A Case Study on Dust Storms/Thunderstorms over Uttar Pradesh on 2nd May 2018

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ABSTRACT

Thunderstorms are the manifestation of the convective activity in the atmosphere. It's destructive off springs are the hailstorms, lightening, high winds, heavy rains and most violent of all are the tornadoes. Dry thunderstorms produce dust storms which are usually considered to be natural hazards. During such events, dust aerosol is loaded into the atmosphere, directly reducing visibility and effectively reflecting solar radiation back to space. Essential conditions for the formation of a severe thunderstorm are (i) Conditional instability (ii)Availability of moist air at lower levels (iii)Insolation and orography for initial lifting of moist air at higher levels (iv)Presence of high lapse rate of temperature, due to dry westerly at upper levels and moist southerly/southwesterly air at lower levels and (v)Presence of trough or cyclonic circulation in lower levels over the region. In addition, strong vertical wind shear is found to be one of the important factors for the occurrence of severe thunderstorm as the release of latent energy in an environment of strong vertical wind shear often leads to the development of severe convective storms. Though each one of the above mentioned conditions is considered favourable for convective development, their relative importance and the weightage to be given to each factor have not yet been clearly established. Thus, any discussion on this will have to be only qualitative and in general terms. Thunderstorms occur in northwest India and west Uttar Pradesh in all the months of pre-monsoon season. The activity is more in western Himalayas than in the plains. In the plains the activity is more in the second half than in the first half of the season. Dust storm occurs only in the plains. Significant dust storm activity begins in April and reaches its maximum in June. These dust storms are locally known as Andhi.

In this study, Dust storms/Thunderstorms phenomena those occurred in Uttar Pradesh on large scale on 2nd May 2018 have been studied. These deadly storms claimed more than 100 lives in the state. We have analyzed different features of thermodynamic indices and parameters, synoptic situations and various products of numerical weather prediction model and tried to find out probable dynamic and thermodynamic aspects of such weather phenomenon. For study of thunderstorms, the synoptic conditions, current weather observations, satellite imageries and Doppler Weather Radar products have been used.

Keywords: *Western Disturbance, Instability, Wind Shear and Cloud top temperature.*

1. Introduction

March, April and May are categorized as Pre-Monsoon season. This season has high convective activity over northwest India including Uttar Pradesh. Dust storm which is locally known as 'Ándhi' associated with strong surface winds produced by thunderstorm super cells, hails and occasional development of tornado result in loss of property, agricultural damages and high death toll over the area where it develops. The heating starts from the month of March gradually when the northward moving sun reaches to equator and enters into northern hemisphere. Intense heating over the state occurs in the second fortnight of April and May when the maximum temperature continuously persists more than 40^{o}C for many days in different pockets of the state. Heating of the land create convection, which is an important factor for the formation of thunderstorm. In the month of March, isolated thunderstorm activity is seen in association with development of induced low pressure area due to presence of Western Disturbances (WDs). The convective activity increases in the month of April and May.

Rao and Raman (1961) have discussed the frequency of thunderstorms in different months over India. Tyagi (2007) has prepared the annual climatology of thunderstorms over the region. To understand the genesis, development and propagation of these systems and to improve forecast skill for prediction of these severe thunderstorms, a programme named Severe Thunderstorm Observation and Regional Modeling (STORM) has been executed by India Meteorological Department (IMD) since 2005.

It is well known that instability, presence of moisture in the boundary layer and some mechanism to produce vertical motion i.e. a trigger are necessary for the genesis of thunderstorm (TCu or Cb). However, its intensity primarily depends on the degree of instability and availability of moisture. In addition to these conditions, vertical wind shear gives birth to the persistent thunderstorm and severe thunderstorm/tornado.

2. Data Used

Uttar Pradesh has a network of 12 departmental observatories and 18 part time observatories situated in different part of the state (Figure 1). Departmental observatories are run by staff and officers of IMD whereas part time observatories are run with the coordination of staff of state government. These observatories record synoptic observation at different synoptic hours and transmit to Meteorological Centre, Lucknow. In addition to these observatories, data from two Indian Air Force (IAF) observatories at Agra and Chakeri (Kanpur) are received at Met Centre. For this study, data from these 32 observatories have been used.

Uttar Pradesh has 75 districts and it is difficult to record all thunderstorms from existing network. Tyagi (2007) has suggested establishment of one full time current weather observatory in each district to ensure proper reporting of all thunderstorm occurrences for both operational and climatological point of view. Thunderstorm data received from these observatories during 1st March 2018 to 31st May 2018 have been used in the present study.

Cloud CT-BT images obtained from SATMET division at IMD HQ New Delhi, DWR data of Lucknow and Delhi, the gridded rainfall data at the resolution of 0.25°×0.25° lat./long. (Rajeevan et al., 2005) are used for comparison of spatial distribution of convective rainfall and NCEP reanalysis data have been used in this study for deriving several products. NCEP reanalysis data set is widely used by scientific community for meteorological study.

