Comparative Study of Severe Thunderstorms of 15-16 April 2020 and 25-26 June 2020

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ABSTRACT

High impact severe weather events like thunderstorms are associated with strong winds, dust, thunder, lightning, heavy rainfall, hail etc. Such events have devastating consequences particularly leading to aviation hazards, loss of life and damage to property, vegetable crops and food. A severe thunderstorm had caused large scale damage to life and property over Sub-Himalayan West Bengal, Sikkim and North-eastern states during 15-16 April 2020. Similarly, a fusillade of lightning strikes associated with intense thunderstorm spread across the two states of Bihar and Uttar Pradesh on 25-26 June 2020 killed more than 100 people. In the present research, a comparative study has been carried out by investigating synoptic, thermodynamic and dynamical features leading to these two intense systems. Global Forecast System model at 12 Km resolution along with the Weather Research and Forecasting model version 3.6.1 at 3 Km resolution have been used for the analysis of operational forecasts of these two cases i.e. 15-16 April and 25-26 June 2020.

The low-level convergence associated with the cyclonic circulation of strong moist winds from the Bay of Bengal region was responsible for the severe thunderstorm of 15-16 April 2020. Whereas the event of 25-26 June 2020 during the monsoon period, was associated with low level convergence over Bihar and Uttar Pradesh supported by high values of low-level humidity. The global and regional model (GFS and WRF) forecasts indicated the favourable environmental factors for the occurrence of thunderstorms in both the cases.

Keywords: *Thunderstorms, Pre-monsoon, Monsoon, Deep convection, GFS & WRF models.*

1. Introduction

Thunderstorm, resulting from vigorous convective activity, is one of the most spectacular weather phenomena in the atmosphere. Thunderstorms are the typical mesoscale systems dominated by intense convection and mainly occur in the pre-monsoon season from March to May (Mohanty et al., 2008 and Singh et al., 2011). Thunderstorms and lightning are highly damaging natural phenomena which need to be predicted precisely both on spatial and temporal scales in order to save lives and property to the maximum possible extent. These convective systems are formed in an unstable environment. On a broad scale, there are three requirements for the development of intense convection either in the form of a Towering Cumulus or a single cell Cumulo Nimbus (Cb). These are (i) instability, (ii) moisture availability in the boundary layer and (iii) some mechanism to produce vertical motion (i.e., a trigger) of the air parcel up to the level of free convection. Assuming these three conditions are met, a deep convection is expected to develop with its intensity primarily dependent on the degree of instability and availability of boundary layer moisture. Hence, at the outset it may be noted that, an ingredients-based approach to forecasting convection would be the first and foremost step in the prognosis of thunderstorm development.

Though the severe convective events like thunderstorms, lightning, hailstorms & Thunder squalls do occur throughout the year, the peak activity happens during the months of April, May and June. The thunderstorms occurring during pre-monsoon months of April and May are associated with land heating (when surface heating plays a pre-dominant role) over eastern and north-eastern parts of India accompanied by moisture incursion from the Bay of Bengal. However, sometimes thunderstorms also occur over northern and central parts of India during the onset phase of monsoon in June. In the present study, the synoptic, thermodynamic and dynamic aspects of two thunderstorm events occurred recently have been analysed. The two episodes are (i) thunderstorm over the Bangladesh and adjoining north-eastern India during 15-16 April 2020 and (ii) thunderstorm during the onset phase of monsoon from 25-26 June 2020 over Uttar Pradesh and Bihar.

Mesoscale models are helpful for the accurate prediction of such high-impact weather events. Thunderstorm forecasting is one of the most difficult issues in weather forecasting. Forecasting accuracy has improved greatly with the development of Numerical Weather Prediction (NWP) models. Convective parameters are the important tools utilized to forecast, monitor and analyse potential severe convective weather. Many meteorologists have pointed out that convection requires three basic conditions: (i) instability over a layer of sufficient depth; (ii) a moist layer at low levels; and (iii) a mechanism (i.e., lift) that triggers the convection (Doswell III, 1987; Johns and Doswell III, 1992). Over the Indian region, many researchers have done the simulation and forecasting of thunderstorms using meso-scale models like Weather Research Forecasting (Rajeevan et al., 2010; Litta et al., 2012; and Halder and Mukhopadhyay, 2016). Meteorologists have presented many different thermodynamic and kinetic parameters that meet all or some of these requirements to forecast the possibility of thunderstorms by studying pre-convective sounding data or data from NWP models. Thunderstorm parameters describe the potential of thunderstorms. However, the threshold values for thunderstorm occurrences are not uniform over different geographical location and may vary at different locations considering its elevation. The high-resolution global model like operational Global Forecast System (GFS) in IMD at 12 km resolution can also give useful guidance about the favourable large-scale possibility of occurrence of thunderstorm particularly during the monsoon season.

The present study is carried out to compare two such thunderstorm cases by investigating synoptic, thermodynamic and dynamical features leading to these two intense systems. An attempt has also been made to compare the simulated results of Weather Research Forecasting (WRF) model for the two events with a maximum lead time of 48 hrs.

2. Description of the two thunderstorm cases

For the present study, two severe thunderstorm cases i.e., one on 15-16 April 2020 and the other on 25-26 June 2020 have been considered. Based on the forecasting circular No 1/2019 available from IMD (www.imd.gov.in) the thunderstorms are classified into 4 categories viz., (i) Light Thunderstorm, if the wind speed < 41 kmph (21 knots); (ii) Moderate Thunderstorm, if the wind speed is 41-61 kmph (22-33 knots); (iii) Severe Thunderstorm, if the wind speed is 62-87 kmph (34-47 knots) and (iv) Very Severe Thunderstorm, if the wind speed > 87 kmph (> 47 knots). Like the classification based on the wind speed the thunderstorm is also associated with deep convection which can be measured in terms of Cloud Top Temperature (CTT). The nature of convection as classified by IMD and is available in IMD website (www.imd.gov.in) based on CTT are: (i) weak convection with CTT>-25^{0}C, (ii) moderate convection with CTT between -25^{0}C to -40^{0}C, (iii) intense convection with CTT between - 41^{0}C to -70^{0}C and (iv) very intense convection with CTT < -70^{0}C. Some of these parameters are also used in the present case to understand the intensity of these two thunderstorms.

