An Assessment of Relation of Meteorological Parameters and COVID-19 Transmission at the Early Stage during March-May 2020 in India

Krushna Chandra Gouda[1,7], Mahendra Benke[2], Priya Singh[1], Nikhilasuma Pernaje[1], Reshama Kumari[1], Chandrika Murali[3], Geeta Agnihotri[4], Sneh Joshi[5], Smrutishree Lenka[1,6], Rani Devi[1,7], Suryanaryana Murty Upadhyayula[8], Himesh Shivappa[1,7]

[1]CSIR Fourth Paradigm Institute, Wind Tunnel Road, Bangalore-37
[2]India Meteorological Department, Pune
[3]Department of Computer Science, Jain Deemed to be University, Bangalore
[4]Meteorological Centre, India Meteorological Department, Bangalore
[5]Government Degree College, Kanda, Kumaun University, Nainital, Uttarakhand
[6]Dayananda Sagar College of Engineering (VTU), Bangalore
[7]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh, 201002
[8]National Institute of Pharmaceutical Education and Research NIPER, Guwahati
Email: kcgouda@csir4pi.in

ABSTRACT

The Corona virus disease 2019 (COVID-19) mainly caused by the novel severe acute respiratory syndrome corona virus 2 (SARS-CoV-2) became a global pandemic by March 2020. Actual there is no strong evidence of weather and COVD-19 spread relation as it is a new virus. This study is mainly focused on the tropical weather impact on the spatio-temporal spread of COVID-19 during the early stages i.e. March-May 2020 in India, which is a large country where the disease has shown an exponential growth. This study is an attempt to assess the relationship of major meteorological parameters like solar radiation, air temperature and relative humidity with the positive cases of COVID-19 for the period March-May 2020 which is the summer season or pre-monsoon season over India. The time series and significant correlation analysis at daily, weekly scale and the spatial analysis of weather parameters and the COVID-19 cases are presented. The results show significant correlation of solar radiation and atmospheric temperature with COVID-19 cases both at daily and weekly scale in India whereas relative humidity has low correlation in the study period. But the temperature relative humidity index (THI) a measure of the thermal stress shows positive correlation with the disease spread. These results can be a good input for developing the integrated modelling framework for the COVID-19 forecasting using state of art numerical weather prediction model and disease process modelling.

Keywords: *COVID-19, Weather parameters, Temperature, Relative humidity, Solar radiation, Summer and Temperature humidity index.*

1. Introduction

The whole world has been affected by the spread of an epidemic the Corona Virus Disease 2019 (COVID-19), initially started in Wuhan, China in late December 2019 (Li et al. 2020; Lewis 2020; Morawska and Cao 2020). COVID-19 mainly caused by the novel Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (Gorbalenya et al. 2020). In the first quarter of 2020 COVID-19 spread across the globe exponentially and the World Health Organisation (WHO) declared the pandemic on 11 March 2020 (WHO, 2020). The first positive case of COVID-19 in India was reported in Kerala on 30 Jan 2020 where the student has a travel history from Wuhan, China. The positive cases crossed 500 by 23 March 2020 and then India faced a nationwide full lockdown for 21 days. The number of positive crossed 100,000 on 18 May, 2020 i.e. in 111 days from date of incidence. The present trend of the new infected cases shows exponential growing rate and it varies differently over different regions in world. As COVID-19 is a new disease so no evidence of the relation of weather parameters on the disease transmission or spread is known. There is a need of better understanding of the disease-climate parameter interaction by quantifying their relation so that weather parameter enabled modelling effort can be useful in predicting the COVID-19 incidence and the disease spread well in advance.

COVID-19 mainly causes the respiratory illnesses like flu which includes influenza A and influenza B. But it spreads faster and more easily than flu and also the death rate is higher in this disease. There are several studies related to transmission of seasonal flu (influenza) virus which largely controlled by the seasonal climatic factors like temperature and relative humidity, population density, city size and its structure, etc. (Dalziel et al. 2018; Hemmes et al. 1960). In the temperate regions, the seasonal variation of influenza transmission is controlled by the conditions of absolute humidity, levels of susceptibility and changes in population-mixing and contact rates (Shaman et al. 2010) and past studies have shown seasonal patterns of human coronavirus species and annual variation in species (Killerby et al. 2018). Study by Chan et al. (2011) showed in subtropical area during spring season the SARS coronavirus have better stability at low temperature and humidity. The specific climatic condition like the optimal temperature, humidity and wind velocity will help for the survival and transmission of SARS virus, whereas low humidity, high barometric pressure and daily temperature fluctuations will reduce the transmission (Yuan et al. 2006).

Low absolute humidity during winter increases influenza virus survival and thus increases influenza virus transmission efficiency (Shaman et al. 2009). Relative humidity and temperature is sensitive by the aerosol route and insensitive by the contact route in the transmission of the influenza (Lowen et al. 2008). In a temperate region, influenza incidences increase with low temperature and low/high humidity and also with high diurnal temperature range (Park et al. 2020). The efficiency of transmission of influenza virus is affected by the humidity and temperature conditions and the transmission of influenza virus is less dependent on humidity and temperature in the absence of immunity (Steel et al. 2011).

After the widespread establishment of SARACoV-2 infection, the intensity, and timing of pandemic and post pandemic outbreaks will depend on the time of year. The transmission and the level of cross-immunity that present between beta coronaviruses is less depend upon the magnitude of seasonal variation (Kissler et al. 2020). The seasonality of the SARS-CoV-2 has not been established so far but the climate might play a role in the spread of the disease (Shi et al. 2020; Sobral et al. 2020). Some studies have reported that the COVID-19 spread can be affected by a large number of factors including the climate conditions (Qi et al. 2020; Tosepu et al. 2020). Several recent studies have carried out by researcher for finding the relation of weather parameters and COVID-19 in different regions, countries and at global scale (Ahmadi et al. 2020; Araújo and Naimi 2020; Briz-Redón et al. 2020; Bu et al. 2020; Casanova et al. 2010; Chen et al. 2020; Coelho et al. 2020; Islam et al. 2021; Pawar et al. 2020; Oliveiros et al. 2020; Salom et al. 2020; Yang et al. 2021; Yao et al. 2020) but there is lot of divergence in the results as some studies indicated the expansion of COVID-19 is not driven by climate at global scale (Coelho et al. 2020). Several studies established relationship between corona virus and climate parameters like temperature (Marr et al. 2019; Peci et al. 2019; Shahzad et al. 2021) and humidity (Doğan et al. 2020; Zhu and Xie 2020) over different parts in world. But no studies found the significant correlation of the parameters and COVID spread. A recent study also finds the impact of environmental temperature on COVID-19 exponential growth for US and Italy at regional scale (Livadiotis G 2020). In few other studies the results show insignificant correlation of temperature and UV radiation with COVID-19 transmission (Pawar et al. 2020; Yao et al. 2020). Similarly, another time series study over mainland China explains the relation of temperature and humidity with the transmission of COVID-19 (Qi et al. 2020). Few other studies also attempted to find the relation of solar radiation and COVID-19 (Ahmadi et al. 2020; Bäcker 2020; Damette O et al. 2021; Gupta et al. 2020). However, correlation of the spread of COVID-19 with climate is not yet clearly stated since none of the mentioned studies states with strong scientific evidence that solar radiation, temperature and humidity could have significant effect on the COVID spread. Also, no such studies are available on Indian sub-continent. Our study is mainly focused on finding the evidence of influence of the weather conditions particularly air temperature, relative humidity and solar radiation flux in the early stage spreading of COVID-19 epidemic in India using the data for the period March to May 2020.

