Investigation of thunderstorm characteristics with severe lightning events over NE region of India

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Abstract

The north eastern region (NER) of India is among the hotspot regions for thunderstorm events leading to substantial loss of lives and properties every year. A reliable thunderstorm early warning system can prevent these losses. As these events are highly dynamic, prediction becomes equally challenging. Diagnostic studies of such events could provide more understanding of lightning and storms over a region which could then be used as input for the prediction of such events. Improving the efficiency of the prediction of associated meteorological parameters could improve the prediction of thunderstorm. In this study, two thunderstorm events have been identified with high lightning flash counts, using observations from the INSAT-3D satellite and lightning detection sensors. These observations revealed that one of the events was caused by a cloud system that originated elsewhere and travelled over the area of impact while the other event was an isolated convective system that occurred over a small region. The characteristic features of thunderstorms, like vertical wind velocity, cloud ice water content, relative humidity, cloud fraction and radar reflectivity, etc. were simulated using the WRF model. These simulations were validated with the ERA-5 reanalysis data and observations from Radar and satellite data. Validation results suggest that the WRF model could predict these features associated with thunderstorm events quite reliably. The study helped to improve the severe weather warning over NER of India and the stakeholders are trained on effective utilization of such warning.

1. Introduction

Lightning discharge is a natural disaster that impact India severely including the NER of India. The lightning discharges are often accompanied by other severe weather events like hail, high-gusty winds, and heavy rainfall, which damages infrastructure and causes significant economic losses, in addition to causing threat to aviation safety. In many regions, lightning is a significant cause of forest fires, thus damaging the wild lives and their shelter (Gomes, 2012). A few studies have reported an increasing trend of lightning observed in several countries (Qie et. al., 2012). In the Indian subcontinent, several lightning hotspots are found around the Himalayan region with more lighting activities during the pre-monsoon season (Lal and Pawar, 2009). Lightning events occur on a small spatial scale and for a short duration; thus, predicting such events with reasonable accuracy is challenging, making it even more dangerous. There are different atmospheric conditions that triggers such events based on their geographical location and synoptic weather condition. With the advancement of lightning detection instruments and increase in the number of Satellites, Doppler Weather Radars (DWR) and Lightning Detection Systems (LDS), the lightning events are now detected more accurately than in the past. Also, with the advancement in Numerical Weather Prediction (NWP) models and computing facilities, the prediction of lightning events can be achieved with a certain level of accuracy (Lopez, 2016).

The selection of the correct model configuration, which is specific to the region of study, is very important to achieve good accuracy of prediction using the model. Diagnostic studies of these lightning events using NWP models are important to identify the correct model configuration that can be used to accurately predict such events. In this paper, sensitivity analysis of the Weather Research and Forecast (WRF) model has been performed to detect the characteristic feature of two thunderstorm cases with severe lightning activities that occurred over the NER of India. The first event occurred in the south Garo hills region in Meghalaya on 7th May 2021, and the other event occurred in the Nagaon district of Assam on 12th May 2021. Both the events were observed by the INSAT-3D satellite, a LDS network, and the DWR at Sohra (Cherrapunjee), Meghalaya. From LDS data, lightning flash count density was estimated for these events, and from DWR data, reflectivity was observed. INSAT-3D satellite derived Cloud Top Brightness Temperature (CTBT) images were used to analyze the cloud systems over the study region. The cloud top temperature below -55°C was taken as a threshold of cloud systems that cause lightning flashes in the cloud. Characteristic features of these events, like the vertical wind velocity (VWV), relative humidity (RH), cloud ice water content (CIWC), cloud fraction (CF), and radar reflectivity (RR), were also simulated using the WRF model.

2. Data description

The INSAT-3D derived CTBT image (obtained using the Thermal Infrared channel image at 10.8 µm wavelength and at 4 km spatial resolution) from 11:30 to 12:00 Hrs (UTC) duration on 7th May 2021 and of 03:00 to 03:30 Hrs (UTC) duration on 12th May 2021 were used. The lightning flash count data from LDS instruments of the Indian Institute of Tropical Meteorology's (IITM) Indian Lightning Detection Network (ILDN) for both events were also used for the study. Further, hourly reanalysis data of cloud ice water content, vertical wind velocity, relative humidity, and cloud Fraction (0.25º x 0.25º resolution) from ERA-5 were acquired. The Radar reflectivity data for these events from dual-polarized S-band DWR located at Cherrapunjee (25.27º

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N, 91.73 ° E) has also been used. ERA-5 reanalysis, DWR, and CTBT data have been used to validate WRF simulations. The Global Forecast System (GFS); Final Product (FNL) data with a resolution of 0.25° x 0.25° resolution was used for initial condition to run the WRF simulations.

