Numerical simulation of pre-monsoon severe local convective storms formed in and around Bangladesh

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SUMMARY

Bangladesh is a part of tropical monsoon climate. Severe Local Convective Storms (SLCS) are extreme weather phenomena often accompanies lightning, large hail and torrential rains are very frequent and occur almost every year in the pre-monsoon season (March - May) in the country. These are very devastating and cause great loss of lives and properties in almost all parts of the country and also adjoining areas. Predictions of these phenomena are very difficult and sometimes impossible due to their localized formation. An attempt has been made to simulate the thermodynamic features of these events over Dhaka (23.81N, 90.41E) using Advanced Research dynamics solver of Weather Research and Forecasting model (WRF-ARW). The study reveals the threshold magnitudes of thermodynamic indices of Total Total Index (TTI), Lifted Index (LI), Precipitable Water (PW), K Index (KI) and high Convective Available Potential Energy (CAPE) to form SLCS. It is found that strong moisture field and dryline in the vertical profile. Lightning Potential Index (LPI) is also found to be efficient tool to detect genesis, intensification and progression of such event in Bangladesh. To validate the model performance, simulated values are compared with observational data obtained from Bangladesh Meteorological Department (BMD). Rainfall values were compared with that of BMD and Tropical Rainfall Measuring Mission (TRMM) of National Aeronautics and Space Administration (NASA). Model simulated reflectivity is checked with Doppler Weather Radar (DWR) derived reflectivity for better understanding of the events. Based on the comparisons and validations, simulation result is found to be very helpful for detecting the occurrence area with little spatio-temporal variations.

Keywords: Extreme weather, convective Storms, dryline, WRF-ARW, DWR

INTRODUCTION

Pre-monsoon weather is very favorable for frequent occurrence of SLCS in Bangladesh. Lightning (LT) and heavy rainfall (HR) are very frequent in association with SLCS in Bangladesh . Lightning, occurs typically during a thunderstorm, is a leading cause of injury and death. These storms are locally known as Kalbaishahi and the system usually travels north-west direction and also known as Nor’wester. Sometimes those accompany violent tornadoes. During the season, dryline feature identify between warm moist wind that blows from the Bay of Bengal and warm dry westerly wind blows from the highlands of India towards Bangladesh. The confluent zone also initiates convergence at low level of troposphere and presence of upper level divergence. Moderate to strong dry westerly wind also blows in middle and upper level which overlays moist low level southerly wind over Bangladesh. Along with the above synoptic settings high thermal instability and vertical wind shear are also identical in this season and favorable condition for SLCS development over Bangladesh (Weston 1972; Yamane and Hayashi 2006; Akter and Ishikawa 2014).

The present study focused on the significant SLCS events associated with intense LT and HR occurred in 2018. An attempt has been made to simulate the thermodynamic features of few events over Dhaka (23.81N, 90.41E) using Advanced Research dynamics solver of Weather Research and Forecasting model (WRF-ARW). Several stability indices are used by meteorologists to forecast the probabilities of thunderstorms such as Total Total Index (TTI), Lifted Index (LI), K Index (KI), Convective Available Potential Energy (CAPE), Precipitable Water (PW). We also examine vertical moisture profile relative humidity (RH) and mixing ratio (MR) at 500 hPa. Lightning Potential Index (LPI) is also used in the study for evaluating the potential for lightning activity. Lynn and Yair (2008) and Yair et al. (2010) described the development and utilization of the Lightning Potential Index (LPI) for evaluating the potential for lightning activity from WRF model output. LPI is also an empirical equation consisting of cloud-physical parameters, so it can measure potential for electrical activity.

To validate the model performance, simulated values are compared with observational data obtained from Bangladesh Meteorological Department (BMD). Rainfall values were compared with that of BMD and Tropical Rainfall Measuring Mission (TRMM) of National Aeronautics and Space Administration (NASA). Model simulated reflectivity is checked with Doppler Weather Radar (DWR) derived reflectivity for better
understanding of the events. Few studies have so far been conducted for SLCS with HR prediction (Mannan et al., 2017) but very limited studies are conducted so far on LT with SLCS and HR prediction. The present study focuses the prediction ability of simulated result of SLCS with intense LT and HR which occur in Bangladesh.

DATA AND METHODOLOGY

Dates of the SLCS are collected from BMD. Thermodynamic indices of LI, KI, CAPE and PW are calculated as per the standard procedure (Mannan, 2017) using the Rawinsonde observations collected at Dhaka during 00 and 12 UTC of each of the occurrence day. For better understanding the inherent features all of these selected events are simulated using WRF model (version 3.8) with nested domains of D1 (30 km) and D2 (10 km), NCEP-FNL data as initial and boundary conditions, covering sufficient area around Bangladesh. Simulated parameters are displayed using GrADS software. The calculation of LPI (Frisbie et al., 2013) is given below:

\[ A = (\text{RH})^2 \times (\Theta_e \Gamma) \times (LI)^2 \times (-1) \]  
\[ B = (\text{CAPE})^2 \times (PW) \times (RH)^2 \times (0.001) \]  
\[ LPI = (A + B) \times (T_{850} - 272) \]

Where, ‘RH’ is relative humidity at -10°C, ‘\( \Theta_e \Gamma \)’ is equivalent potential temperature lapse rate at 600 hPa level, ‘LI’ is the lifted index, ‘CAPE’ is the CAPE at 0-3 km above ground level, ‘PW’ is precipitable water, T_{850} is temperature in Kelvin at 850 hPa level.

RESULTS AND DISCUSSION

The value of thermodynamic indices of TTI, KI, LI, CAPE, PW along with relative humidity (RH) and mixing ratio (MR) at 500 hPa are calculated from observed data. Indices depict unstable condition of the lower troposphere but the available information is not sufficient for evolution of SLCS events from these data. Simulation exposes the development, progression and movement of TTI as an essential property of SLCS with LT and HR in Bangladesh. Signature of TTI is found as an indicator of the selected events. Simulation exposed that KI with the magnitude of \(\geq 40\) is the most suitable for the occurrence of SLCS over an area. Signature and evolution of KI with these thresholds may therefore be the indication of these types of events. Simulation reveals the presence of strong CAPE in the lower level of troposphere generated over Bangladesh in the early hours of the day which then expanded all most the central and north western part of Bangladesh. In the late hours of the day CAPE field is found to reenergize and enlarge further over. SLCS with LT and HR are found to occur over the areas with the CAPE of 1500 JK^{-1} and it’s above. Vertical profile of CAPE indicates that the system organized and developed vertically with time and finally moved east-southeastwards over Bangladesh following convective system. Analysis illustrates that the progression of PW as well as SLCS are coherent with each other. Similarly, intensification and coverage area of PW are pertinent with the rainfall. The minimum threshold value of PW for the occurrence of TS is 60 mm but in few cases 40 mm with other favourable cases. Due to convection and atmospheric process high RH is seen extend upto 600 hPa level but it is found to extend occasionally at 500 hPa level and remains below this level in in some cases. Similarly, significant amount of MR is found to carry on upto 500 hPa level in maximum number cases but in some cases it expands upto 300 hPa level. LPI specified the likelihood of potential SLCS in the selected dates. But there is little change of LPI indicated area found from the simulation.

CONCLUSION

The study reveals the thermodynamic indices of TTI, KI, CAPE, PW, and strong vertical profile of RH and moisture contents for prediction of SLCS with LT and HR. Radiosonde observations are not sufficient to detect the evolution process of these events. Simulation through WRF model may contribute to generate in this aspects. LPI is also found to be efficient tool to detect genesis, intensification and progression of such event.

REFERENCES

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