2. Materials and Method

In this analysis, we have considered the period March 1 to May 20 as the number of positive cases of COVID-19 became 100,000 on May 18, 2020 in India. The COVID-19 infection data is being collected from sources like Ministry of Health and Family Welfare (MoHFW), Government of India (https://mohfw.gov.in) and Worldometers (https://www.worldometers.info) at daily scale. As mentioned in previous sections not significant relation established with climate and COVID-19 at regional scale, so here we emphasized our analysis over country as a whole instead of city or state scale because there was migration of people from one place to other during March 2020 and after May 03, 2020 when Lockdown-2.0 started in India. The analysis of major climate parameters which affect the virus i.e. solar radiation, temperature and relative humidity are considered. Mean daily downward solar radiation Flux at surface [1.9^o x 1.9^o], mean daily air temperature at 2m [1.9^o x 1.9^o] and mean daily relative humidity at surface [2.5^o x 2.5^o] is obtained from NCEP-NCAR Reanalysis 1 data from the link (http://www.psl.noaa.gov/data/gridded/data.ncep.reanalysis.html). All the parameters are averaged over continental India for each day. For the weekly analysis, the composite plot of 7 days for each parameter is computed and presented for the analysis period i.e. 1 March 2020 to 16 May 2020. The Pearson correlation coefficients (CC) between the climate variables and COVID-19 cases are computed and presented at daily and weekly scale. The Temperature-Humidity Index (THI) is also an important parameter which generally used for determining the heat stress and in this study also as the summer season (March-May) was prevailed so the THI computed using the temperature and relative humidity using the formula defined by Thom (1959) at all India scale and the correlation of THI and COVID-19 cases are explored.

3. Results and Discussion

3.1. COVID-19 spread in India

The daily number of cumulative COVID-19 positive cases reported in India for the period 01 March to 20 May are presented in logarithmic scale in Fig. 1 which shows there is a steady exponential growth in the epidemic numbers during the analysis period. It is clearly indicated that March 4 cases was at 29 and quite linear till April 11 with 8446 cases and there after the growth phase increased very fast and the number became 10453 on April 13 and close to 50000 cases by May 06 and the number crossed 100000 on May 19, 2020. The curve of the COVID-19 spread in India initiated with a pre-exponential phase, which is characterized by a mild logarithmic growth, followed by the exponential growth resulting the disease outbreak. The spatial distribution of the COVID-19 is presented in Fig. 2 which represents the number of cases in each state on 14th March and 16th May 2020, which clearly shows Maharastra, Tamilnadu and Delhi were the most affected states in India so far. There is a challenge to understand the regional variation in the growth rates as it is different for different countries and states and one can consider the weather parameters like temperature and relative humidity etc. as factors affecting the COVID-19 outbreak.

3.2. Weather parameter distribution in India

The spatial distribution of weekly averaged solar radiation flux at surface is presented in Figure 3, which clearly indicates the radiation was very low during the first 3 weeks of March and strong radiation started in the 4th week of March onwards in all over India. During March the northern, eastern and south part receives low radiation compared to the western part of India. Similar pattern also observed over the oceanic parts i.e. over Bay of Bengal and Arabian sea. As this year there was lockdown which in turn reduces the pollutant and aerosol contents in atmosphere resulting more surface radiation compared to other

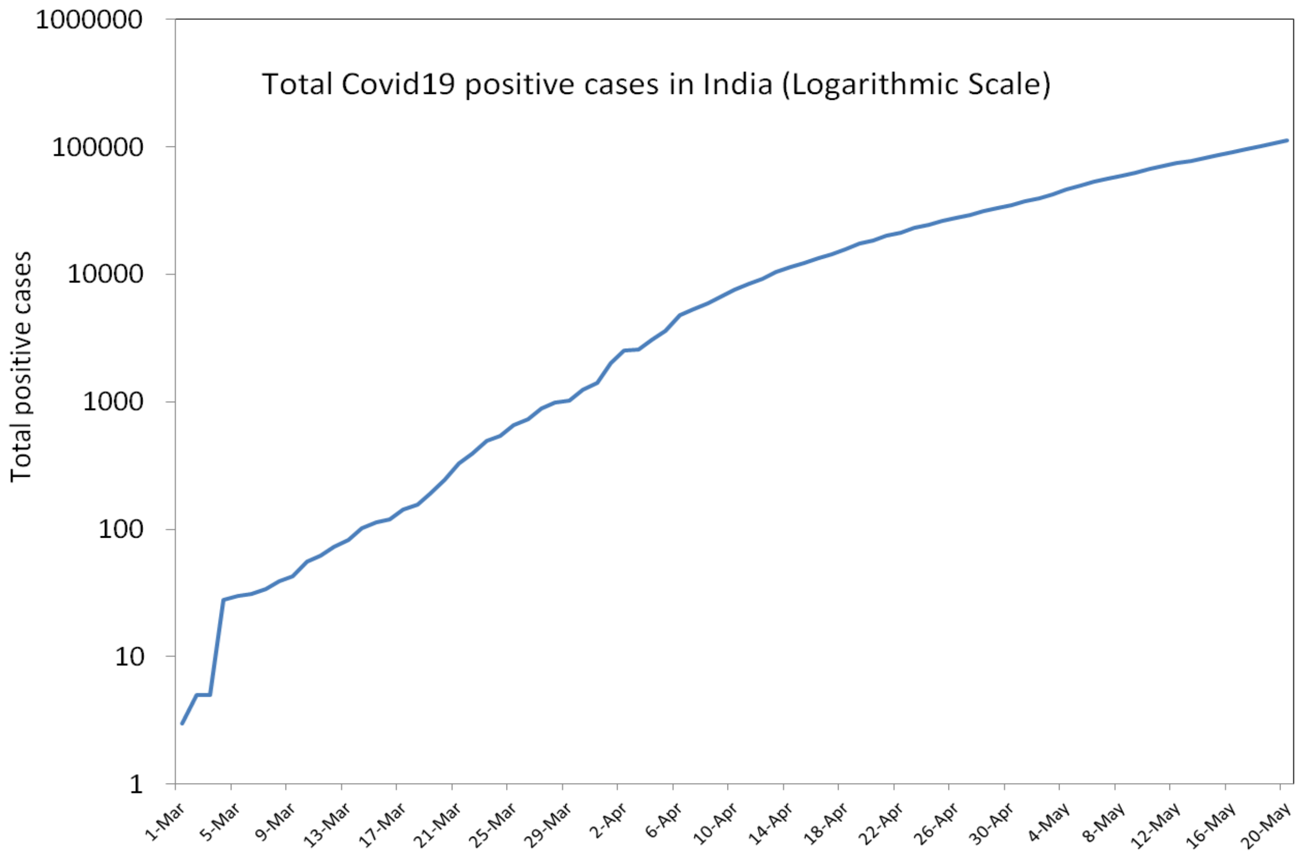

Figure 1: Cumulative number of confirmed positive cases of COVID-19 cases in India reported by MoHFW, Government of India.

years in summer season. During 29 March-18 April almost all regions experienced high solar radiation flux and thereafter the radiation reduces during 26 April to 2 May and again increased in the next 2 weeks in May resulting heat waves in eastern, central and western parts of India.