Case-I: It was a severe thunderstorm event reported on 15-16 April 2020 over Sub-Himalayan West Bengal, Sikkim and North-Eastern states. Since April is the hot weather season, the land heating is dominated leading to the occurrence of the thunderstorm. On 15th April 2020 the synoptic analysis indicated presence of a high pressure area over the Bay of Bengal at sea level chart and associated anticyclonic flow at lower level over the region (Figure 1a). It is also seen that a cyclonic circulation was present over West Bengal & adjoining Bangladesh in the lower levels (Figure 1b). An east-west oriented trough line extended from this circulation to northwest Uttar Pradesh (Figure 1b). There was also a trough in the middle levels along 85ºE. Towards afternoon, as the trough moved eastwards, cold air advection was in the

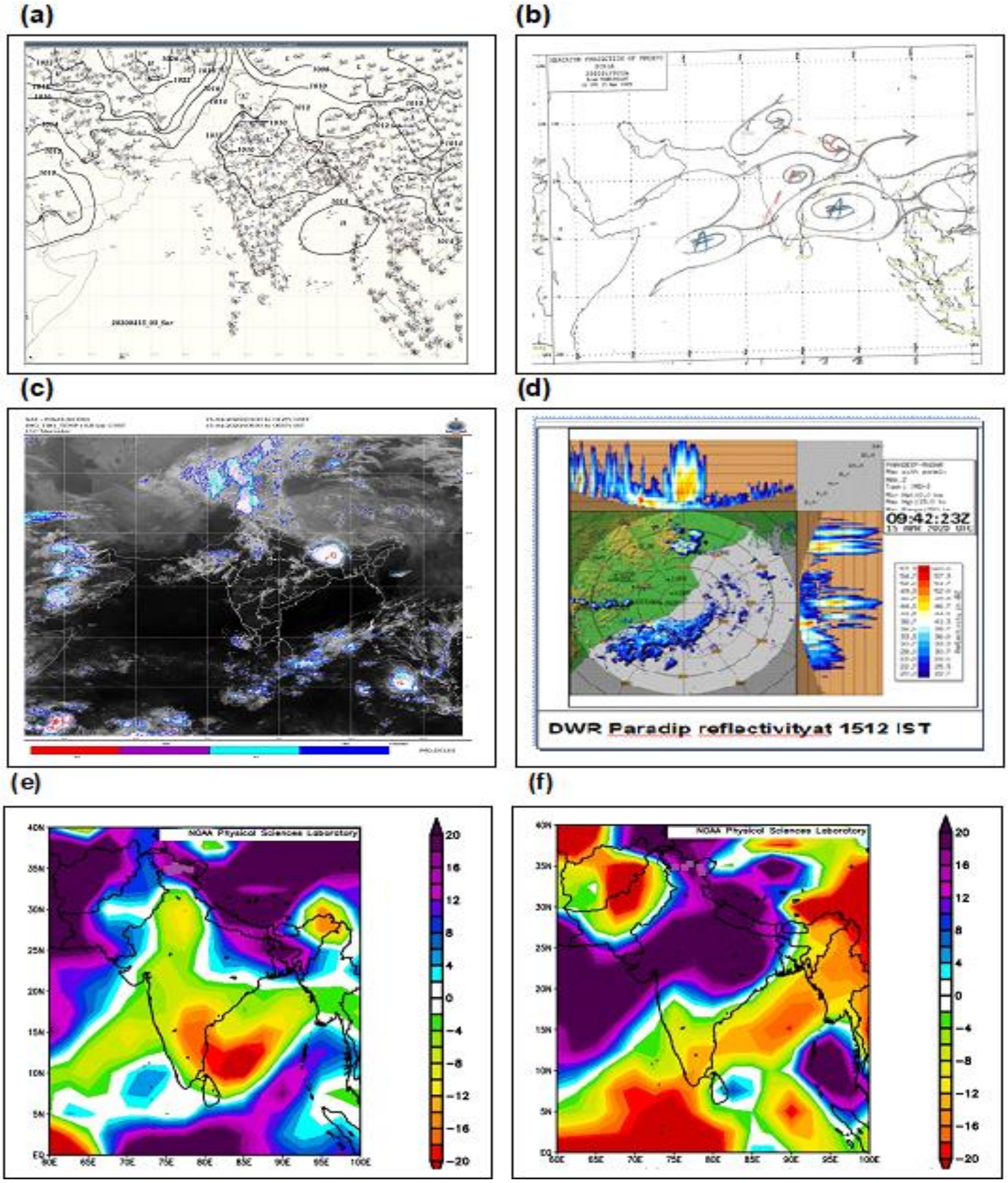

Figure 1: (a) Mean Sea level (MSL) chart of 15th April 2020 indicating the east-west shear line. (b) 0.9 km wind for 0000 UTC of 15th April. (c) & (d) INSAT cloud top temperature at 0100 UTC of 15th April 2020 and (d) DWR Paradip reflectivity at 1512 IST of 15th April 2020. (e) & (f) 850 hPa & 500 hPa RH anomaly of 15th May.

middle levels over North-east India and Bangladesh. Both factors indicated that north-east India was the most convectively prone region. Severe convection, accompanied by strong squally winds at isolated places was prevailing throughout north-east India. The deep convective cloud associated with lower value of CTT and radar reflectivity is also seen in Figure 1c & 1d. The CTT value was between -60^{0}C and -80^{0}C over the region of GWB and neighbourhood with a small pocket indicating CTT less than -80^{0}C.

The synoptic analysis further indicated that there was also a high pressure over the Bay of Bengal

(Figure 1a) and the anticyclonic flows at lower level (Figure 1b) can enhance the moisture feeding from the Bay of Bengal to the northeast & adjoining east India. The INSAT 3D cloud top image valid at 0630 hrs IST of 15th April indicated deep convective cloud over the Bihar and adjoining Sub-Himalayan West Bengal and Bangladesh region (Figure 1c), which gradually moved eastward towards Bangladesh and Northeast India, which can be seen from the Radar image of Paradeep 1512 hrs IST (Figure 1d). Associated with these synoptic features, severe convection, accompanied at isolated places by strong squally winds occurred over northeast India accompanied with heavy rainfall at isolated places. Figure 1e&f also indicate above normal relative humidity mainly at lower tropospheric level, which is favourable for the occurrence of severe thunderstorm.