2.1. Lightning events

Two thunderstorm cases have been considered for this study; the first case is from the South Garo hills region of Meghalaya (25.4° N, 90.3° E), where a lightning event occurred on 7th May 2021 between 11:30 to 12:00 (UTC). No damages or casualties were reported because this lightning event occurred in an isolated location. However, the lightning strikes were captured by lightning detector sensors, and a heavy convective cloud system was visible from INSAT-3D satellite images. The CTBT image from INSAT-3D observed that this cloud system's top temperature was below -60° C and high density of lightning was observed simultaneously as recorded by LDS (figure. 1(a) and 1(b)).

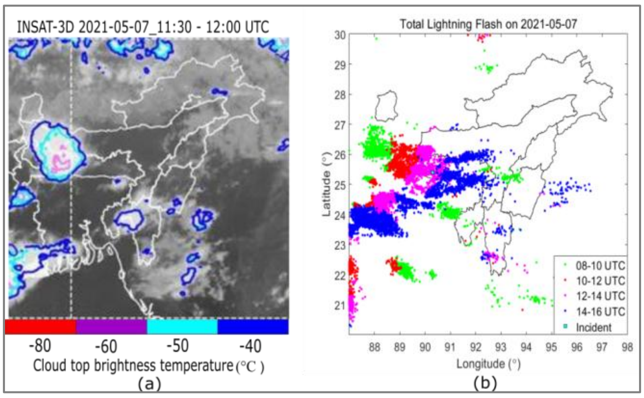

Figure 1. (a) Shows the INSAT-3D CTBT image of 7th May 2021 at 11:30 to 12:00 Hrs (UTC); (b) shows the LDS total lightning flash on 7th May 2021 between 08:00 to 16:00 Hrs (UTC).

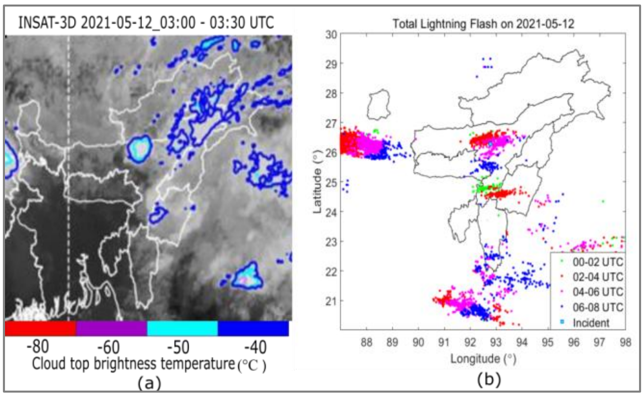

Figure 2. (a) Shows the INSAT-3D CTBT image of 12th May 2021 at 03:00 to 03:30 Hrs (UTC); (b) shows the LDS total lightning flash count on 12th May 2021 between 02:00 to 08:00 (UTC).

The second case is from the Nagaon district in Assam (26.27° N, 92.78° E), where a lightning event occurred on the 12th May 2021 between 03:00 to 04:00 hrs (UTC). In this unfortunate event, eighteen elephants were killed. Upon a post-mortem report, forest officials confirmed that the elephants were killed due to electrocution by lightning strikes. The reported time of death was around 02:00 to 04:00 Hrs UTC. Satellite radar and ground-based LDS data confirmed a lightning strike event at the same time over the same place. The CTBT image of 03:00 to 03:30 Hrs UTC of 12th May 2021 along with the total lightning flash over the place is shown in Figure 2(a) and 2(b).

2.2. WRF model setup

WRF model version 3.8 with the ARW (Advanced Research WRF) dynamical core has been used for this study (Skamarock et. al., 2008). WRF is a non-hydrostatic model suitable for mesoscale events and provides options for several parameterization schemes for representing atmospheric processes. GFS's FNL data (available every 6 hours) was used as the input meteorological data. All the static features for WRF were taken from its prescribed static files except for the land use land cover (LULC) data which is replaced with the ISRO's LULC data which is available at 30s resolution. For this study, the simulation is configured for three nested domains at 27 km, 9 km, and 3 km grid sizes with highest resolution over the study region. The simulation duration used in this study is 24 Hrs for both events and was initiated at 00:00 Hrs (UTC) on the days of the event. The details of the model configuration and parameterization schemes used for both events are mentioned in Table 1.