Same spatial distribution analysis for the 2m air temperature also presented at weekly average scale for the study period of 3 months. The distribution also shows an increasing trend from March (20-28^{o}C) to April (28-32^{o}C) in almost all part of the country. Then most parts the continental India witnessed weekly average temperature above 36^{o}C in the month of May 2020 (Figure 4) representing intense heat wave in various regions. The distribution also shows gradual increase in temperature from western India, followed by central India and overall eastern India recorded high temperature during summer 2020. The positive anomalies of temperature with respect to long term means indicates high temperature observed over the continental India in 2020 summer.

The relative humidity variability also presented week wise for the period March to May 2020 in Figure 5 and it clearly indicates the wider spatio-temporal variability in the distribution of water vapour. The relative humidity variability shows an increasing trend in first 2 weeks in March then decreasing trend from March 20 to 2nd week of April, and increased in the last week of April and again decreased in May over most of regions in India. In general, the western and central part shows comparative low relative humidity as against the north, east, south and north-east India regions during the study period.

3.3. Relation between weather parameters and COVID-19 cases

The daily time series of all India averaged relative humidity (upper panel), air temperature (middle panel) and downward solar flux are presented along with the daily reported number of COVID-19 cases in India (Figure 6) for the period i.e. 1 March to 16 May 2020. Daily variation of COVID-19 infected

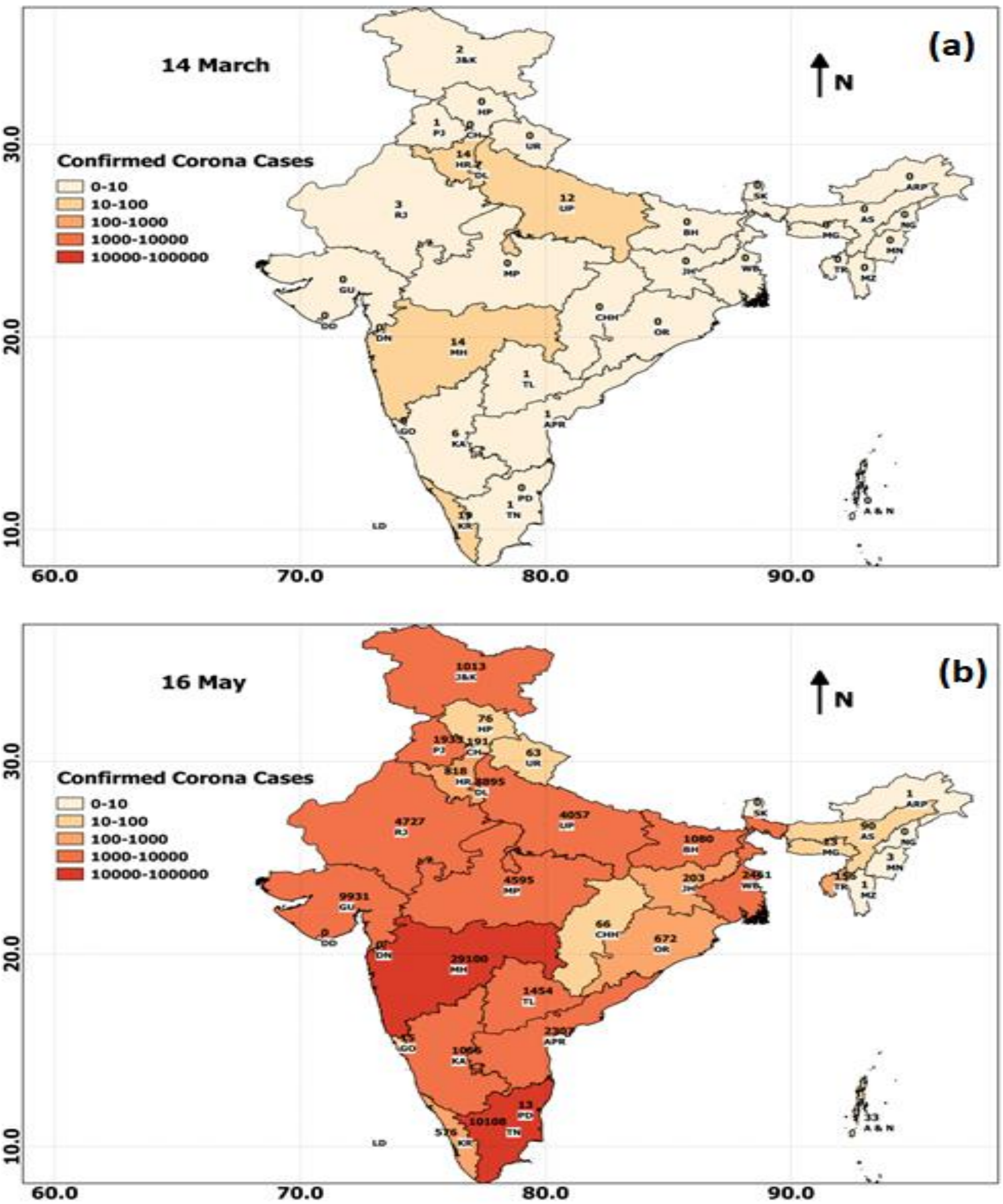

Figure 2: Spatial distribution of COVID-19 positive cases over states in India till (a) 14th March and (b) 16 May 2020 as reported by MoHFW, Government of India.

cases observed in India and weather parameters i.e. relative humidity (upper panel), air temperature (middle panel) and downward solar flux (bottom panel) averaged over continental India for the period 01 March-16 May 2020. The correlation analysis of daily time series for 76 days shows there is strong and significant relation (CC = 0.82) of 2m. air temperature and COVID-19 and the value is only 0.39 with 95% significant in case of downward solar radiation flux but it is insignificantly having zero correlation with the relative humidity.

The time series analysis is carried out by considering the weekly average values and it is observed that at weekly scale also temperature, solar flux and relative humidity have correlation 0.86, 0.45 and 0.11 respectively with COVID-19 cases in India in the summer season. The relation of temperature and solar flux is more significant in weekly scale also as presented in Figure 7. These results are consistent with few recent other studies, where it is observed that the combined temperature and humidity profile favors rapid COVID-19