Case-II: It was a severe thunderstorm reported on 25-26 June 2020 over Bihar and Uttar Pradesh which continued for two days. The synoptic analysis indicated that on 25th June the cyclonic circulation over the Bay of Bengal has moved westward since 24th June and lay over southwest and adjoining southeast Bay of Bengal in the middle levels, tilting south-westward with height. This halted the deep moisture flow from the Bay of Bengal into northwest India. The two cyclonic circulations over northeast Rajasthan and central Pakistan persisted in the lower levels.

The trough at mean sea level ran from central Pakistan to Bihar (Figure 2a). The moisture incursion into northwest India from Arabian Sea was continued, which can be seen from the surface analysed charts of 24th June 2022, along with lower levels wind from Global Forecast System (GFS) at 0000 UTC of 25th (Figure 2b). Further, the INSAT satellite imagery with overlying lightning observation is also shown in Figure 2c-d respectively**.** The deep convection associated with lower value of CTT (Value < -80^{0}C) in Figure 2c in the morning hour (0400 UTC) over Bihar and Uttar Pradesh region over an extended region is the indication of very intense convective cloud associated with Thunderstorm. Thus, an extended region was associated with very intense convective cloud over large part of Uttar Pradesh and Bihar associated with Thunderstorm in this case. However, in case of case-I thunderstorm in April the CTT was less than -80^{0}C over a small pocket. Similarly, the lightning flash, as indicated in Figure 2d, over the convective band over Bihar and Uttar Pradesh measured at 1000 UTC (1530 hrs IST) is the reflection of very intense convective thundercloud. Figure 2e&f also indicated above normal relative humidity mainly at lower tropospheric level, which is favourable for the occurrence of severe thunderstorm.

Some of the synoptic and thermodynamic conditions associated with these two thunderstorm cases are given in Table 1. The convective available potential energy (CAPE) is also obtained from the nearest station associated with these two thunderstorm cases.

3. Numerical Model Forecasts and discussion of the Results

In order to examine the performance of numerical model in forecasting the two thunderstorm events discussed above, which are contrasting in the sense that in case-II thunderstorm occurred during the monsoon season supported by conducive large-scale features, whereas the case-I is the typical pre-monsoon thunderstorm affecting eastern and adjoining north-eastern parts of the country in an environment of warmer land-surface condition. Here the outputs from the operational Global and Regional models used by IMD are used. The GFS is run with 12 km horizontal resolution along with WRF model version 3.6.1 at 3 km resolution has for simulation and investigation of the above two cases of thunderstorms during 15-16 April over West Bengal and adjoining north-eastern regions and during 25-26June 2020 for Bihar and Uttar Pradesh.

3.1 Case-I: Thunderstorms during 15-16 April 2020

During the pre-monsoon period (March–May) of 2020, heating of the land surface, prevailing synoptic situation ensuring moisture convergence from the Bay of Bengal, with the aid of orographic features had given rise to significant convective activity over north-eastern parts of India and adjoining Bangladesh during 15-16 April. As

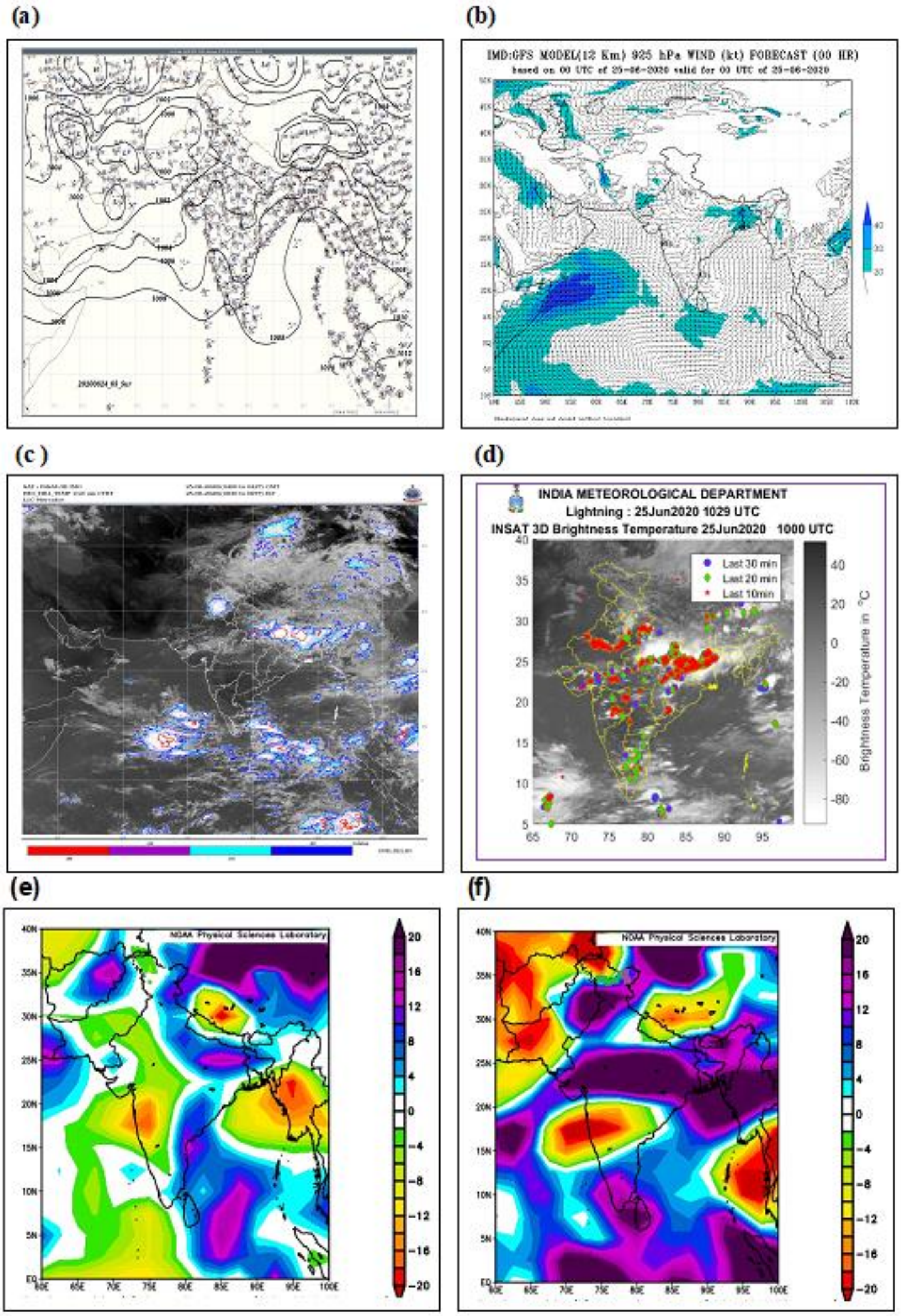

Figure 2: (a) Mean Sea level (MSL) chart of 24th June 2020 indicating the east-west shear line. (b) 925 hPa analysis of Global Forecast System for 00 UTC of 25th June. (c) & (d) INSAT cloud top temperature at 04 UTC of 25th June. (d) Lighting flash overlying on satellite imageries at 1000 UTC of 25th June. (e) & (f) 850 hPa & 500 hPa RH anomaly of 25th May.