Table 1: WRF model configuration utilized for this study

Number of vertical grids	36
Number of horizontal grids	350 X 350
Surface parameterization schemes	Noah-MP land surface model
Longwave radiation scheme	Rapid radiative transfer model
Shortwave radiation scheme	Dudhia scheme
Microphysics scheme	WSM 6-class graupel scheme
Planetary boundary layer scheme	Mellor-Yamada-Janjic-TKE scheme

3. Results and Discussion

3.1. Vertical wind velocity

Vertical wind velocity (VWV) provides information about the updraft and downdraft winds, which are essential characteristic features of convective systems. The updraft winds help transport heat and moisture from lower to upper-pressure levels. These updrafts play a critical role in cloud electrification as it aids in the formation of graupel and ice crystals and enhances the collision of particles, which enables charge separation inside clouds and lead to lightning discharge (Deierling and Petersen, 2008). The WRF-simulated VWV was compared with ERA-5 vertical velocity at the lightning incident locations. Figure 3 (a, b) shows the hourly variation of VWV at different pressure levels obtained from ERA5 reanalysis data and WRF, over the lightning strike location in the South Garo hills district in Meghalaya on 7th May 2021.

Figure 5 (a, b) shows the same comparison over the region near to Nagaon district in Assam on 12th May 2021 respectively.

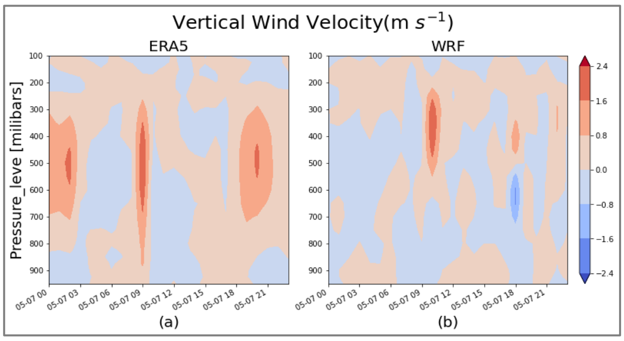

Figure 3. Hourly variation of VWV on 7th May 2021; over the lightning-strike location in south Garo hills: (a) ERA reanalysis VWV and (b) WRF simulated VWV.

For the South Garo hill lightning incidence, the VWV variation of ERA 5 (Figure 3) shows three incidents where upward vertical velocity is more than 2.4 ms^{-1} (at around 02:00, 09:00 and 20:00 Hrs). At 02:00 and 20:00 Hrs, upward VWV of more than 2.4 ms^{-1} was seen between 600 and 400 mb pressure levels, while at around 09:00 Hrs, a similar magnitude of VWV is observed between 700 to 300 mb for a short duration of time. The lightning incidents over this location were recorded between 11:00 and 12:00 Hrs (UTC). The strong VWV may have carried lower level moisture upward and resulted in the formation of cloud systems observed during the lightning incident. Simulation of VWV from the WRF (Figure 3b) model also shows an upward wind velocity of more than 2.4 ms^{-1} around 09:00 Hrs between 400 mb to 300 mb for a short duration. No significant downward wind motion was observed in either ERA5 reanalysis data or WRF model simulation for this case. It was noted that the simulated vertical wind by WRF model underestimates the vertical stretch of upward wind motion between 09:00 to 10:00 Hrs.

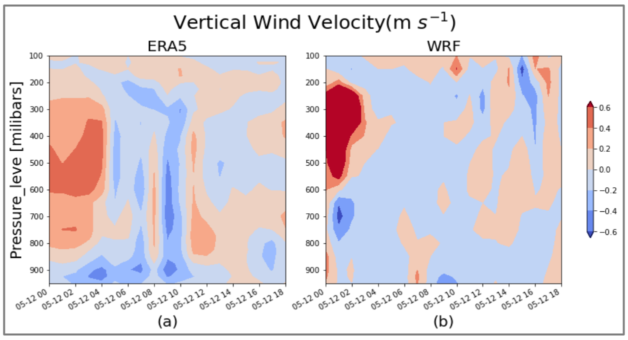

Figure 4. Hourly variation of VWV on 12th May 2021; over the lightning-strike location near Nagaon: (a) ERA reanalysis VWV and (b) WRF simulated VRV

