Study of Severe Thunderstorm Event on 30-31 May 2014

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ABSTRACT

High Impact Severe weather like thunderstorms are associated with strong winds, dust, thunder, lighting, heavy rainfall, hail. It occursin India during Pre-monsoon season. It has devastating consequences particularly as aviation hazards, loss of life and damage to property, vegetable crops and food. This paper focuses on the study of severe thunderstorms which continued and their presence was felt for two days, starting from Northwest India (Himachal Pradesh, Punjab, Haryana, Delhi and Uttar Pradesh) on 30th May 2014 and moved towards East India (Bihar, Odisha, Gengatic West Bengal) on 31st May 2014 and got dissipated over Kolkata. Weather Research and Forecasting model version 3.6.1 has been used for simulation and investigation of these cases. Sensitivity experiments have been conducted to study the performance of higher grid resolutions (9km, 3km and 1km) domains. The simulated results using WRF-ARW V-3.6.1 model have been used to describe in details the wind flow characteristics of the events at higher resolution domain. Also, simulated geo-potential, CAPE, reflectivity and rainfall have been discussed in details.The model results are being compared with Doppler Weather Radar (DWR) and INSAT 3-D data. The experimental results are presented and discussed in the paper.

Keywords: *Weather Forecasting, Pre-monsoon season, Sensitivity Experiment and Severe Thunderstorm.*

1. Introduction

Severe weather systems like thunderstorms are resulting from intense activity in the atmosphere due to convection activity in the atmosphere. During pre-monsoon season the northwestern,eastern and northeastern part of Indian region experiencesthe thunderstorms at lower levels of the atmosphere due to sudden variation in temperature and wind speed (Saxena et al, 2009;2010). Sometimes the range of wind speed is greater than 130-150 km/hr and it takes place as a non synoptic event such as tornado (Litta et al, 2012). These storms are responsible causes for aviation hazards, loss of life and damage to property, vegetable crops and food. Thunderstorms are associated with high speed ofwind, sudden variation in temperature, hail, lighting and heavy rainfall because of the sufficient moisture content of air parcel present in the atmosphere (Science Plan, 2005). In the month of April-May, every year approximately 28 thunderstorm events are accompanied by hail and squall lines over the northwestern and eastern region of India. Its movement is generally from northwest to southeast, also called Norwester in India. According to Hindi month of Baishakh (April-May), locally they are called as Kal-Baishakhi (SAARC Storm Project, 2014).The life cycle of thunderstorms is described in three phases on the basis of cloud given in Figure1.

(i) Towering Cumulus Stage - Updraft of the cloud cell.

(ii)Mature Stage - Updraft and downdraft, both the process of cloud cells are present in this stage.

(iii) Dissipating Stage - Downdraft of the cloud cell.

Towering cumulus stage clouds have the capability to producing lightening and thunder. Its range is few kilometers and duration less than an hour. But multicells thunderstorms have duration more than an hour and journey over a few hundreds of kilometers. It is generated due to air mass uplift by the heated land and begins convective mostly in tropical belt (Science Plan, 2005).

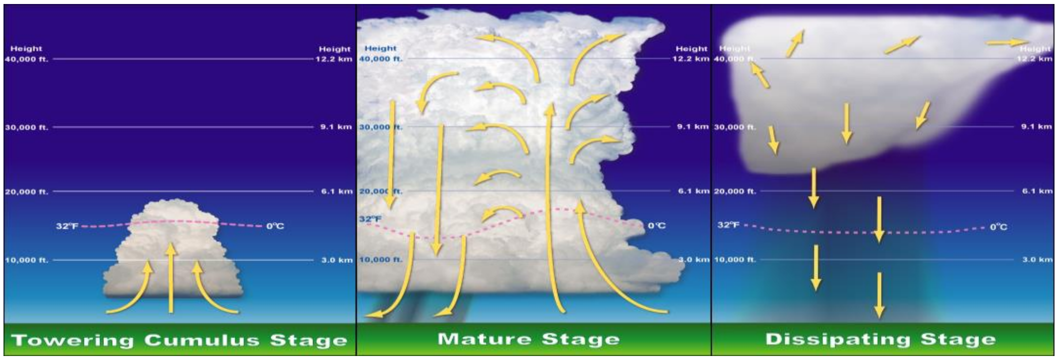


Figure 1: The Life Cycle of Thunderstorm Cloud (http://severewx.pbworks.com/Thunderstorms)

