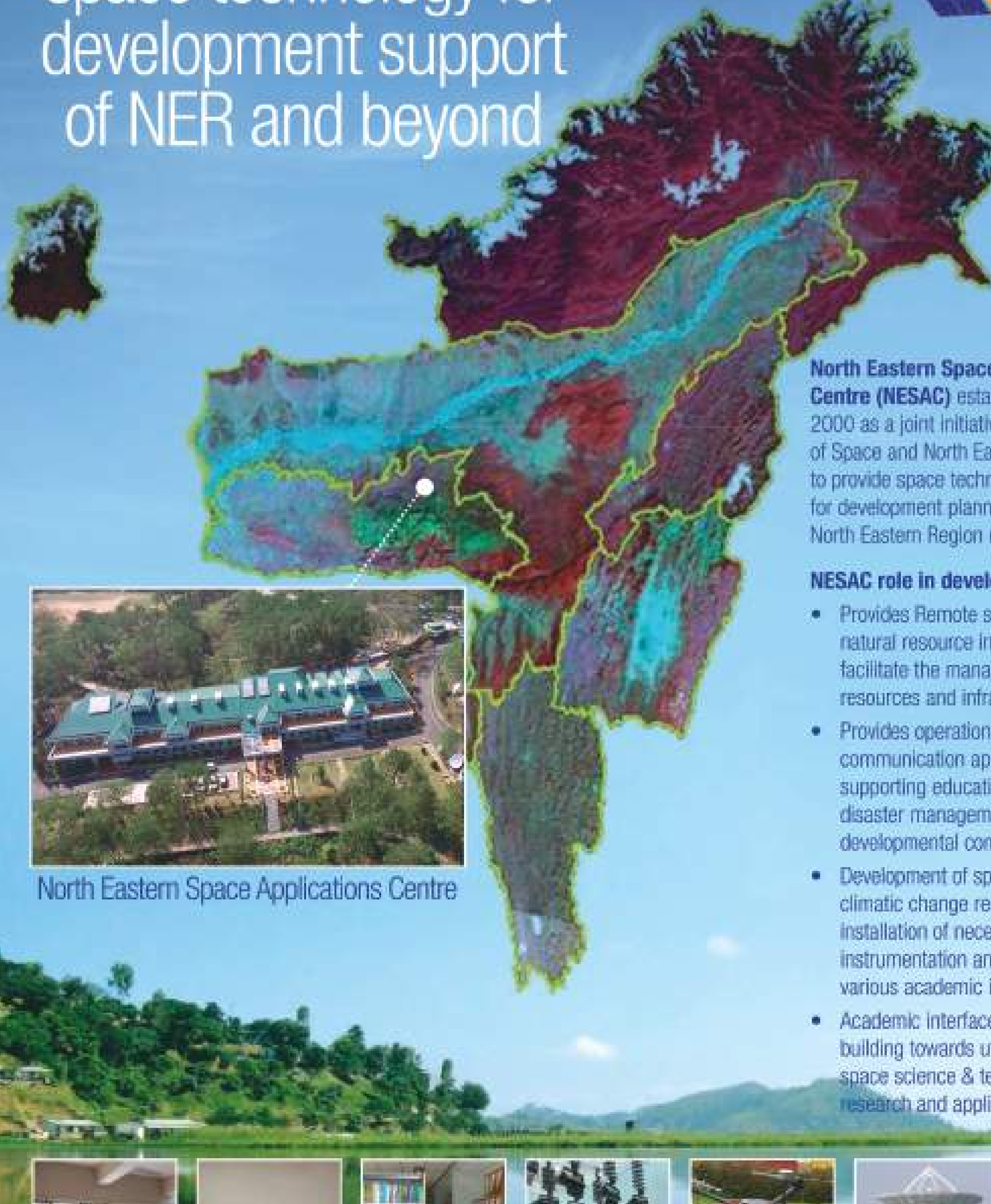
Lightning is the transient impulse of static current. Thunder is created when lightning passes through the air. This study addresses the role of convective available potential energy (CAPE) and total total index (TTI) in the genesis of lightning followed by thunder. Additionally, it also examines the scope of lightning forecast based on CAPE and TTI values. Pre-monsoon radiosonde 00 UTC data (15th March to 31st May) of RMC Guwahati with realized convective weather data for the last four years (2017 -2020) have been studied for analysis. CAPE is calculated by integrating vertically the local buoyancy of a parcel from the level of free convection (LFC) to the equilibrium level (EL). In the thermodynamic diagram, this represents the area that is between the curve of lifted air parcel from the level of free convection (LFC) to the equilibrium level (EL) of the environment. The TTI is calculated by the formula TTI= T(850) +Td(850) - 2T(500); where T(850), Td(850) represent the dry bulb and dew point temperatures at 850 hPa level respectively and T(500) is the dry-bulb temperature at 500 hPa level. During updraft and downdraft within CB clouds the Ice crystal and water droplets bump together, this rubbing makes a static electrical charge in the clouds. A stroke of lightning may explode the air having a peak value of temperature up to 50,000 degrees Fahrenheit (F), which is enough to damage anything. The study unveils that CAPE and TTI are thinly responsible for the occurrence of lightning during convective weather. However, the encouraging result is that the probability of occurrence of lightning is higher when TTI and CAPE values are higher. But for precise lightning forecast, deep research is required comprising all thermodynamic parameters as well as prevailing synoptic conditions, lifting mechanism of the atmosphere, etc. Still, a significant forecast can be provided by utilizing some threshold value of CAPE and TTI.

Keywords: CAPE, TTI, thermodynamic, electrical discharge, threshold value

Harnessing space technology for development support of NER and beyond



North Eastern Space Applications Centre

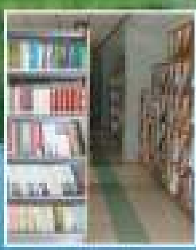
North Eastern Space Applications Centre (NESAC) established in the year 2000 as a joint initiative of Department of Space and North Eastern Council (NEC) to provide space technology support for development planning in the North Eastern Region (NER).

NESAC role in development support

- Provides Remote sensing based natural resource information base to facilitate the management of natural resources and infrastructure planning.
- Provides operational satellite communication applications services supporting education, health care, disaster management and developmental communication.
- Development of space science and climatic change research hub by installation of necessary instrumentation and networking with various academic institutions of NER.
- Academic interface and capacity building towards utilisation of space science & technology in research and applications.

NER-DRR Lab

Soil Laboratory



Library

Satcom Studio

An UAV at NESAC

IRNSS receiving antenna

Trace gas analyser

For details please contact:
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