For the Nagaon lightning case, the upward motion of VWV of more than 0.6 ms^{-1} was observed from ERA5 (Figure 4(a)) between 600 to 450 mb pressure level during 00:00 to 02:00 Hrs, which then stretches vertically from 600 to 350 mb pressure level during 02:00 to 04:00 Hrs. After 4:00 Hrs, there is a sudden change in wind motion from upward to downward direction, with wind velocity ranging from 0.2 to more than 0.6 ms^{-1}. WRF simulated VWV (Figure. 4(b)) also shows an upward wind movement with wind velocity ranging from 0.2 to more than 0.6 ms^{-1} during 00:00 to 02:00 Hrs confined between 600 to 200 mb pressure level. Simulated downward vertical wind movement shows a downdraft with wind speed ranging from -0.2 to -0.6 ms^{-1} during 00:00 to 02:00 Hrs between 800 to 600 mb pressure levels. Upward vertical movement of wind preceded by downward motion seen in ERA5 hints at thunderstorm formation during 02:00 to 04:00 Hrs (UTC). The time of occurrence of the lightning strikes reported at Nagaon is approximately the same as corroborated by ERA5 and the model findings in this study. The WRF-simulated vertical wind could capture the major updraft wind and downdraft wind movement, as seen in ERA-5. However, there were some temporal and vertical level shifts for downdraft wind movement compared to ERA-5 data.

3.2. Cloud ice water content

The larger the cloud ice water content (CIWC), the higher the chances of developing more electric charge inside the cloud and development of favorable conditions for lightning. The CIWC simulated from WRF was compared with ERA-5 for both lightning incidents. Figure 5 (a, b) compares the hourly variation of CIWC at different pressure levels obtained from ERA5 reanalysis data and WRF model over lightning strike location in south Garo hills district. Figure 6 (a, b) shows the same comparison over the region near to Nagaon district in Assam.

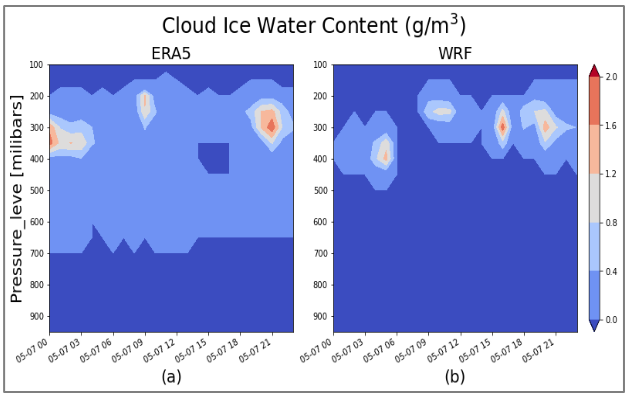

Figure 5. Hourly Variation of CIWC on 7th May 2021; over lightning strike location in south Garo hills: (a) ERA reanalysis CIWC and (b) WRF simulated CIWC.

ERA5 CIWC data for the South Garo hills lightning incident (figure. 5(a)) shows a continuous range of CIWC between 0.4 to 0.8 g/m^3 between 700 and 200 mb pressure level for the whole day. In this continuous CIWC range, a few instances were noted where the CIWC rose above 0.8 g/m^3. At 00:00 Hrs, CIWC value was in the range of 1.2 to 2 g/m^3 at 400 to 250 mb pressure levels, which then decreased after 04:30 Hrs. From 09:00 Hrs, an increase in CIWC values was again observed, reaching up to the range of 1.6 to 2 g/m^3 at 300 to 200 mb pressure levels, which decreases after 11:00 Hrs. CIWC values again increased after 19:00 Hrs, reaching up to 1.6 to 2.0 g/m^3 range between 400 to 250 mb pressure levels and decrease after 21:00 Hrs.

ERA-5 data show the presence of high CIWC, before the lightning incident (around 00:09 to 11:30 Hrs (UTC)), which might have triggered the lightning incident (at around 12:00 Hrs). Simulated CIWC from the WRF model (Figure. 5(b)) shows a value between 0.4 to 1.6 g/m^3 at 500 to 250 mb pressure levels during 00:00 to 06:00 Hrs. Also, in simulated CIWC after 08:00 Hrs, continuous CIWC of 0.4 to 0.8 g/m^3 range between 350 to 150 mb pressure levels was seen. In between this continuous CIWC range, a few instances were observed where the CIWC value reached above 1.2 g/m^3. Between 09:00 to 12:00 Hrs, CIWC value increased and reached up to 1.2 to 1.6 g/m^3 range at 300 to 200 mb pressure level. Simulated CIWC also showed an increase at around 19:00 Hrs and 21:00 Hrs, between 400 to 250 mb pressure level where the value reached more than 1.2 g/m^3. Hence, it may be inferred that CIWC simulated by the model is able to show incidents where CIWC was more than 1.2 g/m^3 in between 00:00 to 06:00 Hrs, between 06:00 to 09:00 Hrs and again at around 21:00 Hrs, which is also visible in ERA 5 but with slight temporal and pressure level shifts.