In this case raindrops collide with each other and convert into the large droplets due to the turbulence in the cloud. The beginning of mature stage of clouds starts when raindrops become large and heavy enough to fall from the cloud on the surface. In dissipating stage, downdrafts have a very high speed when mid tropospheric air become cool over the large volume of rain. Updraft cells produce an energy for air parcels which are supposed to be in moist adiabatic ascentand depend on magnitude of CAPE (convective available potential energy) where as downdrafts have very high speed when mid tropospheric air become cool across the large volume (Millar, 1958).Vertical wind shear influence the motion of updrafts and downdrafts so systematized that they do not interrupt with each other, its results that severe thunderstorm forms with maximum potential of CAPE (Ludlam, 1980). When CAPE should be larger (< 2000) and vertical wind shear at 500 hPa level from surface is greater (< 6km) then a huge long lasting thunderstorm with a single violently rotating updraft produce tornadoes and downdrafts (Ahrens, 2009). In ananalysis 40 cases of Andhi occurred at Delhi airport during 1973 to 1977 by using different meteorological instruments and found four types of Andhi in different cases. During this analysis, radar depicts that a distance larger than 30 km may be there between Andhi wall dust at suface and associated cumulonimbus cloud (Joseph et al, 1980).In India, the highest monthly annual frequency of thunderstorms occurred over eastern India. In this region the annual average frequency of thunderstorms are 75 days per year (Rao et al, 1961). However, the most thunder affected area in India is northeast Assam with an average exceeds 100 days per year and over western Himalayas, southern Kerala and adjacent Tamil Nadu average is 50 days per year (Alvi& Punjabi, 1966). Every year in pre-monsoon period, Gangetic West Bengal and surrounding regions are affected by severe thunderstorms followed by high surface wind squalls, heavy rainfall, hail and induce tornadoes (Science Plan, 2005)**.** Better prediction of this extreme event in terms of precise time, location and intensity is important to minimize the loss of lives and damage to the property. Squall lines were noticed in severe thunderstorms using satellite imagery (Purdom, 1971). The studies, several ideas have presented to improve the forecast using geostationary imagery. The best knowledge of location of boundaries and mesoscale characteristics in higher resolution geostationary imagery was also proposed (Purdom, 1976). It was also emphasized that terrain affects the formation of convective clouds.The favorable environmental conditions for severe thunderstorms and integration of boundaries were studied (Maddox et al, 1980).Sensitivity experiments have been carried out using different microphysical schemes in forecasting the severe thunderstorm over Kolkata on 15 May 2009 (Litta et al, 2012). An experiment also conducted for 4 severe thunderstorms that happened in pre-monsoon season of 2006, 2007 and 2008 by simulated radar reflectivity through WRF-NMM and validate the results with Kolkata DWR observations. Simulated results depict reflectivity clearly as observed by DWR imageries but in terms of intensity it was not clear as observations. This study show, potential of higher resolution i.e. 3 km model has improved the prediction of this event over east and northeastern part of India. A wide range of mesoscale models i.e. RAMS, ETA, ARPS, HILRAM, MM5, WRF etc have been developed with varying horizontal and vertical grid resolutions, nesting domains, different physical parameterization schemes (Anthes, 1990., Dudhia, 1993., Cotton et al., 1994). Different applications can be examined using wide varieties of parameters in the models. Initial and boundary conditions have been taken by Global model and for better prediction mesoscale model simulations can be run at higher resolutions (Mohanty et al., 2003). In a study overSpanish east coast complex terrain is numerically simulatedbased on horizontal grid selection and its impact has been carried out by RAMS model. This study is contributed a useful direction in grid size selection on mesoscale models (Salvador et al., 1999). The results depict that at higher horizontal grid resolution i.e. 2 km wind pattern does not change dramatically but some more small features present and vertical convection is influenced.