Table 1. Synoptic and thermodynamic features associeted with two thunderstorms.

Synoptic Features	**CASE-I 15th-16th April 2020**	**CASE- II 25th -26th June 2020**
Season	Pre-Monsoon Season (April)	Monsoon Season (June)
Synoptic System	Cyclonic circulation extending up to 0.9km above mean sea level over West Bengal and adjoining Bangladesh at lower tropospheric levels.	Trough at mean sea level from north-west Rajasthan to south Bihar ran from central Pakistan to Bihar across north-west Rajasthan, Haryana, Uttar Pradesh.
CAPE (00UTC)	3117.69 J/Kg (Kolkata Station)	2166.10 J/Kg (Gorakhpur Station)
Low/Middle humidity	Above Normal (Positive anomaly)	Above normal (Positive anomaly)
Cloud Top Temperature (CTT)	Less than -800C over a very small region with single cell structure	Less than -800 C over an extended region with multi cell structure

discussed above, on 15 April, 0000 UTC a cyclonic circulation lay over West Bengal and adjoining Bangladesh in the lower levels. An east-west oriented trough line extended from this circulation to northwest Uttar Pradesh. There is also a trough in the middle levels along 85^0E. Towards afternoon, as the trough moves eastward, cold air advection is likely in the middle levels over Northeast India and Bangladesh.

The WRF meso-scale model forecasts (for 24 hr and 48 hr) mean layer wind (850 -300 hPa) along with the relative humidity (RH) based on 14^{th} April, 0000 UTC initial condition and valid for 15^{th} 0000 UTC and 16^{th} 0000 UTC are shown in Figure 3a&b respectively. As it is seen, the 24hrs forecast based on 14 April 0000UTC and valid for 15 April 0000UTC, indicates RH 70 to 80% over the parts of north-eastern states and further RH increases to 90% in 48 hr forecast valid for 16 April 0000 UTC. Accompanied by this high RH, the mean wind indicates strong warm north-westerly wind from north-west India approaching towards Bangladesh and adjoining northeast India indicating wind convergence supported by moisture incursion from Bay of Bengal, which can create favourable condition for the occurrence of Thunderstorm (Figure 3a&b). The upper level (200 hPa) forecast wind also indicates trough in westerly oriented almost parallel to the east coast of India, thereby creating additional convergence at lower level to the east of the trough line over Bangladesh and north-eastern states (Figure 3c&d). Similarly, the 24hr forecast CAPE valid for 15 April as shown in Figure 6e indicates values around 2500 Joules/Kg over the region of West Bengal, Bangladesh and adjoining north-eastern states. The day-2 forecast, valid for 16 April 00 UTC indicates CAPE values exceeding 2500 and at places it is higher than 3500 Joules/Kg particularly over the southern parts of Bangladesh (Figure 6f). Thus, the WRF model indicates favourable conditions for the occurrence of thunderstorm on 15-16 April 2020 over Bangladesh and adjoining north-eastern states.

The development of convective band over Bangladesh and adjoining northeastern states is very clearly seen based on the forecast reflectivity from WRF model based on 14 April 0000 and 15 April 0000 UTC initial conditions. As seen in Figure 4a, the 37 hr forecast reflectivity valid for 1300 UTC of 15 April 2020 indicates a value greater than 50 dBZ over central parts of Bangladesh. Similarly, based on the IC of 15 April 0000 UTC, the 10 hr forecast indicates reflectivity exceeding about 45 dBZ over Bihar, Bangladesh and parts of northeastern states (Figure 4b). Thus, the model did capture the potential thunderstorm over Bangaladesh and adjoining northeast region for 15 and 16 April, 2020. Associated with the thunderstorm activity, the 24 hr WRF model forecast based on 14 April 0000 UTC and valid for