For the region near Nagaon district, the CIWC from ERA5 reanalysis data (Figure 6(a)) shows a cloud system of CIWC ranging from 2 to 2.4 g/m^3 at around 300 mb pressure level between 02:00 to 04:00 Hrs. While in the WRF model (Figure. 6(b)), simulated CIWC of 2 to 2.4 g/m^3 is observed between 360 to 270 mb pressure level during 00:00 to 02:00 Hrs, and CIWC of 1.6 to 2 g/m^3 is seen between 430 to 220 mb pressure level during 00:00 to 04:00 Hrs. Hence, it may be inferred by comparing Figures 6(a) and 6(b) that although the WRF model accurately predicts the high magnitude of CIWC, there is a temporal lag in the model predicted values. It should also be noted that a few instances of CIWC are overestimated in the WRF simulation. Nonetheless, the presence of CIWC hints at the potential thunder cloud which may have led to the lightning strike event over the study locations.

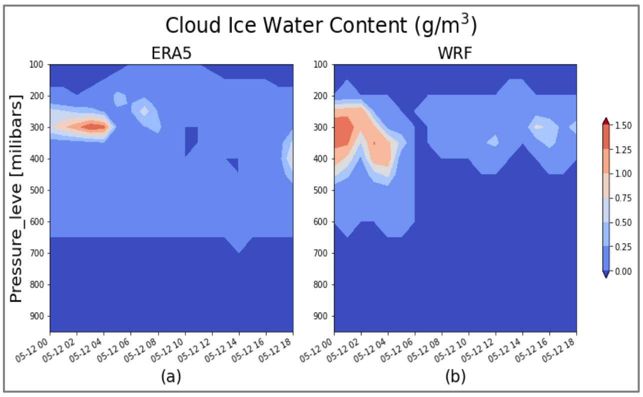

Figure 6. Hourly Variation of CIWC on 12th May 2021; over lightning strike location near Nagaon: (a)ERA reanalysis CIWC, (b) WRF simulated CIWC.

3.3. Relative humidity

Water vapor, often described as relative humidity (RH) plays a key role in forming hydrometeors inside the cloud, which in turn enhances lightning activity inside the cloud. Thus RH becomes a crucial parameter in the electrification of cloud and lightning discharge (Shi, 2018). Figure 7 (a, b) compares the hourly variation of RH at different pressure levels obtained from ERA5 reanalysis data and WRF model respectively, over the lightning strike location in the South Garo hills district in Meghalaya. Figure 8 (a, b) shows the same comparison over the region near to Nagaon district in Assam.

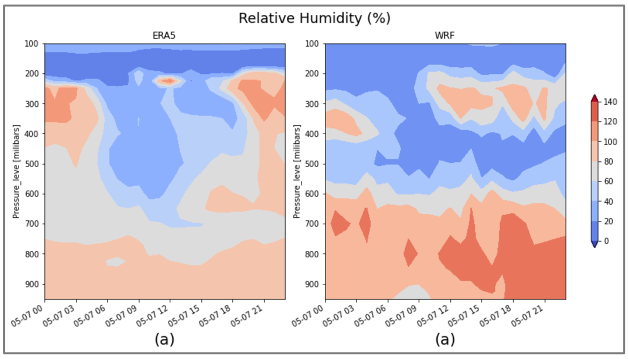

Figure 7. Hourly variation of RH on 7th May 2021; over lightning strike location near Nagaon: (a) ERA reanalysis RH (b) WRF simulated RH

For the South Garo Hill region, the diurnal variation of ERA-5 RH data for 7th May 2021, is shown in Figure 7(a). A value of more than 100% RH was observed during 00:00 to 03:00 Hrs for pressure levels between 350 to 240 mb. After 05:00 Hrs, the RH values dropped suddenly to the 20 to 40% range for pressure levels between 600 to 200 mb. After 11:00 Hrs, RH again increased with values reaching more than 100\% between 250 to 300 mb pressure levels, which further decreased to the 20 to 40% range after 13:00 Hrs. RH value of more than 100% at the time of lightning incident (around 12:00 Hrs) indicated high moisture availability inside the cloud, which might have aided in the process of lightning. In comparison, WRF-simulated RH (figure 8(b)) shows the values in the range of 80 to 100% from 00:00 to 03:00 Hrs between 380 to 320 mb pressure levels. After 03:00 Hrs, the RH value started declining to reach 20% after 04:00 Hrs. From 09:00 Hrs, the same again started increasing for pressure levels between 250 to 400 mb with maximum values in the range of 80 to 100% from 12:00 to 17:00 Hrs. Here, it is observed observed that WRF-simulated RH could capture major variations, as seen in ERA-5, but with temporal and pressure level differences.