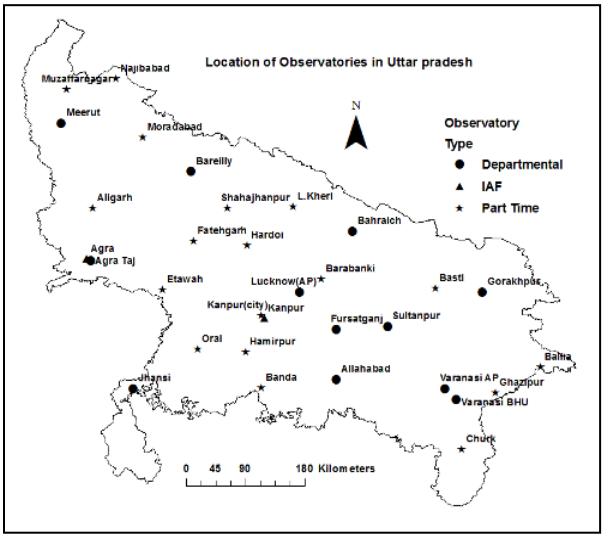

Figure 1: Observatories Network in Uttar Pradesh.

Uttar Pradesh is divided into two Met Sub-divisions viz. East Uttar Pradesh and West Uttar Pradesh. There were 11, 38 and 77 events of thunderstorms in East Uttar Pradesh and 6, 48 and 47 events of thunderstorms in the west Uttar Pradesh during March, April and May respectively, in 2018. Tyagi (2007) made detailed analysis of thunderstorms and reported that thunderstorms progressively increase from March to May and frequency of thunderstorms in most parts of the country including Sub-divisions of Uttar Pradesh in the month of May is similar to that of April. In this study also, it has been found that frequency of thunderstorms increased progressively from March to May in both the Sub-divisions. In April and May 2018, almost similar number of thunderstorms were reported in West Uttar Pradesh whereas number of thunderstorms in the month of May were almost double to that in April in East Uttar Pradesh.

3. Case Study

3.1 Large scale convective activity over the state on 2-3 May 2018

On 2-3 May 2018, large number of convective activities took place over the state where 16 events of Dust storm/Thunderstorm with rain were recorded in East Uttar Pradesh and that of 11 events