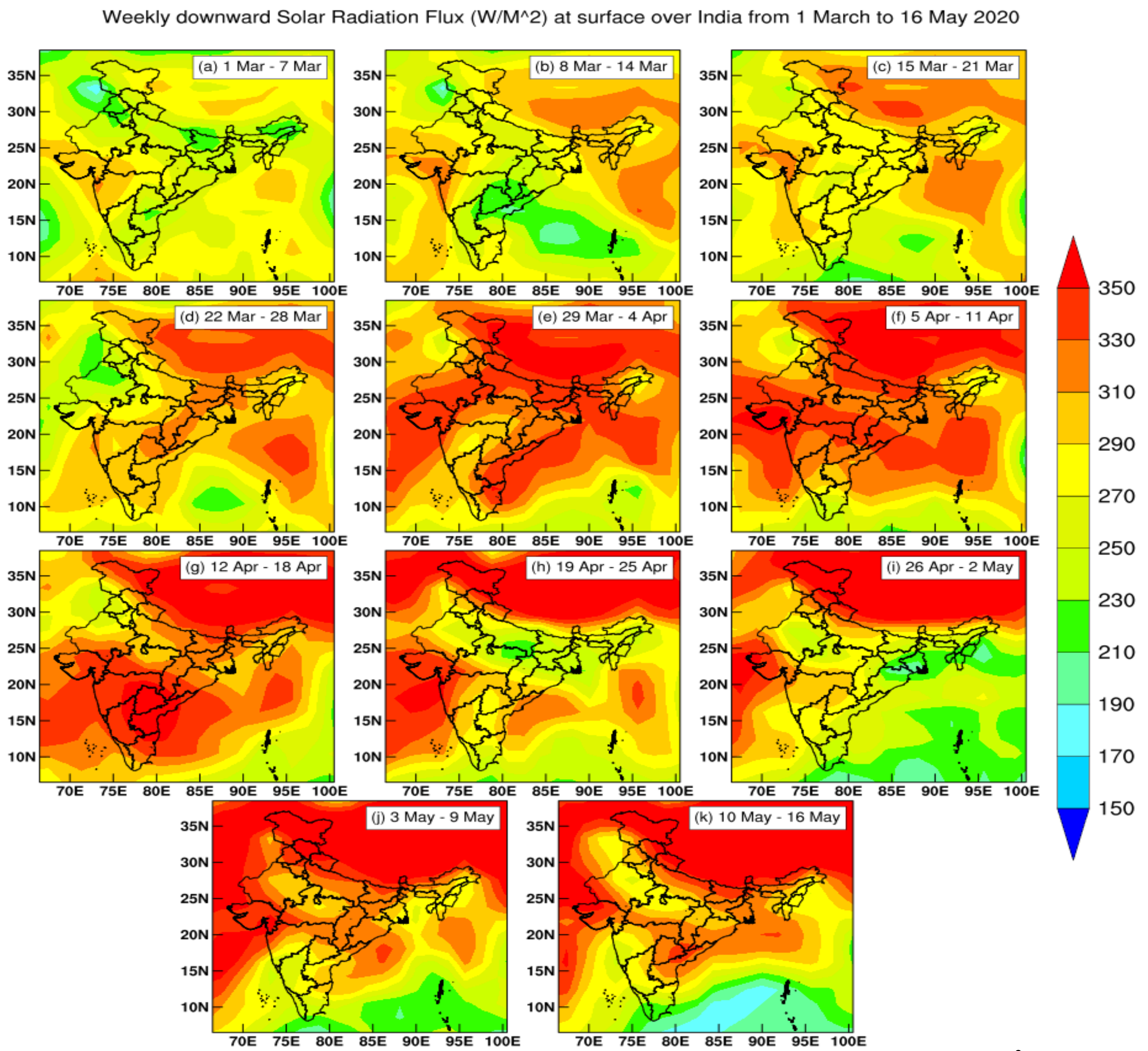

Figure 3: Spatial distribution of weekly averaged downward solar radiation flux (w/m^2) derived from NCEP reanalysis product over Indian region for the period 01 March- 16 May 2020.

growth at the initial phase in India (Sasikumar, 2020; Pawar et al. 2020; Kumar 2020) and other parts in world (Livadiotis 2020; Yao et al. 2020; Bu et al., 2020; Qi et al. 2020; Bherwani et al. 2020; Hridoy et al 2020). A study by Bukhari and Jameel (2020) indicated that the relation between temperature and COVID-19 spread is strong. Another study infers COVID-19 transmission was favored by the coupling influence of mean temperature, relative humidity, and wind speed. (Hridoy et al 2020) in Bangladesh. Few studies also reveal that relative humidity was not linked with COVID-19 spread in India (Bashir et al. 2020 and Kumar 2020) and it supports the result of the current study.

As generally the summer season prevails in the month of March to May so the THI which is a measure of the thermal stress (Thom 1959) is computed and also compared with COVID-19 cases at all India scale and it is observed that both in daily and weekly averaged analysis there is strong correlation between the THI and COVID-19 cases (Fig. 8) and the correlation found to be 0.6 at 95% significant level. This result indicates the combined effect of Temperature and relative humidity are the main driving meteorological factors in the COVID-19 spread in India and the variation in relations also depends on the season and location like inland or coastal city etc. (Yang et al. 2020). Results from several research works also showed the role of meteorological parameters and COVID-19 transmission is not same everywhere and it varies between different geographic regions like tropical and temperate etc. (Tosepu et al. 2020; Auler et al. 2020; Bu et al. 2020). The difference relationship

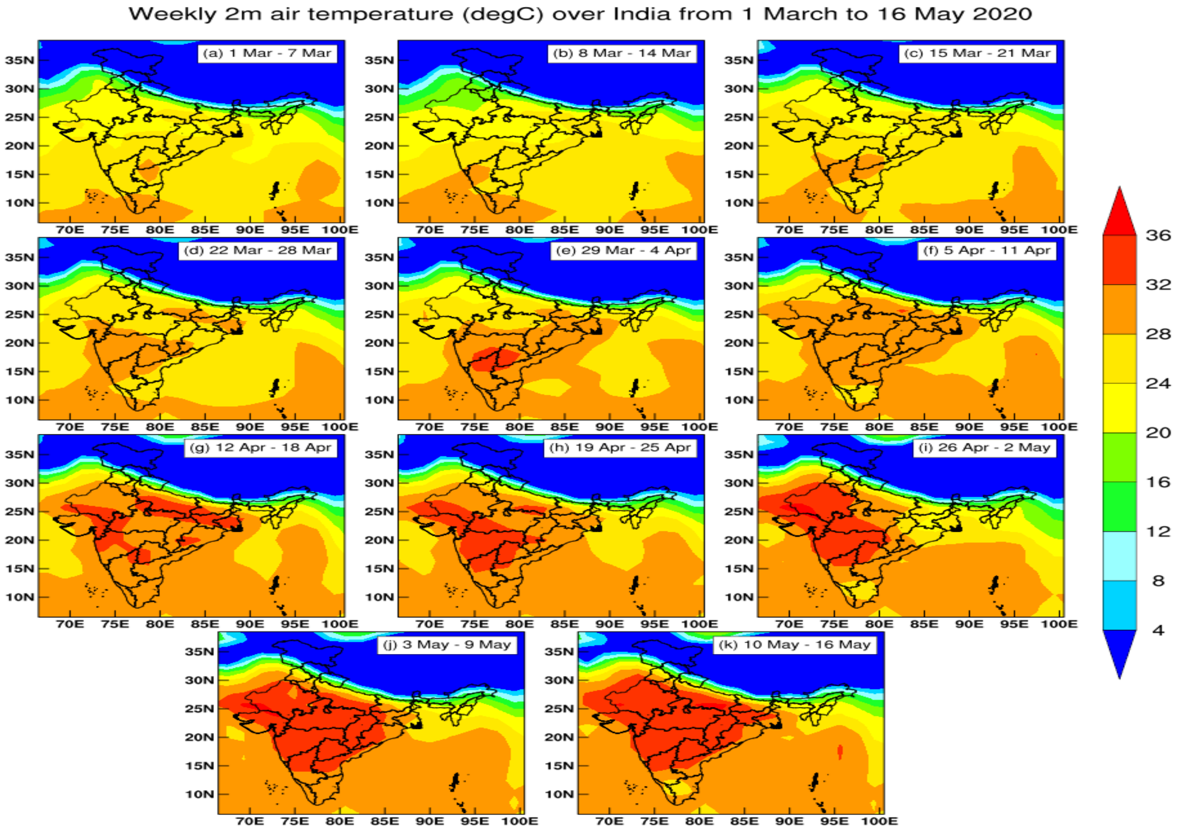

Figure 4: Spatial distribution of weekly averaged air temperature (^{o}C) derived from NCEP reanalysis product over Indian region for the period 01 March- 16 May 2020.