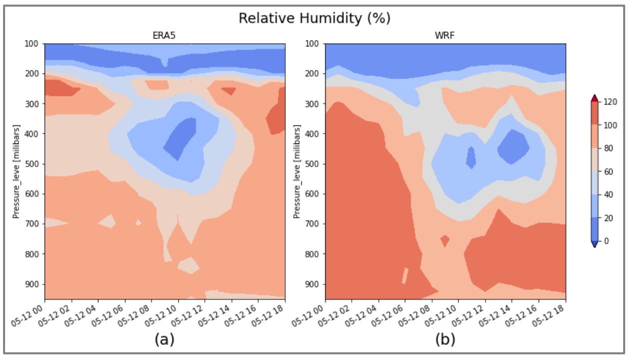

Figure 8. Hourly Variation of RH on 12th May 2021; over lightning strike location near Nagaon: (a) ERA reanalysis RH (b) WRF simulated RH

For the Nagaon region, high RH with values reaching more than 100% can be seen at between 300 to 200 mb pressure levels during 00:00 to 02:00 Hrs from ERA5 reanalysis data, after which it starts declining. After 06:00 Hrs, a sudden drop in ERA-5 RH values was observed at 500 to 300 mb pressure levels till 14:00 Hrs, with RH values dropping to 0 to 20% range. High RH just before the lightning incident time (03:00 to 04:00 Hrs), as observed in ERA-5, may have initiated the process of lightning formation, which is responsible for the event. Moreover, a sudden reduction of RH values observed in ERA-5 may be linked to the complete dissipation of thunderstorms, after the lightning incident. While the WRF simulated RH values show higher values of more than 100% from surface level to around 300 mb pressure level from 00:00 to 07:00 Hrs, a sudden decrease in RH value similar to ERA-5 is also seen here at 600 to 400 mb pressure levels during 10:00 to 16:00 Hrs, where the RH value drops to 0 to 20% range. WRF simulated RH is able to capture the hourly variation as seen in ERA5 but with slight temporal and pressure level shifts. WRF simulations also show slight overestimation at lower to mid-pressure levels in the value of RH in comparison to ERA-5.

3.4. Cloud fraction:

Figure 9 (a, b) shows INSAT-3D CTBT image of 7th May 2021 at 11:30 Hrs to 12:00 Hrs (UTC) and WRF simulated cloud fraction (CF) of same day at 12:00 Hrs (UTC) respectively. The figure 10 (a, b) shows the CTBT image from the INSAT-3D satellite for 12th May 2021 at 03:00 Hrs to 03:30 Hrs (UTC) and WRF simulated CF for the same day at 04:00 Hrs (UTC) respectively.

For the South Garo Hill region, a dense cloud system was observed over parts of western Meghalaya and Assam at 11:30 to 12:00 Hrs (UTC) from the CTBT image. This showed a CTBT of less than -60° C at its core, which is over the South Garo hill region of Meghalaya, where the lightning event occurred. WRF simulation of cloud fraction at 12:00 Hrs (UTC), shown in Figure 9(b) shows a CF ranging between 0.8 to 1 over the lightning event location in the south Garo hill region at 12:00 Hrs (UTC), representing a heavy cloud system at this location. WRF cloud fraction image cloud capture the cloud system, which is also evident in the CTBT image of INSTA-3D. However, the cloud system in the satellite image has more spatial coverage around the lightning location than WRF-simulated CF.

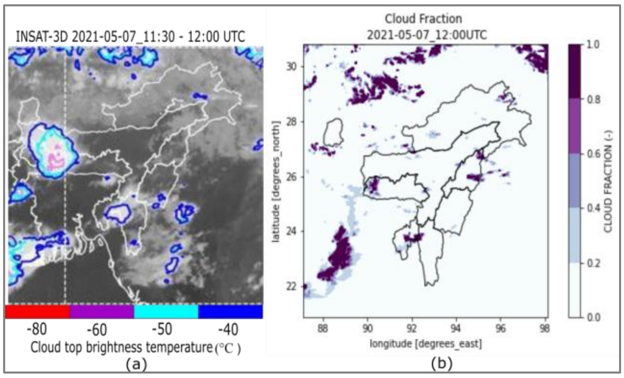

Figure 9. (a) The INSAT-3D CTBT image of 7th May 2021 at 11:30 to 12:00 Hrs (UTC), and (b) WRF simulated CF of the NE India region on 7th May 2021 at 12:00 Hrs (UTC)