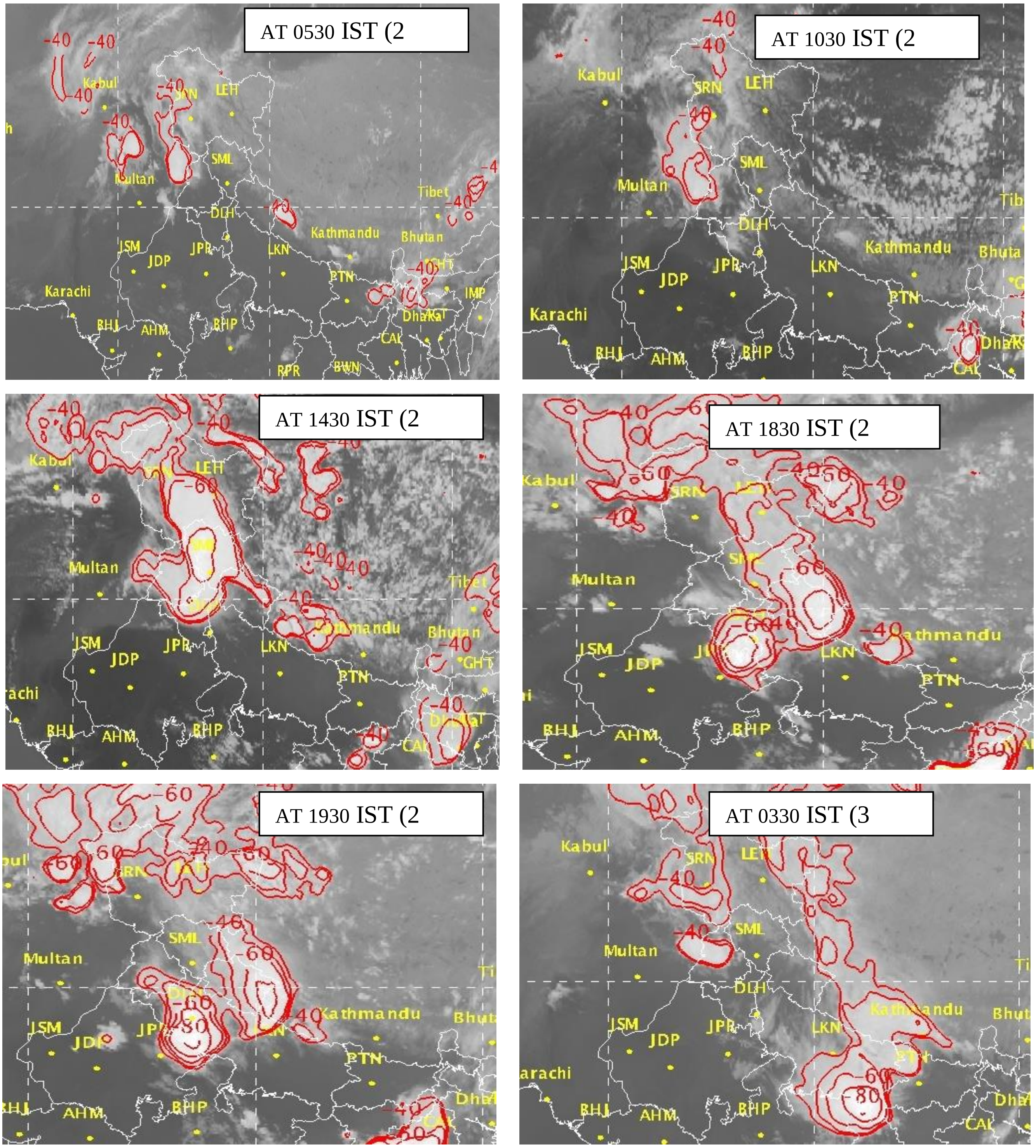

Figure 2: CT-BT image at different hours on 2 & 3 May 2018.

were recorded over West Uttar Pradesh. More than hundred people have lost their lives in Uttar Pradesh on that day. On 2nd May 2018, IAF Agra reported gale wind from 20:45 to 21:00 hrs IST when mean wind direction was 310^0 and mean wind speed was 107 kmph and maximum wind was 125Kmph.

3.2 Satellite data (CT-BT) Image analysis

Vertically developed convective clouds with cloud top temperature (CTT) below -40 degree Celsius were seen over North Pakistan, Jammu&Kashmir and Punjab at 0530 hrs IST in the morning of 02 May 2018.

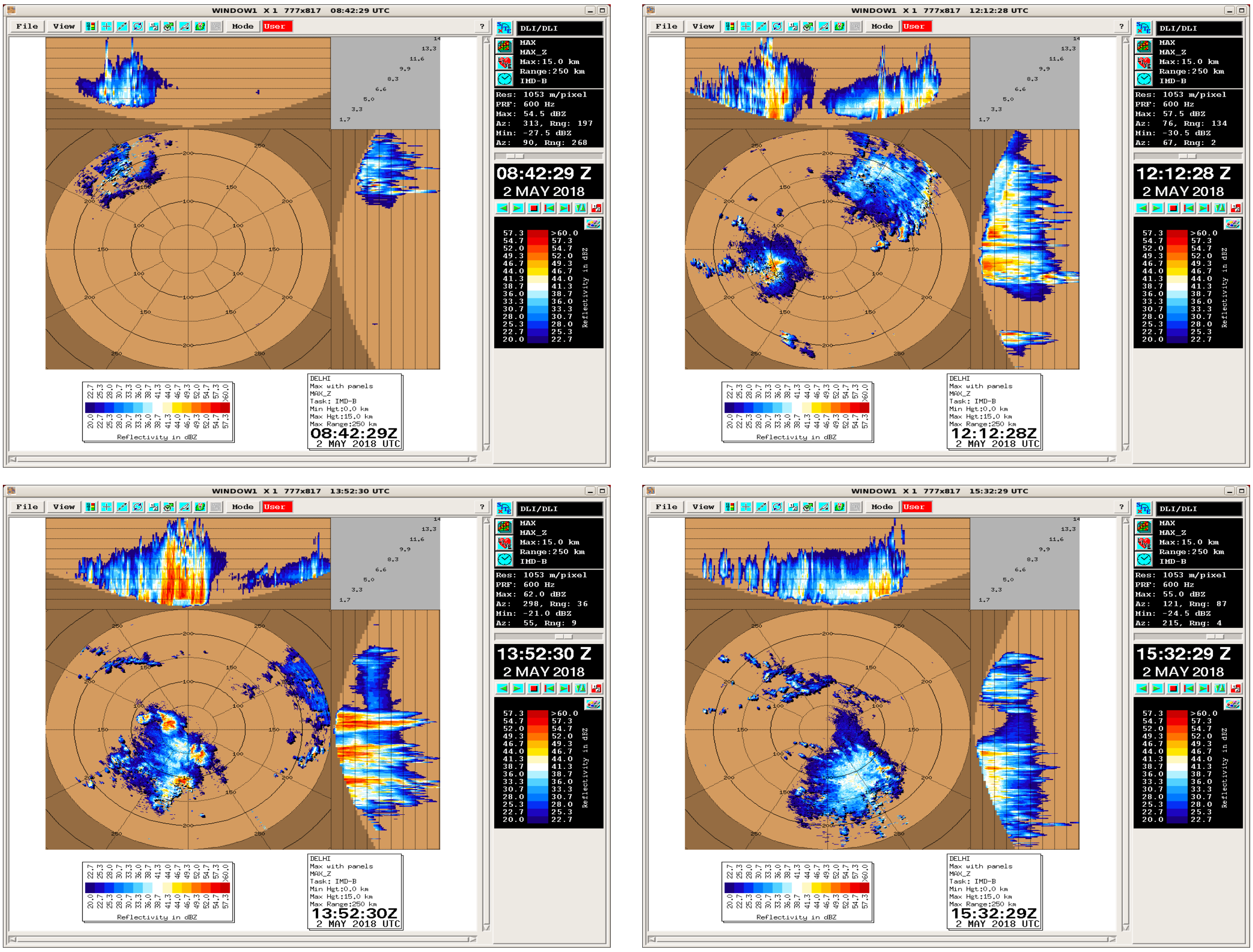

Figure 3: Image showing Maximum reflectivity by DWR Delhi at different hours.