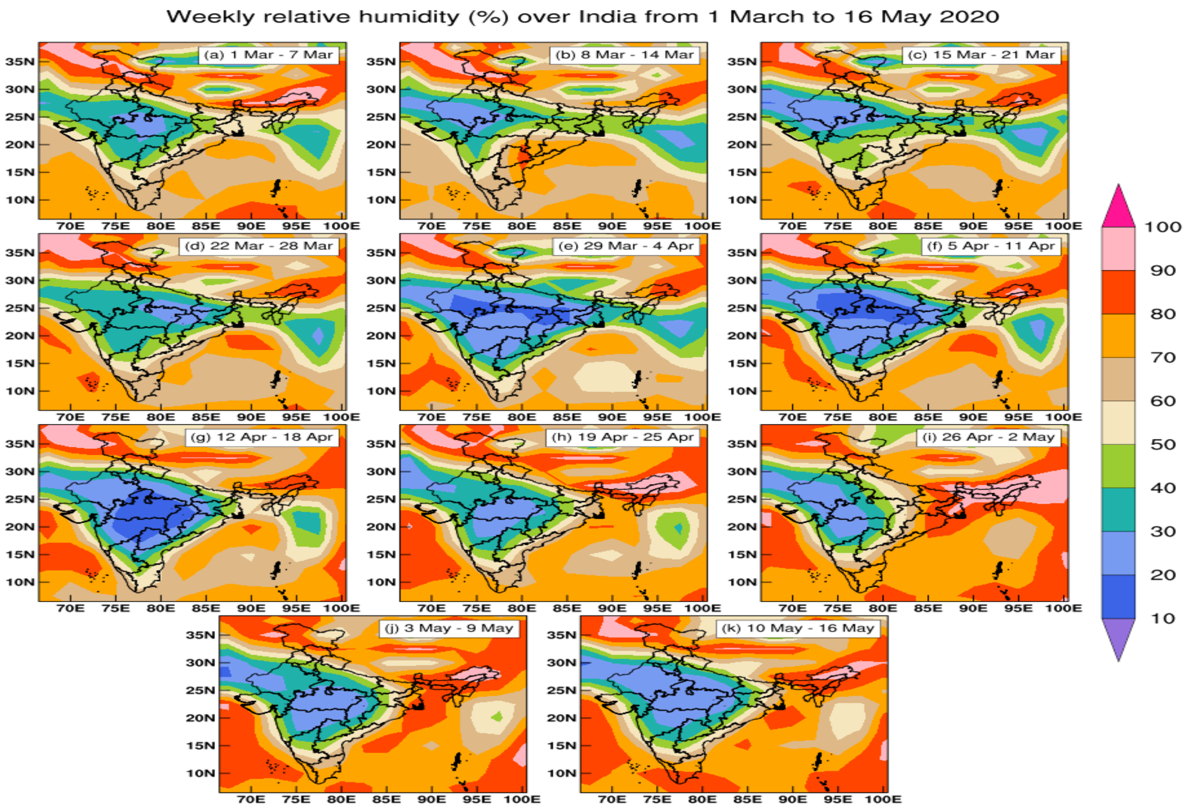

Figure 5: Spatial distribution of weekly averaged relative humidity (%) derived from NCEP reanalysis product over Indian region for the period 01 March- 16 May 2020.

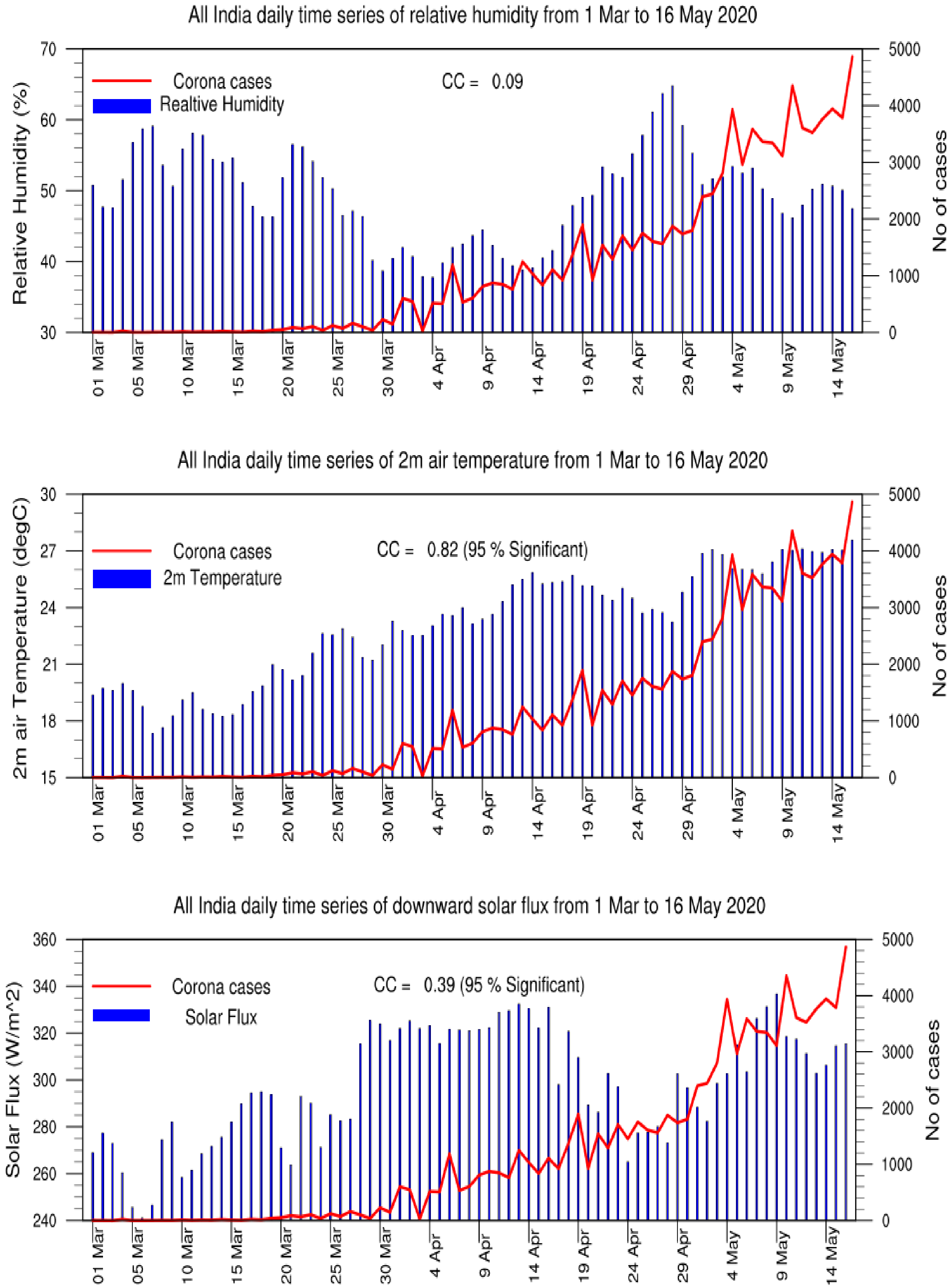

Figure 6: Daily variation of COVID-19 infected cases observed in India and weather parameters derived from NCEP-NCAR reanalysis i.e. relative humidity (upper panel), air temperature (middle panel) and downward solar flux (bottom panel) averaged over continental India for the period 01 March-16 May 2020. The correlation between COVID-19 cases and weather parameter are presented in each panel.