For the region near the Nagaon district, the INSAT-3D CTBT image Figure 10(a) shows a dense cloud system at 03:00 to 3:30 Hrs (UTC) with a CTBT of less than -50° C over the lightning event location. The WRF simulated CF also shows values ranging from 0.8 to 1 at 3:00 Hrs over the lightning event location. Simulations from WRF model at 04:00 Hrs shows a high CF over our lightning event location, where a dense cloud system is also seen from CTBT images of INSAT-3D at the time of occurrence of the event. In this case also, it was observed that the spatial extent of the cloud system by WRF is underestimated.

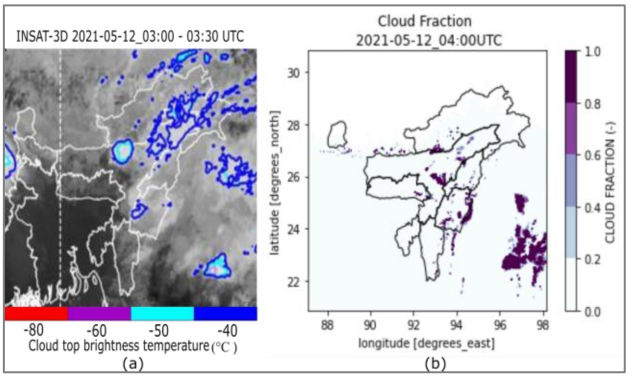

Figure 10. (a) The INSAT-3D CTBT image of 12th May 2021 at 03:00 to 03:30 Hrs (UTC), and (b) WRF simulated CF of the NE India region on 12th May 2021 at 04:00 (UTC)

3.5. Radar Reflectivity

Hourly variation of radar reflectivity (RR) observed from DWR at Sohra (Cherrapunjee), Meghalaya, India and the same as simulated using the WRF model for the South Garo Hill region in Meghalaya for 7th May 2021 from 00:00 to 24:00 Hrs (UTC) is shown in Figure 11. The hourly variation of RR for the region near the Nagaon district in Assam for 11th May 2021 18:00 Hrs (UTC) to 12th May 2021, 18:00 Hrs (UTC) is shown in Figure 12.

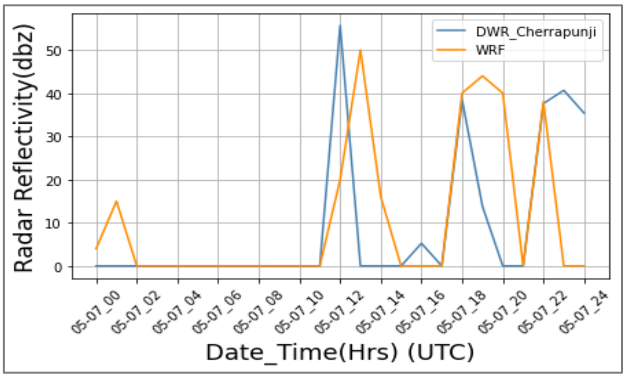

Figure 11. The hourly variation of RR from DWR and simulated RR from WRF on 7th May 2021 over the lightning strike location in south Garo hill.

For the South Garo Hill lightning case, the hourly variation of RR observed from DWR Sohra (Figure 11) remains at 0 dBZ between 00:00 to 10:30 Hrs (UTC), after which it suddenly peaks to more than 50 dBZ at 11:00 Hrs (UTC) and then declines again to reach 0 dBZ after 12:30 Hrs (UTC). After this, two significant reflectivity peaks between 14:30 to 18:00 Hrs (UTC) and again after 20:30 Hrs (UTC) were observed, where the reflectivity value of DWR reached approximately 40 dBZ. The first peak observed between 11:00 to 12:30 Hrs (UTC) corresponds to the time when the lighting event occurred over this region. The WRF-simulated RR could capture these peaks observed by the DWR. However, at the time of the lightning event, the peak in reflectivity represented by WRF shows a time lag of approximately 30 minutes and a minor underestimation in the reflectivity values.