These clouds moved in southeasterly direction intensified subsequently and covered large area of Jammu&Kashmir, Punjab, Haryana, Himachal Pradesh, Uttrakhand and Nepal with the progress of the day. It entered West Uttar Pradesh at 1400 hrs IST propagated further and covered northeast Rajasthan and parts of West Uttar Pradesh with CTT of -60 ^{0}C or less by 1800 hrs IST of 2nd May. At 1930 hours IST the CTT was -80 ^{0}C or less. Moving further SE-wards, it further concentrated over East Uttar Pradesh with CTT less than -80 ^{0}C, by 0300 hrs IST of 3rd May (Figure 2**).**

3.3 Doppler Weather Radar (DWR) data analysis

Thunderstorm activity on 2-3 May 2018 over the state was a synoptic scale activity which commenced from north Pakistan affected Uttar Pradesh in addition to many other states of India as discussed in Section 3.2. DWR is an important tool for monitoring of thunderstorm formation, intensity and its expected movement. In present study, DWR data of Delhi and Lucknow have been utilized.

3.3.1 Maximum Reflectivity (Max_Z)

(a) DWR Delhi observation

Multiple thunderstorm Cells with maximum reflectivity 40-45 dBZ and height 10-12 km moving from northwest direction were observed by DWR Delhi in the afternoon of 2nd May 2018. These cells moved southeastward and hit over the area closed to Himalayas in the evening of 2nd May. As a result, devastating dust storm/Thunderstorm with rain occurred over the districts of Bijnor, Muzaffarnagar, Meerut, Moradabad etc. Another cluster of thunderstorm cells with Max_Z 40-45 dBZ and height between 10-12 Km were captured inthe west of DWR Delhi at 1742 hrs IST and moved southeastwards and hit over northwest

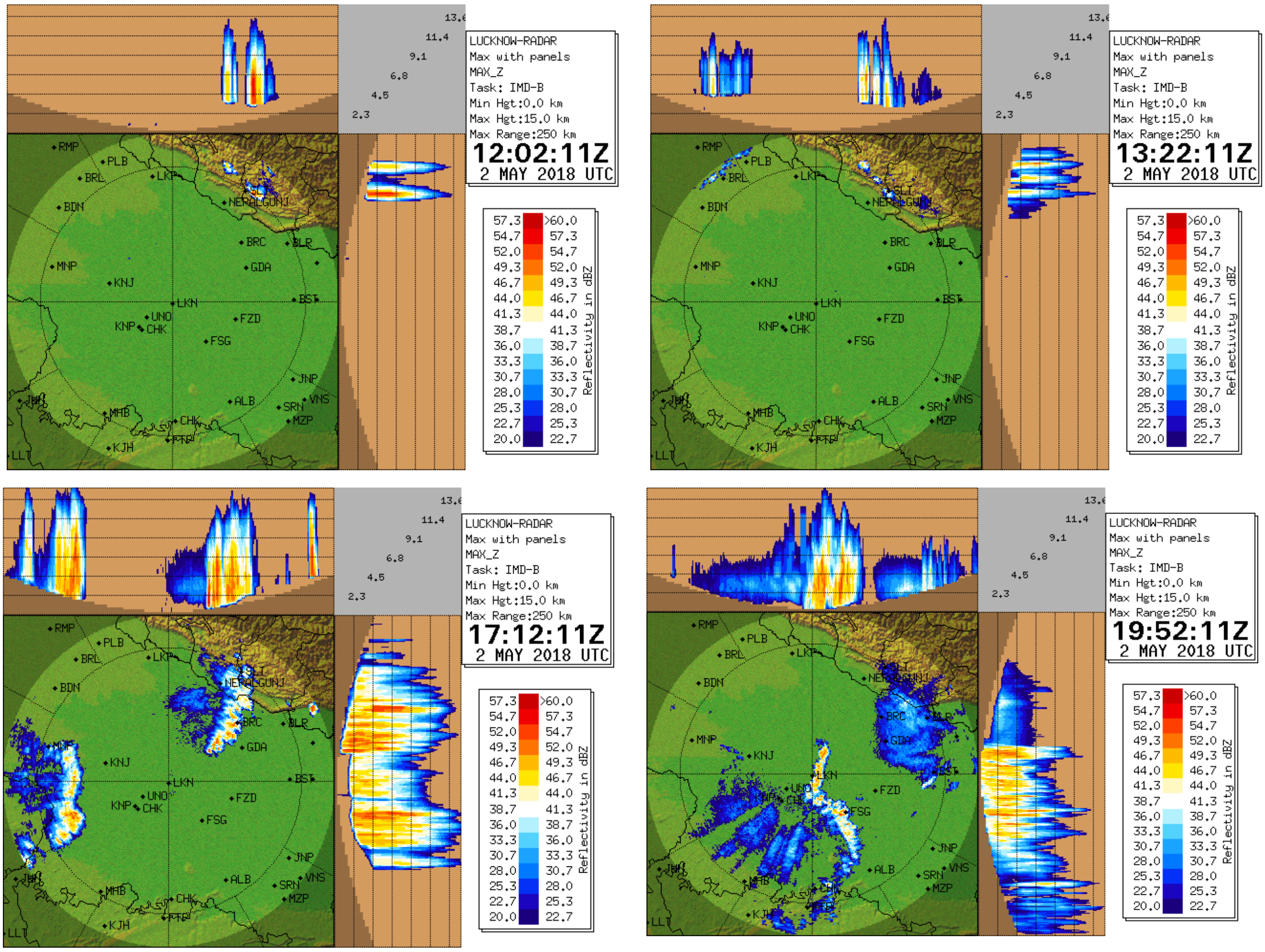

Figure 4: Image showing Maximum reflectivity by DWR Lucknow at different hours.