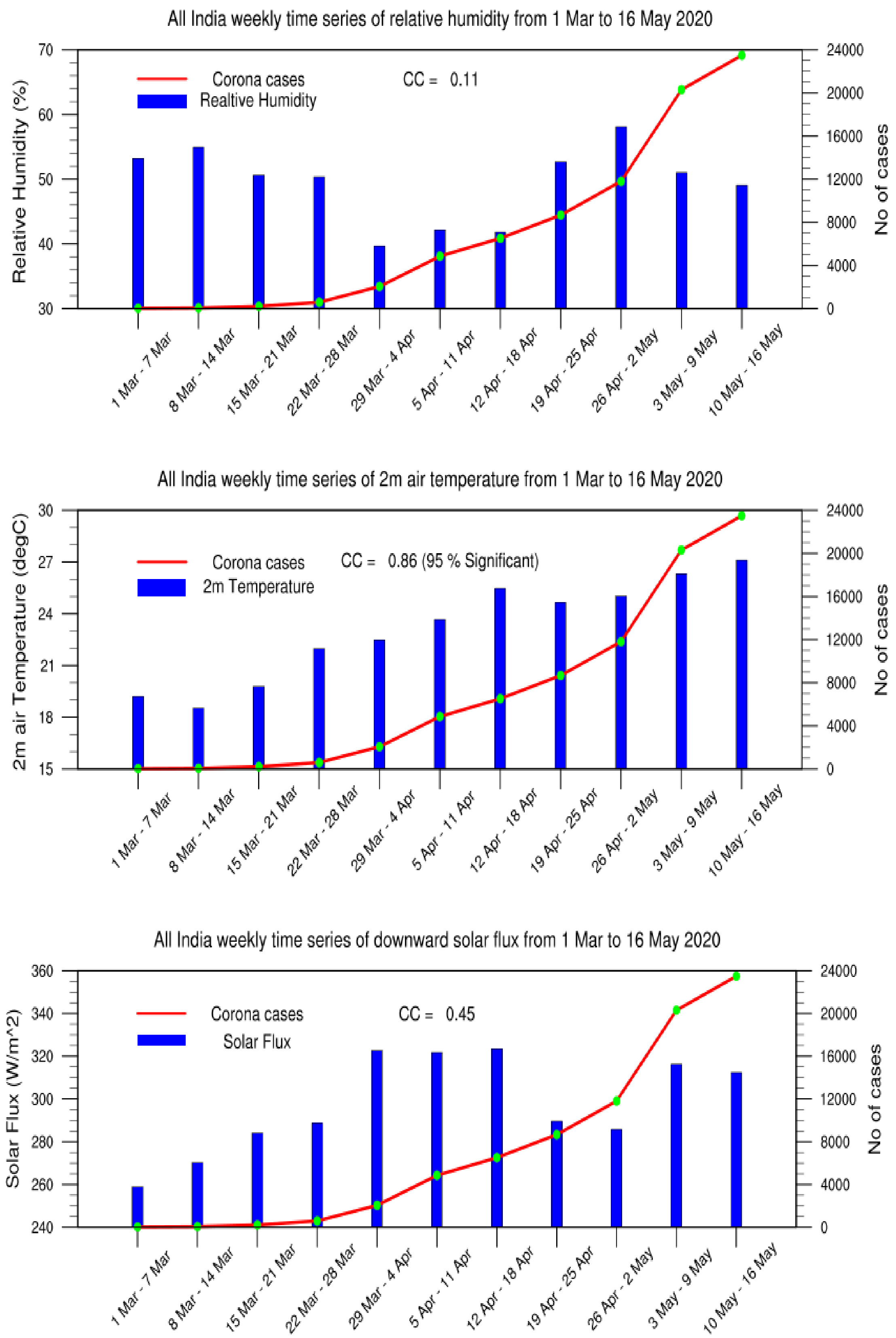

Figure 7: Weekly variation of COVID-19 infected cases observed in India and weather parameters derived from NCEP-NCAR reanalysis i.e. relative humidity (upper panel), air temperature (middle panel) and downward solar flux (bottom panel) averaged over continental India for the period 01 March-16 May 2020. The correlation between COVID-19 cases and weather parameter are presented in each panel.