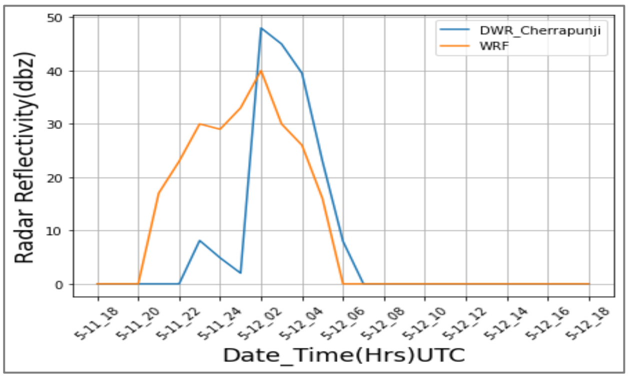

Figure 12. The hourly variation of RR from DWR and simulated RR from WRF model on 12th May 2021 over the lightning strike location Nagaon district

For the region near the Nagaon district, RR observed from DWR shows a significant increase from 0 dBZ after 22:00 Hrs (UTC) on 11th May 2021 to 48 dB at 02:00 Hrs (UTC) on 12th May 2021 and then decreases after that to reach 0 dBZ at 07:00 Hrs (UTC). The high RR observed by DWR at the time of the lightning incident indicates the presence of a dense cloud system over the location. The simulated WRF values show an increase in RR from 0 dBZ on 11th May 2021, 20:00 Hrs (UTC) to 40 dBZ on 12th May 2021, 02:00 Hrs (UTC). Simulated reflectivity from WRF could capture the variations that occurred in observed reflectivity from 11th May 2021 at 20:00 Hrs (UTC) to 12th May 2021 at 01:00 Hrs (UTC). However, we also observed a slight underestimation in the simulated RR at 02:00 Hrs (UTC).

4. Conclusion

In this study, two notable thunderstorms in the northeast region of India with huge lightning events have been analyzed using the INSAT-3D satellite images, lightning flash count density by the LDS network, ERA-5 reanalysis data, and WRF model simulations, for a comprehensive understanding of their underlying characteristics. The hourly variation of VWV, CIWC, and RH obtained from ERA-5 reanalysis data were examined; concurrently, the CF and RR as acquired from INSAT-3D CTBT and DWR, Sohra have been investigated, for both lightning incidents. The results highlight that a significant increase in the values of all five parameters was observed just before the lightning incident. For the south Garo hills incident, a VWV of 2.4 ms^{-1}, CIWC of 1.3 g/m^3, RH of more than 100%, CF of 0.8, and RR of 50 dBZ were observed just before the occurrence of the lightning incident. While for the Nagaon region, a VWV of 0.6 ms^{-1}, CIWC of 1.8 g/m^3, RH of more than 100%, CF of 0.8, and RR of 48 dBZ was seen before the occurrence of the lightning incident.

A comparison between the model-simulated results with ERA-5 reanalysis data illustrates that the WRF model can significantly represent the major variations of VWV, CIWC, and RH, albeit with some temporal and pressure level shifts and minor differences in values. A high value of these thunderstorm characteristic features indicates the presence of severe thunderclouds, which facilitates severe lightning incidents. Additionally, WRF-simulated CF was compared with INSAT-3D CTBT data, which revealed that simulated CF for both locations can capture the cloud system responsible for lightning events. However, it was observed that the spatial extent of the cloud system, as seen in simulated CF, was underestimated compared to the system seen in satellite images over our lighting incident location. For both study locations, results generated by WRF model further reveal that simulated RR portrays the major peaks and variations with slight underestimation and temporal shifts from the observed RR of DWR, Sohra. Our study suggests that the configuration of the WRF model adopted for this study effectively captures the important variations in the observed values of thunderstorm characteristic features for both incidents. The present study suggests that high values of these characteristic features could indicate the presence of a severe thundercloud which may lead to hazardous lightning incidents.

The findings of this study are valuable as they provide insight into the behavior of thunderstorms and lightning events in a specific region. Understanding the indicators of severe thunderclouds and potential lightning hazards can help authorities and the public prepare for and mitigate the impacts of such events. The ability to simulate these features using the WRF model shows promise for accurate forecasting, which could lead to more effective emergency response and public safety measures. The knowledge gained in the study has been applied while assimilating the lightning data in WRF-Elec model to improve the lightning early warning services in NER of India (Srivastava, 2023). Stakeholder meetings (on 11 May, 2023, with more than 100 participants from all eight NE states of India) and familiarization program was conducted to make the decision makers aware about the severe storm and lightning early warning services to enable them to take timely and effective decisions. This increases the capacity of the society to become more lightning resilient. However, further research is necessary to confirm and improve the understanding of lightning behavior in this region. The continued study of lightning events through case studies and modeling efforts can help to better predict and prepare for such events, ultimately reducing the risk to people and property.

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