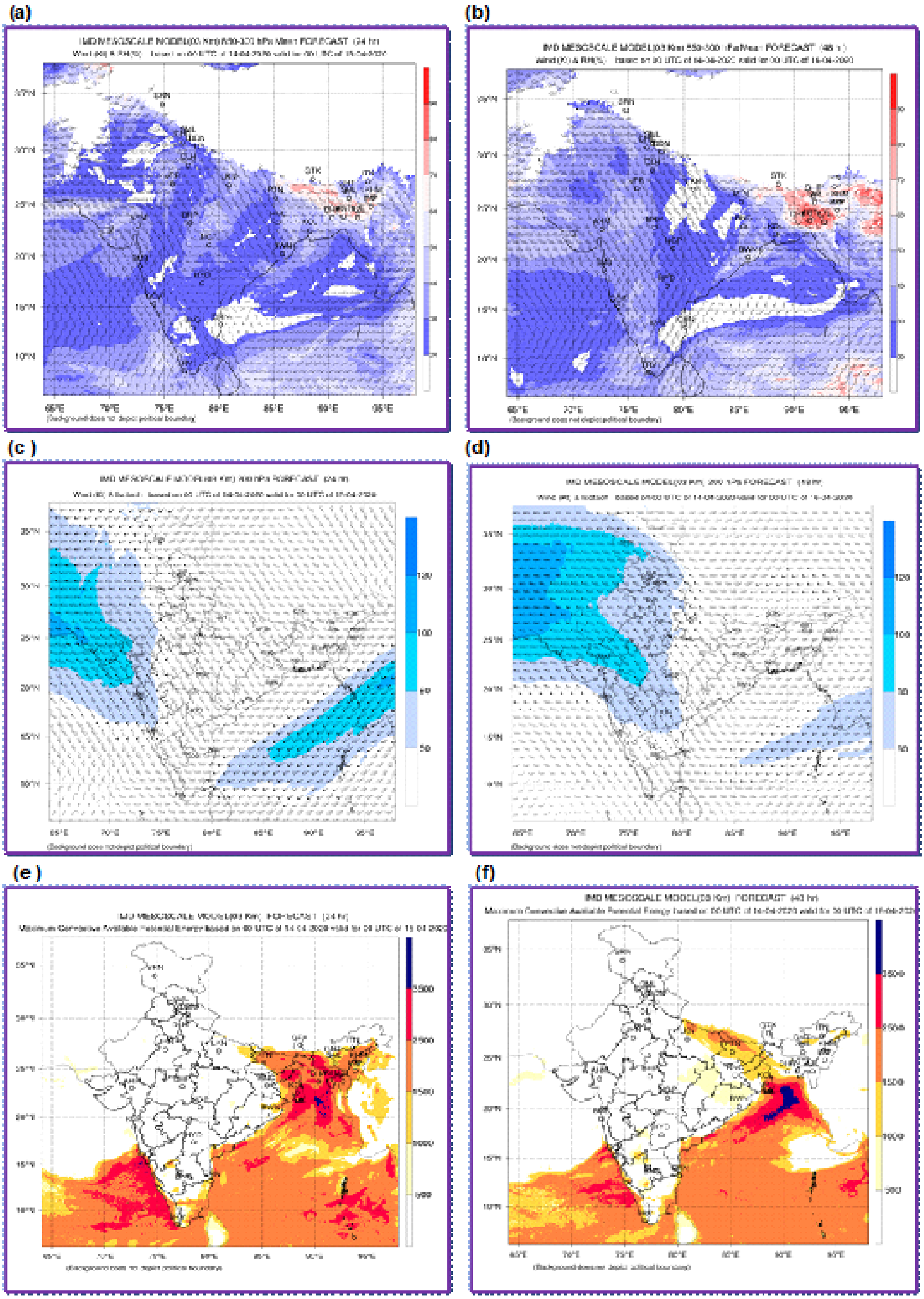

Figure 3: (a) and (b) The WRF meso-scale model forecasts (for 24 hr and 48 hr) mean layer wind (850-300 hPa) along with the relative humidity (RH) based on 14th April, 0000 UTC and valid for 15th 0000 UTC and 16th 0000 UTC. (c) and (d) is the 200 hPa wind forecast and (e) & (f) is the corresponding forecast of CAPE respectively.

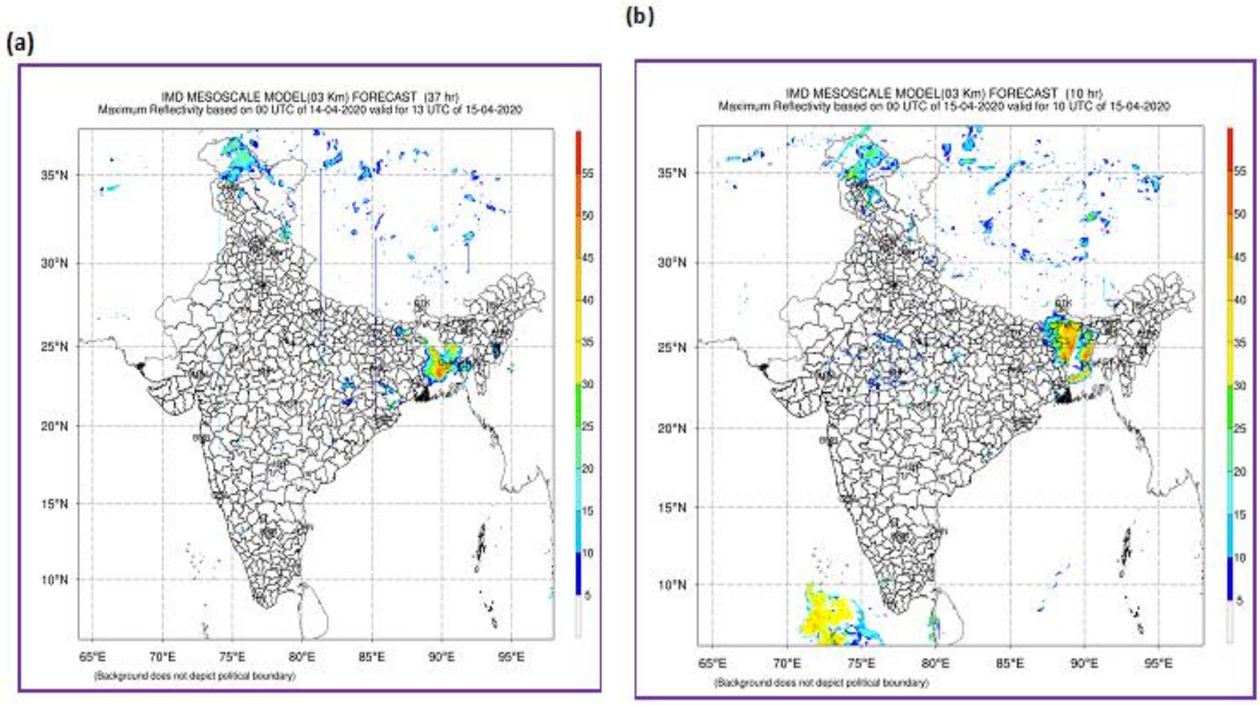

Figure 4 : WRF mesoscale model forecast (3 km) Reflectivity (a) based on the initial condition of 14th April 0000 UTC valid for 13 UTC of 15th April (37 hr) , and (b) based on the initial condition of 15th April 0000 UTC & valid for 10 UTC of 15th April, (10 hr).