Uttar Pradesh and further continued to move southeastwards (Figure 3). IAF Agra reported Gale winds between 20:45 to 21:00 hrs IST on 2nd May from 310^{0}direction and mean wind speed of 107 kmph and maximum wind 125 kmph.

(b) DWR Lucknow observation

Isolated thunderstorm cells with maximum reflectivity more than 50dBZ and height more than 13 km were captured by DWR Lucknow at 1732 hrs IST over Nepal and dissipated there by 1932 hrs IST. Multiple thunderstorm cells entering from northwest direction were captured by DWR Lucknow at 1852 hrs IST continued to move in southeast direction with maximum reflectivity more than 50dBZ and height more than 13 km (Figure 4). During the course of its movement, these cells formed line squalls and dust storms/ thunderstorms with rain (2 to 3 cms) occurred over the Northern parts of state over the area where these cells passed by (Figures 5&6).

Line squall after having devastating affect over East Rajasthan and West Uttar Pradesh was observed by DWR Lucknow at 2102 hrs IST, moving Easterly/southeasterly with maximum reflectivity more than 55dBZ and height more than 14km (Figure 4). Dust storm/ Squall/ Thunderstorm with rain were observed over most parts of south Uttar Pradesh. Rainfall recorded by it was up to 5 cm (Figures 5 & 6) and Table 2. Due to the movement of these severe thunderstorms through the state more than hundred people, many animals lost their lives and properties worth millions of Rupees were damaged.

On the basis of DWR observations, Nowcast Warnings were issued to District Magistrates of concern districts, Doordarshan, All India Radio, State Disaster Management Authority by

Table 1. At 00 UTC Thermodynamic Parameters of various stations on 2 May 2018.

Indices	Delhi	Lucknow	Gorakpur	Gwalior
Convective Available Potential Energy (CAPE) (J/KG)	1839.01	1461.37	1017.51	1685.08
Total Total Index (^{0}C)	55.00	52.40	48.60	53.00
Lifted index (^{0}C)	-5.45	-5.50	-1.64	-5.52
SWEAT index	298.51	244.00	193.38	235.60
K index (^{0}C)	29.30	30.70	34.50	31.30
Perceptible water [mm] for entire sounding	33.30	34.68	41.59	32.60

Table 2. Station wise rainfall recorded on 3rd May, 2018.

Rainfall < 7.5 mm				Rainfall > 7.5 mm			
Stations	**Rainfall**	**Stations**	**Rainfall**	**Station**	**Rainfall**	**Stations**	**Rainfall**
Varanasi (AP)	0.3	Manjhanpur	3.2	Ghatampur	8	Kunda	18
Meerut	0.3	Mohanlalganj	3.2	Akbarpur (KanpurDehat)	8	Dudhi	18
Padrauna	1	Bilhaur	3.5	Iglas	8	Karchhana	19
Dhampur	1	Soraon	4	Fatehpurobsy	8.2	Rath	19
Deoband	1	Utarala	4	Bara banki	8.4	Meja	20
Lucknow (AP)	1.8	Jalesar	4	Bindki	8.8	Kaiserganj	20
Machhlisnahr	2	Muzaffarnagar	4	Domeriaganj	9	Allahabad sadar	20.2
Kanpur Tehsil	2	Jasrana	4.3	Hamirpurobsy	9	Chayal	20.4
Biswan	2	Hata	4.5	Sirathu	9.4	Mirzapur tehsil	21
Purwa	2	Bharthana	4.6	Sikandraknp	10	Gorakhpur	21.2
Bah	2	SirauligauspurTehsil	5	Kirawali	10	Beberu	22.4
Bidhuna	2	PratapgarhTehsil	5	Shikohabad	10.2	Bara	23
Bareilly (PBO)	2	Amethi	5	Mankapur	11	Kalpi tehsil	24.8
Bareilly Tehsil	2	Aligarh	5	Mariahu	12	Naraini	26.2
Jalaun	2	Bijnor	5	Agra obsy	12	Bhinga	28
Bhogaon	2	Maudaha	5	Ghorawal	13	Bhingahmo	28
PilibhitTehsil	2	Bahraich	5.2	Varanasi-b.h.u.	13	Mahoba	30
Saharanpur	2	Nawabganj Tehsil	6	Pharenda	15	Allahabad(PBO)	31
Baheri	2.2	Nighasan	6	Orai	15	Handia	31
Chhata	2.5	Deoria	7	Fursatganj	15.2	Kanpur IAF	35
Nanpara	3	Bansgaon	7	Kherilakhimpur	15.4	Banda	37
Haidargarh	3	Chunar	7	Robertsganj	15.6	Koraon	42
Salempur	3	Mau tehsil	7	Khairagar	16	Phoolpur(Allahabad)	42
Bhognipur	3	Mauranipur	7	Maharajganj	17	Attarra	48
Salon	3	Karhal	7	Churk	17.4	Agra(IAF)	48
Hasanganj	3	Kanpur Obsy	7.4				

Meteorological Centre, Lucknow at different hours on 2nd and 3rd May 2018. Warnings issued and their realization have been shown in Table 3. Due to low density of Observational Network, some of the weather phenomena remained unreported.