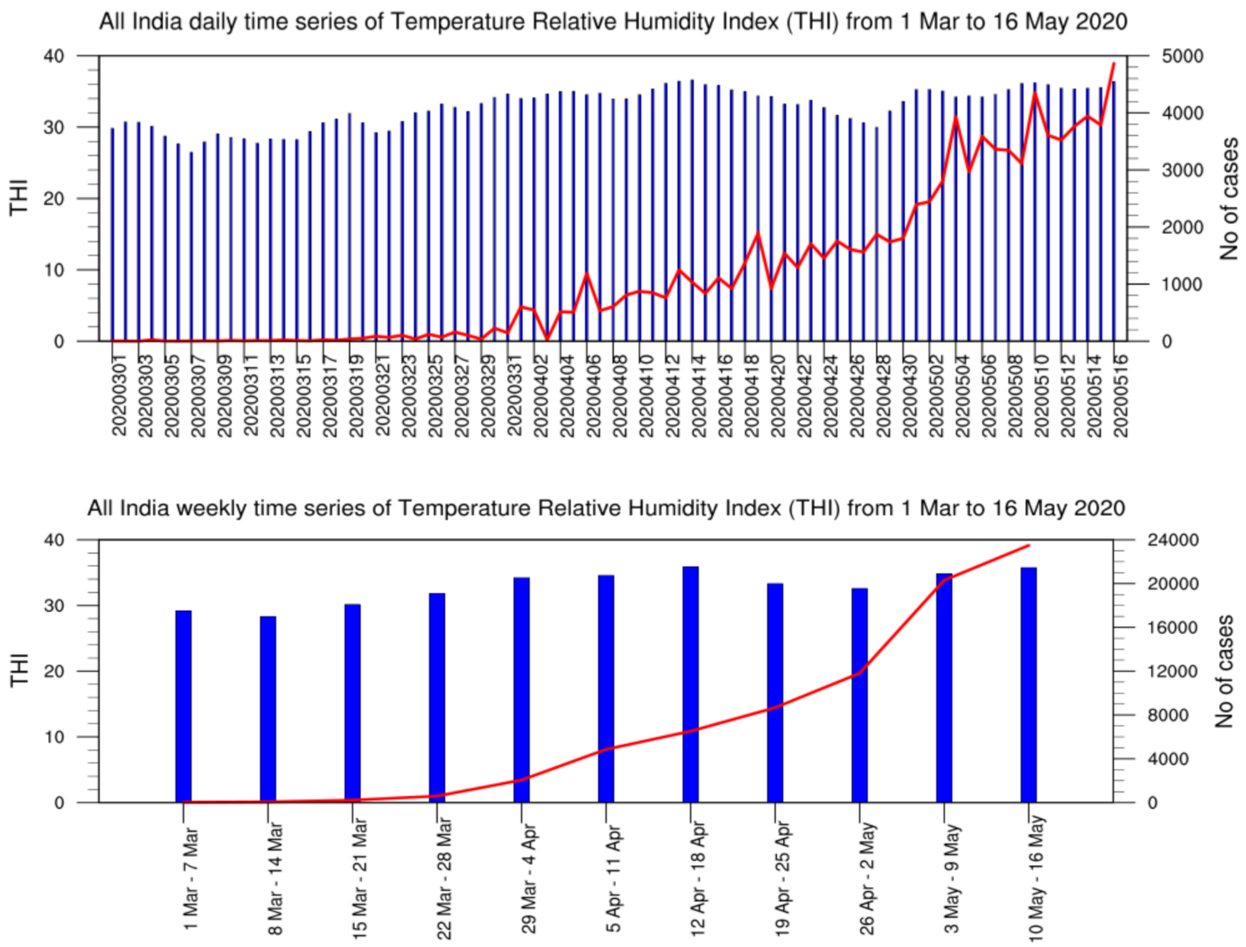

Figure 8: Daily (upper panel) and weekly (lower panel) variation of COVID-19 infected cases observed in India and THI averaged over continental India for the period 01 March- 16 May 2020. The correlation between the two time- series is 0.6 in both the cases.

between the meteorological parameters and COVID-19 spread also related to the positive cases reported, epidemic prevention and control measurements by the local government (Luo et al. 2020), so the results suggest that the role of these weather parameters are secondary in the COVID-19 disease transmission.

4. Conclusions

The COVID-19 spread shows exponential growth rate by May 2020 in India. Further, it is going to be more in the coming months as the summer season strengthens due to low emission and aerosol in the atmosphere thereby enhancing both the solar radiation and temperature. The present study over India shows significant correlation of solar radiation and atmospheric temperature with COVID-19 cases whereas relative humidity has low correlation during the study period. Also, the THI a measure of the thermal stress shows positive correlation with the COVID-19 spread. To be more precise in finding the role of meteorological parameters, particularly temperature and relative humidity in the spread of COVID-19, more intensive studies with longer period and covering different climate zones are required. The association found at all India scale is found to be inconclusive, and this finding will surely provide the baseline data for the experimental and clinical studies for the robust estimation of the relation of temperature, humidity and COVID-19 spread. In the coming days, there is need for confirming these relations for robust estimation and evidence by considering long term data as the COVID-19 shows rapid transmission in India. Along with monitoring the weather parameters there is also requirement of other prevention activities for the control of the ongoing pandemic.

Acknowledgements

This work is supported by the projects funded by the Department of Science and Technology under Epidemiology Data Analytics (EDA) of Interdisciplinary cyber physical systems (ICPS) programme (Grant number: DST/ICPS/EDA/2018), Govt. of India and another project funded under National Mission on Himalayan Studies (NMHS) of Ministry of Environment, forest and climate change, Govt. of India (grant no: GBPNI/NMHS-2019-20/MG/315). The CSIR 4PI high-performance computing (HPC) facility used for computing is acknowledged gratefully. The authors acknowledge Head, CSIR 4PI for support and encouragement. Authors acknowledge National Center for Atmospheric Research (NCAR) and National Centers for Environmental Prediction (NCEP) for providing the analysis data used in this study.

References

Ahmadi M, Sharifi A, Dorosti S, Ghoushchi SJ, Ghanbari N (2020) Investigation of effective climatology parameters on COVID-19 outbreak in Iran. Sci Total Environ 729:138705. 10.1016/j.scitotenv.138705.

Araújo MB, Naimi B (2020) Spread of SARS-CoV-2 Coronavirus Likely Constrained by Climate, medRxiv 2020.03.12.20034728. doi: https://doi.org/10.1101/2020.03.12.20034728.

Auler AC, Cássaro FAM, Silva VOD, Pires LF (2020) Evidence that high temperatures and intermediate relative humidity might favor the spread of COVID-19 in tropical climate: A case study for the most affected Brazilian cities. Sci. Total Environ. 2020, 729, 139090.

Bäcker A (2020) Slower COVID-19 morbidity and mortality growth at higher solar irradiance and elevation. SSRN. https://ssrn.com/abstract=3604729.

Bashir, MF, Ma B, Komal B, Bashir MA, Tan D, Bashir M (2020) Correlation between climate indicators and COVID-19 pandemic in New York, USA. Sci. Total Environ. 728, 138835.

Bherwani H, Gupta A, Anjum S, Anshul A, Kumar R (2020) Exploring dependence of COVID-19 on environmental factors and spread prediction in India. npj Climate and Atmospheric Science, *3*(1), 1-13.

Briz-Redón Á, Serrano-Aroca Á (2020) The effect of climate on the spread of the COVID-19 pandemic: A review of findings, and statistical and modelling techniques. Progress in Physical Geography: Earth and Environment, 44(5), 591-604.

Bu J, Peng DD, Xiao H, Yue Q, Han Y, Lin Y, Hu G, Chen J (2020) Analysis of Meteorological Conditions and Prediction of Epidemic Trend of 2019-nCoV Infection in 2020. medRxiv preprint, 10.1101/2020.02.13.20022715. doi:https://doi.org/10.1101/2020.02.13.20022715

Bukhari Q, Jameel Y (2020) Will coronavirus pandemic diminish by summer? SSRN Electron. J. doi: 10.2139/ssrn.3556998.

Casanova LM, Jeon S, Rutala WA, Weber DJ, Sobsey MD (2010) Effects of air temperature and relative humidity on coronavirus survival on surfaces. Appl Environ Microbiol 76, pp. 2712-2717, 10.1128/AEM.02291-09.

Chen B, Liang H, Yuan X, Hu Y, Xu M, Zhao Y, Zhang B, Tian F, Zhu X (2020) Roles of Meteorological Conditions in COVID-19 Transmission on a Worldwide Scale. medRxiv preprint, 10.1101/2020.03.16.20037168. doi: https://doi.org/10.1101/2020.03.16.20037168

Coelho MTP, Rodrigues JFM, Medina AM, Scalco P, Terribile LC, Vilela B, Diniz-Filho JAF, Dobrovolski R (2020) Exponential phase of covid19 expansion is driven by airport connections, medRxiv preprint, 10.1101/2020.04.02.20050773. doi: https://doi.org/10.1101/2020.04.02.20050773

Dalziel BD et al (2018) Urbanization and humidity shape the intensity of influenza epidemics in US cities. Science. 362: 75–79.

Damette O, Mathonnat C, Goutte S (2021) Meteorological factors against COVID-19 and the role of human mobility. PLOS ONE 16(6): e0252405. https://doi.org/10.1371/journal.pone.0252405.