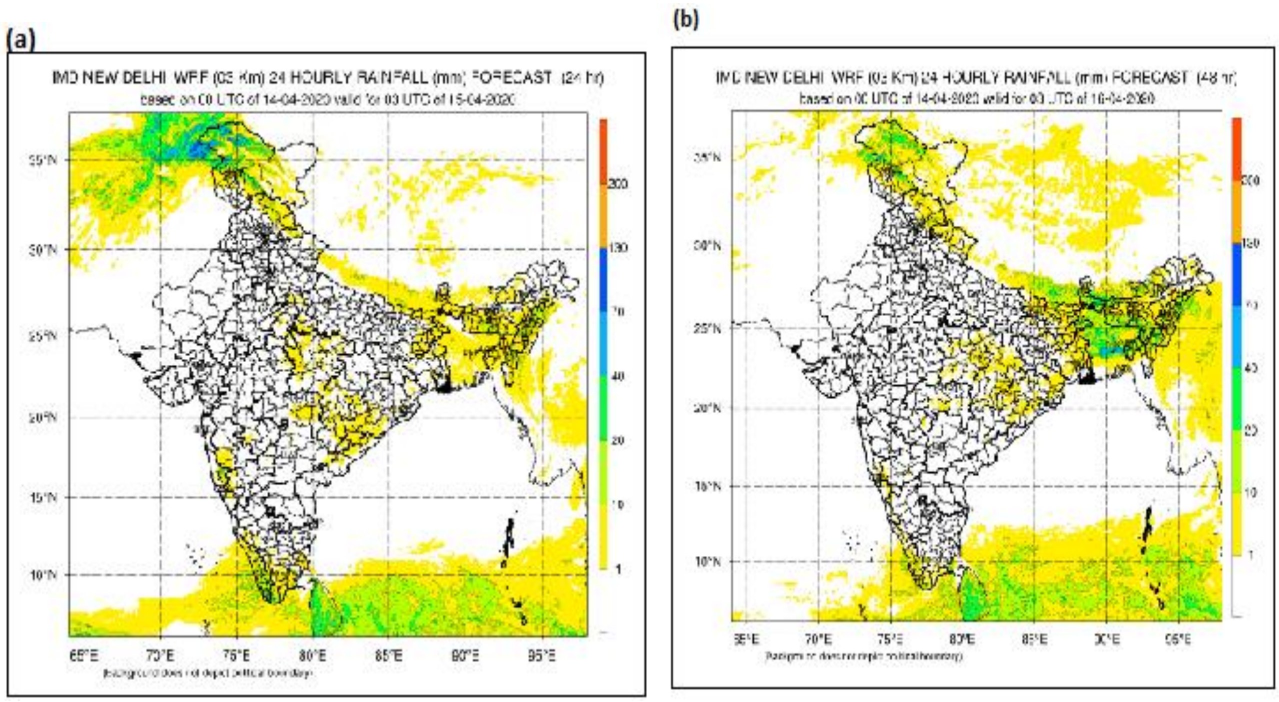

Figure 5 : WRF mesoscale model forecast rainfall (mm) based on initial condition of 14 April 0000 UTC and valid for (a) 24 hr forecast (15 April 0300 UTC) and (b) 48 hr forecast (16 April 0300 UTC).

15 April 0000 UTC (Figure 5a) also indicates rainfall over Bangladesh and neighbourhood, which increased significantly in 48 hr forecast valid for 16 April 0000 UTC (Figure 5b) due to the associated thunderstorm on 15-16 April 2020.

3.2 Case-II: Thunderstorms during 25-26 June 2020

Looking at the large-scale feature (10 m wind) during the monsoon period of case-I, the GFS

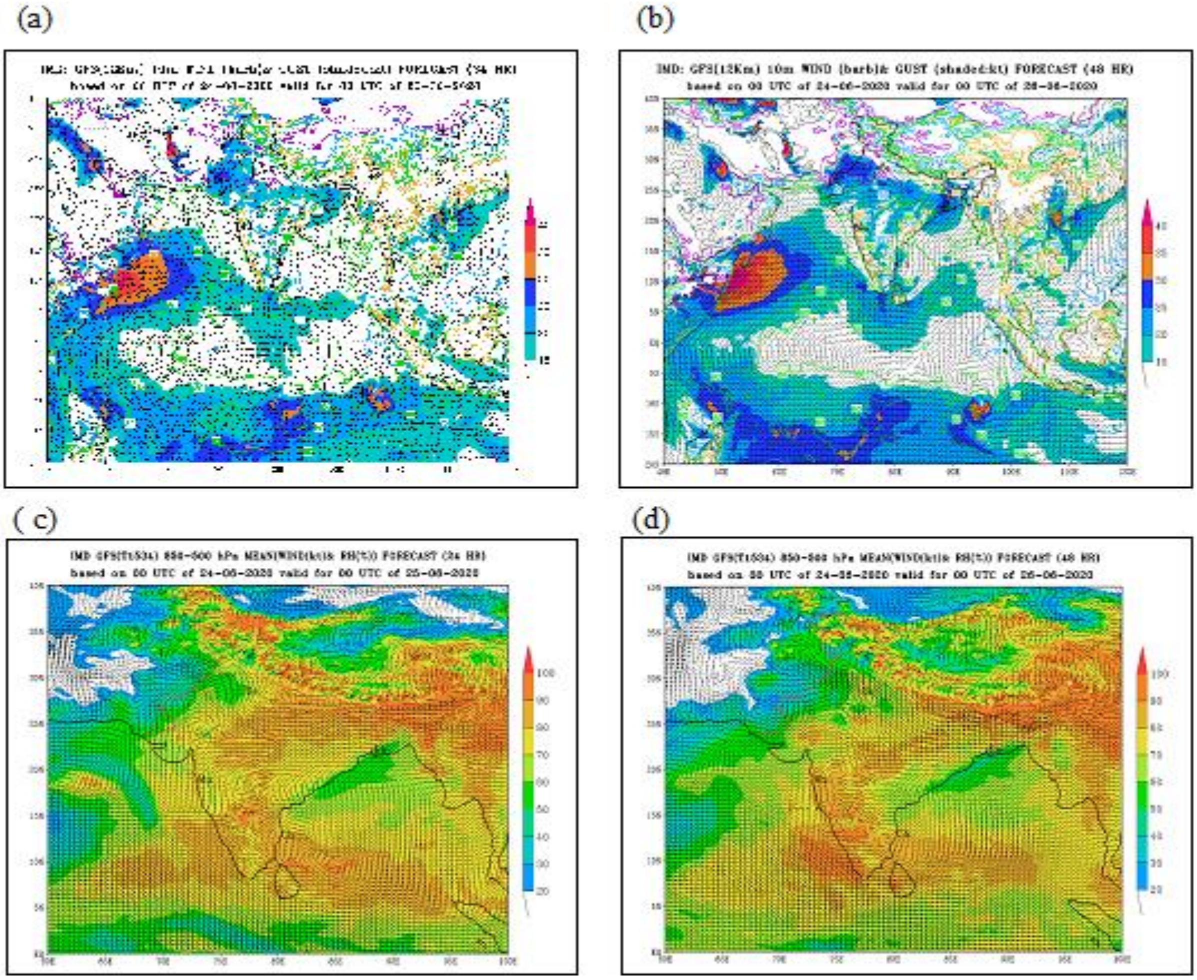

Figure 6: (a-b) 10m forecast wind from IMD GFS model for 2 days based on 24th June and valid for 25th June and 26th June 2020. (c) & (d) same as 'a' and 'b' but for mean layer wind between 850 and 500 hPa levels.