3.3.2 Thermodynamic conditions

Maximum temperatures over Rajasthan were more than 40 ^{0}C and it was persisting for last few days and intense convection occurred over the region (Figure 7). Moisture convergence is also important for assessment of large scale occurrence of thunderstorm activity. In this study, moisture convergence at 850hPa at different hours of the day has been calculated. For calculation of Moisture Convergence, Specific humidity multiplied by zonal and Meridional component of wind at same level have been used (Figure 8). It indicates that northwest and southeast oriented moisture belt across West Rajasthan, East Rajasthan, West Madhya Pradesh was present at 00 UTC of 2 May 2018. At 12 UTC moisture Convergence over most part of Uttar Pradesh was of the order of 0.05-0.06 Kg/Kg.m/s and most of the event have taken place after that.

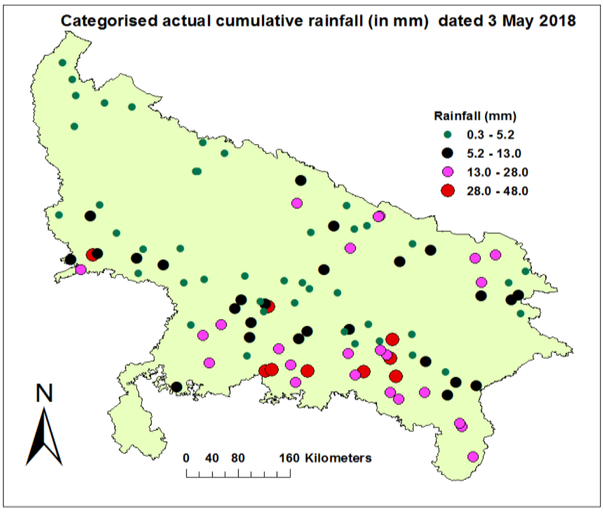

Figure 5: Categorised actual cumulative rainfall.

Thermodynamic indices are also important tools for forecasting of thunderstorms. Tyagi et al. (2011) have calculated threshold values of many thermodynamic indices over Kolkata for the occurrence of thunderstorms in pre-monsoon season. Uttar Pradesh has two RS/RW stations at Lucknow and Gorakhpur. Data of two nearby RS/RW stations at Delhi and Gwalior have also been used to examine thunderstorm probability in nearby stations of Uttar Pradesh.

Table 1 shows that CAPE values were in between 1000-1800 J/Kg. Total Total Index (TTI) was more than 50 over all the places except at Gorakhpur where it was 48.6 and favourable for thunderstorm to occur. Lifted index were less than -2 over all places except at Gorakhpur where it was -1.67. K-index was between 30 and 35. Precipitate water (mm) for entire sounding was between 30 and 35 at all places except at Gorakhpur where it was very high i.e. 41.59 mm. As per Tyagi et al. (2011) CAPE≥1000, Total Total Index ≥46, Lifted Index ≤-3, SWEAT index ≥180 and K index ≥24 are favourable for pre-monsoon thunderstorms over Kolkata. Results of this study exhibit the same relevance for thunderstorms in pre-monsoon season over Uttar Pradesh.

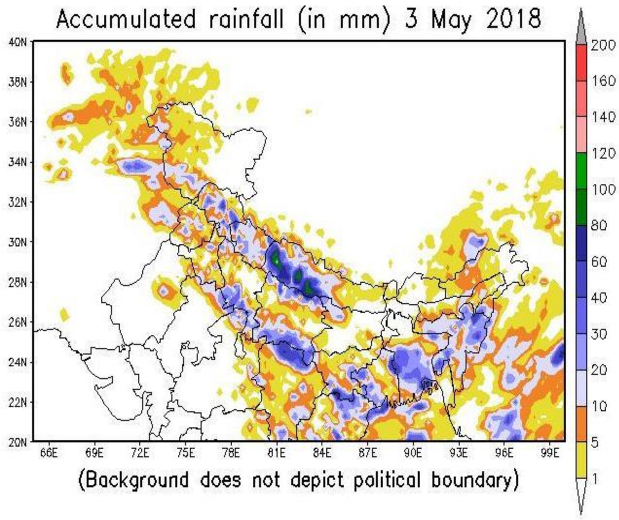

Figure 6: Gridded rainfall at the resolution of 0.25°×0.25° lat./long.

3.3.3 Synoptic conditions on 2nd May 2018

(1) A trough from north Pakistan to north Chhattisgarh across Rajasthan and Madhya Pradesh exists (Figures 9 & 10).