Doğan B, Ben Jebli M, Shahzad K, Hassan Farooq T, Shahzad U (2020) Investigating the effects of meteorological parameters on COVID-19: case study of New Jersey, United States. Environ Res 191:110148. https://doi.org/10.1016/j.envres.2020.110148

Gorbalenya AE, Baker SC, Baric RS et al (2020) The species severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. Nat Microbiol 5:536–544.

Gupta A, Banerjee S, Das S (2020) Significance of geographical factors to the COVID-19 outbreak in India. Model Earth Syst Environ 6(4):2645–2653.

Hemmes JH, Winkler KC & Kool SM (1960) Virus survival as a seasonal factor in influenza and poliomyelitis. Nature 188: 430–43.

https://mohfw.gov.in

http://www.psl.noaa.gov/data/gridded/data.ncep.reanalysis.html

https://www.worldometers.info/coronavirus/#countries

Islam, N., Bukhari, Q., Jameel, Y., Shabnam, S., Erzurumluoglu, A. M., Siddique, M. A., Massaro, J. M., & D'Agostino, R. B., Sr (2021). COVID-19 and climatic factors: A global analysis. Environmental research, 193, 110355. https://doi.org/10.1016/j.envres.2020.110355

Killerby ME et al (2018) Human coronavirus circulation in the United States 2014–2017. J Clin Virol 101: 52–56 .

Kissler SM, Tedijanto C, Goldstein E, Grad YH, Lipsitch M (2020) Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. Science 368(6493):860-868. doi: 10.1126/science.abb5793. Epub 2020 Apr 14. PMID: 32291278; PMCID: PMC7164482.

Kumar S (2020) Effect of meteorological parameters on spread of COVID-19 in India and air quality during lockdown. Science of the Total Environment, 745, p.141021.

Lewis D (2020) Is the coronavirus airborne? Experts can't agree. Nature News 580: 175pp.

Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, Ren R, Leung K, Lau E, Wong J et al (2020) Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. N Engl J Med 382: 1199–1207.

Livadiotis G (2020) Statistical analysis of the impact of environmental temperature on the exponential growth rate of cases infected by COVID-19. PLoS ONE 15(5): e0233875. https://doi.org/10.1371/journal.pone.0233875.

Lowen AC, Steel J, Mubareka S, Palese P (2008) High temperature (30^{o}C) blocks aerosol but not contact transmission of influenza virus. J Virol 82: 5650–5652.

Luo, W.; Majumder, M.; Liu, D.; Poirier, C.; Mandl, K.; Lipsitch, M.; Santillana, M. (2020) The role of absolute humidity on transmission rates of the COVID-19 outbreak. SSRN 2020

Marr LC, Tang JW, Van Mullekom J, Lakdawala SS (2019) Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence. J R Soc Interface 16(150):20180298. https://royalsocietypublishing.org/doi/https://doi.or/10.1098/rsif.2018.0298

Mecenas P, Bastos RTDRM, Vallinoto ACR, Normando D (2020) Effects of temperature and humidity on the spread of COVID-19: A systematic review. PLoS one, 15(9), e0238339.

Morawskaa L, Cao J (2020) Airborne transmission of SARS-CoV-2: The world should face the reality. Environ Int 139:105730.

Oliveiros B, Caramelo L, Ferreira NC, Caramelo F (2020) Role of temperature and humidity in the modulation of the doubling time of COVID-19 cases. medRxiv. https://doi.org/10.1101/2020.03.05.20031872.

Park JE et al (2020) Effects of temperature, humidity, and diurnal temperature range on influenza incidence in a temperate region. Influenza Other Respir Viruses 14: 11–18.

Pawar S, Stanam A, Chaudhari M, Rayudu D (2020) Effects of temperature on COVID-19 transmission. MedRxiv. https://doi.org/10.1101/2020.03.29.20044461.

Peci A, Winter AL, Li Y, Gnaneshan S, Liu J, Mubareka S, Gubbay JB (2019) Effects of absolute humidity, relative humidity, temperature, and wind speed on influenza activity in Toronto, Ontario, Canada. Appl Environ Microbiol 85(6):e02426–18.

Qi H, Xiao S, Shi R, Ward MP, Chen Y, Tu W, Su Q, Wang W, Wang X, Zhang Z (2020) COVID-19 transmission in Mainland China is associated with temperature and humidity: a time-series analysis. Sci Total Environ 728: 138778.

Salom I, Rodic A, Milicevic O, Zigic D, Djordjevic M, Djordjevic M (2020) Effects of demographic and weather parameters on COVID-19 basic reproduction number. arXiv preprint arXiv:2010.09682.

Sasikumar K, Nath D, Nath R, Chen W (2020) Impact of Extreme Hot Climate on COVID-19 Outbreak in India. GeoHealth 4(12), e2020GH000305. https://doi.org/10.1029/2020GH000305.

Shahzad K, Hassan Farooq T, Doğan B, Hu LZ, Shahzad U (2021) Does environmental quality and weather induce COVID-19: case study of Istanbul, Turkey. Environ Forensics.

Shaman J, Pitzer VE, Viboud C, Grenfell BT, Lipsitch, M. (2010) Absolute humidity and the seasonal onset of influenza in the continental United States. PLoS Biol 8: e1000316.

Shaman J, Goldstein E, Lipsitch M (2010) Absolute humidity and pandemic versus epidemic influenza. Am J Epidemiol 173:127–135.

Shi P, Dong Y, Yan H, Zhao C, Li X, Liu W, He M, Tang S, Xi S (2020) Impact of temperature on the dynamics of the COVID-19 outbreak in China. Sci Total Environ 728: 138890.

Sobral MFF, Duarte GB, da Penha Sobral AIG, Marinho MLM, de Souza Melo A (2020) Association between climate variables and global transmission oF SARS-CoV-2.I.729: 138997.

Steel J, Palese P, Lowen AC (2011) Transmission of a 2009 pandemic influenza virus shows a sensitivity to temperature and humidity similar to that of an H3N2 seasonal strain. J Virol 85:1400–1402.

Tosepu R, Gunawan J, Effendy DS, Ahmad LOAI, Lestari H, Bahar H, Asfian P (2020) Correlation between weather and COVID-19 pandemic in Jakarta, Indonesia. Sci Total Environ 728: 138810. 10.1016/j.scitotenv.138436.

Thom E C (1959) The Discomfort Index. Weatherwise 12:2, 57-61. DOI: 10.1080/00431672.1959.9926960.

WHO characterizes COVID-19 as a pandemic (2020).

Yao Y, Pan J, Liu Z, Meng X, Wang W, Kan H, Wang W (2020) No association of COVID-19 transmission with temperature or UV radiation in Chinese cities. The European respiratory journal 55(5): 2000517. https://doi.org/10.1183/13993003.00517-2020.

Yang XD, Li HL, Cao YE. Influence of Meteorological Factors on the COVID-19 Transmission with Season and Geographic Location (2021). Int J Environ Res Public Health 18(2):484. doi: 10.3390/ijerph18020484. PMID: 33435301; PMCID: PMC7827058.

Yuan J et al (2006) A climatologic investigation of the SARS-CoV outbreak in Beijing, China. Am J Infect Control 34: 234–236.

Zhu Y, Xie J (2020) Association between ambient temperature and COVID-19 infection in122 cities from China. Sci Total Environ 724:138201. https://doi.org/10.1016/j.scitotenv.2020.138201