model forecasts for 2 days based on 24 June initial condition and valid for 25 and 26 June is shown in Figure 6. The low-level flow indicates easterly winds to the north of east-west trough over Uttar Pradesh and Bihar both in day 1 and day 2 forecasts valid for 25 June and 26th June respectively (Figure 6a&b). It is also seen that the large-scale monsoon flow with strong south-westerly monsoon current from the Arabian Sea brings moisture to the central and northern parts of the country. Further, the southerly wind from the Bay of Bengal also brings additional moisture convergence to the eastern parts of India. The large-scale features in day 1 and day 2 forecasts in terms of mean layered wind between 850 to 500 hPa and mean Relative Humidity (RH in %) indicate the high humidity value exceeding 80 to 90% over Uttar Pradesh and Bihar, which is also a favourable condition for the occurrence of deep convective cloud (Figure 6c&d). The close cyclone circulation in the low-level mean layered wind seen in Figure 3c over Uttar Pradesh and adjoining Bihar region can increase the low-level moisture convergence.

The forecasts from WRF model are also analysed to study the meso-scale convective parameters like the Convective Available potential Energy (CAPE) and the reflectivity as shown in Figure 7. The index CAPE is indicative of instability through the depth of the atmosphere. The index thus quantifies how strong the updrafts will be if a convective system develops. On a skew-T/T-ϕ diagram, it represents the positive area on the vertical sounding. The positive area is the one where the parcel's (theoretical) temperature is greater than the environmental temperature at each pressure level in the troposphere. The 24hr and 36hr forecasted CAPE values based on the initial condition of 25 June at 0000 UTC and valid for 26 June 0000 UTC and 26 June 1200 UTC are shown in Figure 7a&b

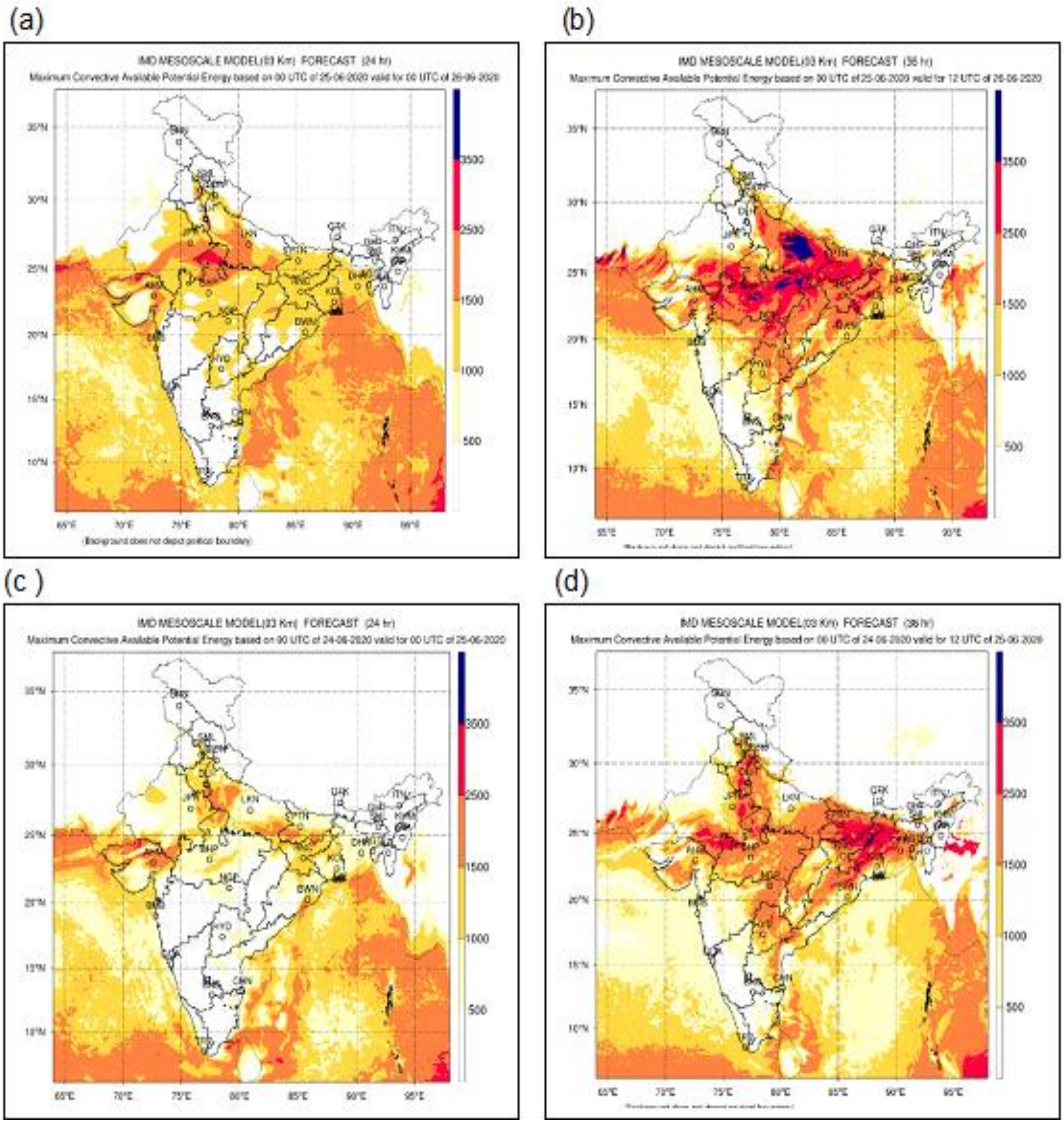

Figure 7 : IMD WRF mesoscale model forecast (3 km) of Convective Available Potential Energy (CAPE) based on 25th June IC 0000 UTC and valid for (a) 26th June 0000 UTC and (b) 26th June 1200 UTC. (c) and (d) Same as 'a' and 'b' but it is forecast CAPE based on 24th June 0000 UTC and valid for 25th 0000 UTC and 25th 1200 UTC respectively.

respectively. This indicates CAPE values exceeding 2500 Joules/Kg over most parts of Uttar Pradesh and Bihar. CAPE values exceeding 3500 J/Kg are also seen over parts of Uttar Pradesh, conducive for the deep convection. The CAPE forecasts based on 24 June 0000 UTC and valid for 25 June 0000 UTC and 25 June 1200 UTC are shown in Figure 7c&d respectively. This figure indicates the values of CAPE ranging between 2500 to 3500 J/Kg over Bihar and adjoining eastern parts of Uttar Pradesh very conducive for the occurrence of deep convection.The development of convective band over eastern Uttar Pradesh and adjoining Bihar is very clearly seen in 0400 UTC forecast valid for 25 June 2020 (Figure 8a) with the value exceeding 50 dBZ. This gradually moves eastward and is seen over northeast India region on 26 June morning (0000 UTC of 26th) (Figure 8b) with main convection band shifting gradually towards Bihar and northeastern states.