(2) An upper air cyclonic circulation extending upto 3.1 km above mean sea level was lying over north Pakistan and the neighbourhood.

(3) An upper air trough at 1.5 km above mean sea level was passing from East Uttar Pradesh (Figure11).

(4) Col region was present over Haryana (Figure 11).

The above synoptic systems in pre-monsoon season are indicators of extensive thunderstorm activity over the region.

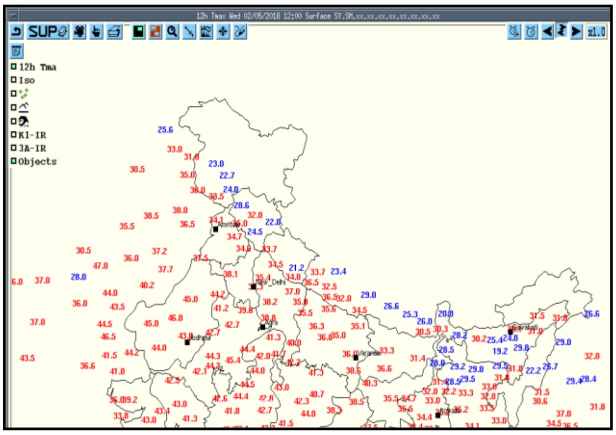

Figure 7: Maximum temperature on 2 May 2018.

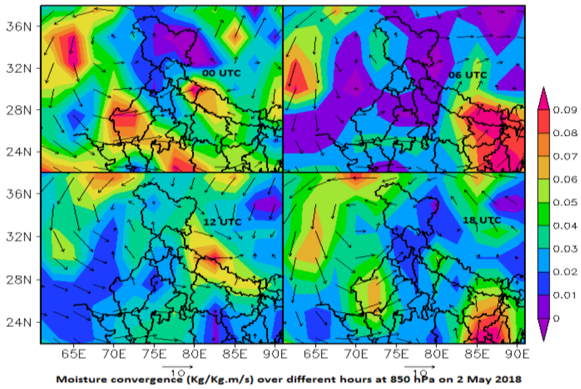

Figure: 8 Moisture convergence at different hours of the day at 850 hPa on 2 May 2018.

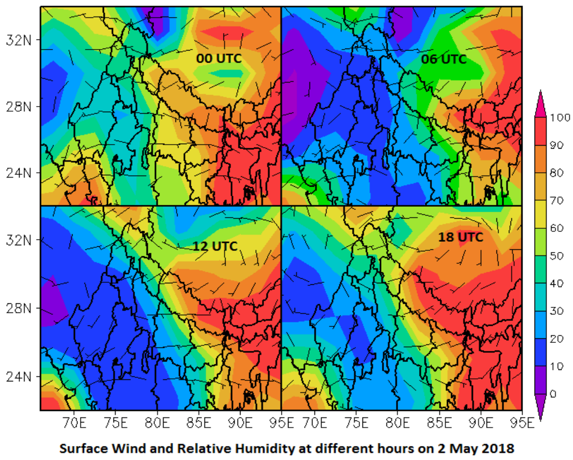

Figure 9: Surface wind and R.H. at different hours.

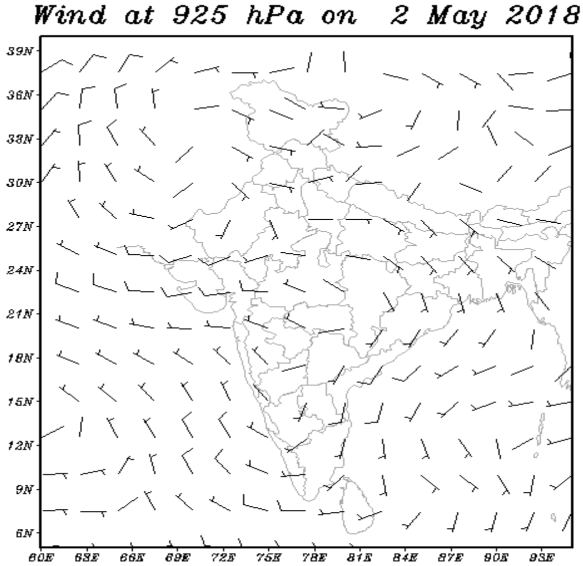

Figure 10: Wind flow at 925 hPa.

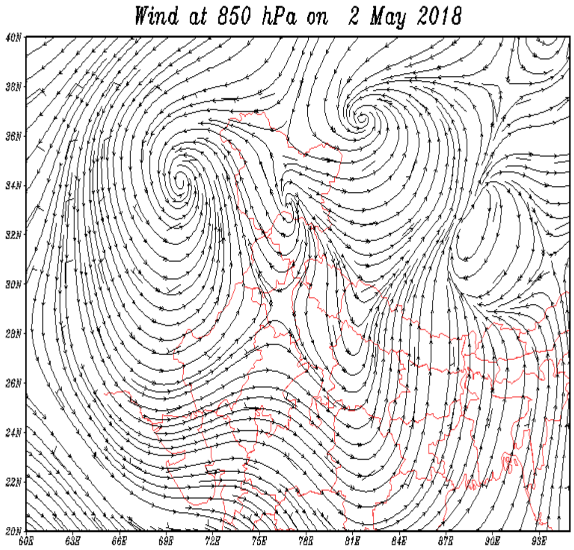

Figure 11: Streamline at 850 hPa.

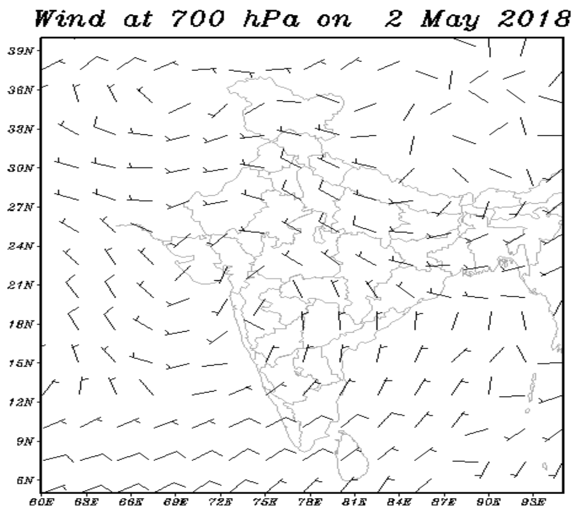

Figure 12: Wind flow at 700 hPa.

Table 3. Nowcast issued by M. C. Lucknow and it's realization.

S. No.	Date & Time (IST) of issue of Nowcast	District for which Nowcast warning was issued	Weather realized
1.	02.05.2018 at 20:52 hrs	Bareilly, Pilibhit, Badaun, Shahjahanpur, LakhimpurKheri	Duststorm/Thunderstrom with rain occurred in the district of Bareilly, Pilibhit&LakhimpurKheri
2.	02.05.2018 at 20:43hrs	Aligarh, Mathura, Gautam Buddha Nagar, Ghaziabad, Sitapur, Hardoi	Duststorm / Thunderstrom with rain occurred in the district of Aligarh, Mathura, &Sitapur.
3.	02. 05.2018 at 21:23 hrs	Hardoi, Kannauj, Bahraich, Sitapur	Duststorm / Thunderstrom with rain occurred in the district of Bahraich&Sitapur
4.	02. 05.2018 at 22:17 hrs	Etawah, Auraiya, Jalaun, Agra, Mainpuri, Firozabad	Duststorm / Thunderstrom with rain occurred in the district of Etawah, Auraiya, Jalaun, Agra, Mainpuri& Firozabad
5.	02. 05.2018 at 23:15 hrs	Gonda, Barabanki, Shravasti, Balrampur, Basti, Faizabad, Siddharthnagar, Etah, Kanpur Nagar and Dehat, Hamirpur, Kannauj, Gorakhpur, SantKabirnagar	Duststorm / Thunderstrom with rain occurred in the district of Gonda, Barabanki, Shravasti, Balrampur, Siddharthnagar, Etah, Kanpur Nagar and Dehat, Hamirpur& Gorakhpur
6.	03. 05.2018 at 00:59 hrs	Unnao, Lucknow, Raebareli, Amethi, Banda, Fatehpur	Duststorm / Thunderstrom with rain occurred in the district of Unnao, Lucknow, Raebareli, Amethi, Banda &Fatehpur
7.	03. 05.2018 at 08:03 hrs	Meerut, Muzaffarnagar, Bijnor	Duststorm / Thunderstrom with rain occurredin the district of Meerut, Muzaffarnagar & Bijnor

4. Conclusions

Local development of isolated thunderstorm cells over the state is a common feature in pre-monsoon season and light to moderate dust storms are observed over the small area. However, if synoptic situations and thermodynamic conditions are also favorable, then severe dust storms/thunderstorms with rain at large scale with narrow belt of hail/squall take place on the track of movement. These conditions prevailed on 2nd& 3rd May, 2018. Many people succumbed to death. Loss of animals, agricultural crops, government and public property worth millions of rupees took place due to these severe thunderstorms. In this study, we have noticed that large scale severe thunderstorm activity was not a result of local developments. These thunderstorms were developed thousands of kilometers far away in the northwest of the state i.e. in Pakistan. Synoptic systems and NWP models were showing high probability of Thunderstorms over large area of the region on that day. However, temporal and spatial activity of thunderstorm can only be captured by DWR with reasonable degree of accuracy. These thunderstorm cells were actually captured by DWR at Delhi before entering into the state. Synoptic conditions and thermodynamic indices were also indicating favorable condition. Large scale severe thunderstorm activity covering northwest and east India on 30-31 May 2014 was also originated from north Pakistan moving southeastwards and affected the Uttar Pradesh. Thus, in pre-monsoon season when synoptic and thermodynamic conditions are favorable then it is desired to monitor development and movement of convective cells from Pakistan and further when these are captured by DWR Delhi, their movements need to be tracked for dissemination of location specific warning to disaster managers with sufficient lead time. It is also noted that in East Uttar Pradesh, almost double the number of thunderstorm events (77) occurred in the month of May to that in April (38).

Acknowledgements

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