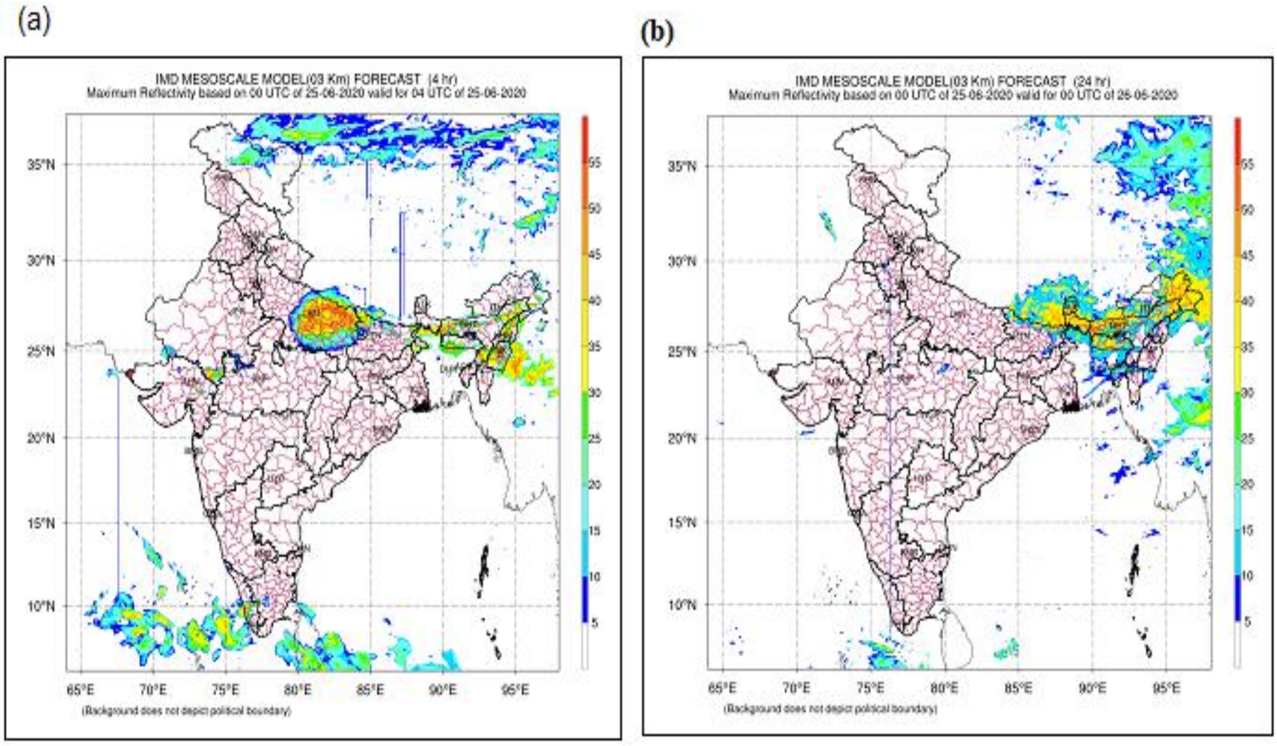

Figure 8: IMD WRF mesoscale model forecast (3 km) of Reflectivity based on the initial condition of 25th June 0000 UTC and forecast valid for (a) 25th June 0400 UTC and (b) valid for 26th June 0000 UTC.

4. Summary of the Results

The synoptic and thermodynamic aspects of the two thunderstorms, one occurring during the pre-monsoon month April and the other during the monsoon season (June) have been analysed in this study. In the first thunderstorm event during 15-16 April 2020, heating of the land surface, prevailing synoptic situation ensuring moisture convergence from the Bay of Bengal, with the aid of orographic features had given rise to significant convective activity over north-eastern parts of India and adjoining Bangladesh during 15-16 April. In this case, the CTT value was between -60^{0}C to -80^{0}C over the region of GWB and neighbourhood. A small pocket indicating CTT less than -800C moved towards Bangladesh and adjoining northeastern states like the pre-monsoon type thunderstorm. The WRF model forecasts at the lower and upper levels indicate the convergence of wind from northwest India at lower level along with additional convergence to the east of westerly trough over Bangladesh and adjoining northeast India. 24hr forecasted CAPE is around 2500 Joules/Kg over the region of West Bengal, Bangladesh and adjoining north-eastern states. The 37 hr forecast reflectivity valid for 1300 UTC of 15 April 2020 indicates values greater than 50 dBZ over central parts of Bangladesh. Thus, the WRF model indicates favourable conditions for the occurrence of thunderstorm on 15 and 16 April 2020 over Bangladesh and adjoining north-eastern states.

The other thunderstorm event of 25 June 2020 is associated with the presence of a cyclonic circulation over south-west and adjoining south-east Bay of Bengal in the middle levels, tilting south westwards with height. This halted the deep moisture flow from the Bay of Bengal into the northwest India. The low/mid-level relative humidity is associated with large positive anomaly over Bihar and Uttar Pradesh region accompanied by very intense convective cloud with CTT value lower than -80^{0}C over an extended region covering Bihar and Uttar Pradesh. For this event, the forecasts from GFS and WRF models indicate favourable large-scale features with high mid-level humidity and high CAPE values exceeding 2500 Jules/Kg over most parts of Uttar Pradesh and Bihar and also values exceeding 3500 J/Kg over some parts of Uttar Pradesh. This situation is conducive for the deep convection. The development of convective band over eastern Uttar Pradesh and adjoining Bihar is very clearly seen at 0400 UTC forecast valid for 25 June 2020 with value of reflectivity exceeding 50 dBZ.

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