This paper focuses on a severe thunderstorm which was experienced over northwestern India to east India. It had two days life span from 30th May 2014 to 31st May 2014. In Numerical Weather Prediction (NWP) system, sensitivity experiments are conducted by using WRF-ARW (advanced research WRF) version 3.6.1 to explore about the characteristics like wind vector (500hPa and 850hPa), wind speed at 10m, Geo-potential, CAPE, reflectivity and rainfall of this event at higher resolutions (9km, 3km and 1km) domain. This study has the following contents. Section 2 presents the numerical experiment of this event. Results and discussion are illustrated in section 3 and the conclusion is presented in Section 4.

2. Numerical Experiment

In pre-monsoon season i.e. mid-May to mid-Junea large numbers of severe thunderstormsare experienced every year over the northern part of Indian region. Its behavior and strength are varying due to complexity of topography and instability in the atmosphere. Its severity in terms of hazards provokes the scientists and researchers to study in depthabout the characteristics of this severe eventand improve the quality of the forecast with respect to precise time, location and intensity (Figure .2).

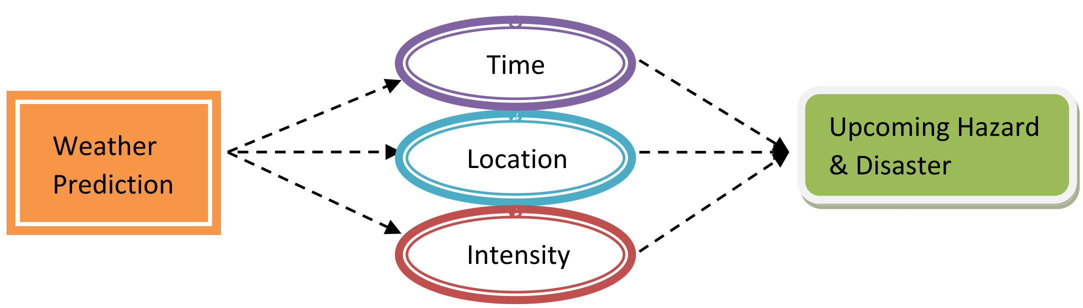


Figure 2: Scope of this Numerical Experiment (*Source*: Jaya et al. 2015)

Sensitivity experiments had beenconducted to simulate numericallythis eventusing WRF-ARW (advanced research WRF) Version 3.6.1 model. This multi level model is a genX mesoscale forecasting system which isapplicable forthe purposes, atmospheric research and operational forecasting (Skamarock et al, 2008).This study has beenfacilitated by Aditya HPC system which is 790 + Teraflops High Performance Computing System (HPCS). The program flowof the WRF model which is used for this experiment is given belowFigure 1.2. It has following constituent sub sets.

2.1 WRF Preprocessing System–WPS preprocessing system has geogrid.exe, ungrib.exe and metgrid.exe to generate input for real data simulations. Model domains and interpolates terrain data to the grids defined by geogrid.exe. Ungrib.exe interpolates the time varying meteorological data from GRIB files and metgrid.exe interpolates the data horizontally on model domain. A common namelist file i.e. namelist.wps of parameters is provided for WPS. This file contains separate data for each program and a shared namelist record (WRF model chapter 5; http:// www.mmm.ucar.edu / wrf /users / pub-doc.html). Brief introductions of these programs are given in Figure 3.

- **Geogrid.exe** –Itinterpolatesthe terrestrialdata setson model grids.To computegrid points, grid resolutions, longitude and latitude it regularly interpolates terrestrial height, land use categories and soil categories, temperature, vegetation and many others on model grid. It interpolates approximately all continuous and categorical fields on model domain (WRF model Chapter 5; http:// www.mmm.ucar.edu / wrf /users / pub-doc.html).
- **Ungrib.exe** –It reads GIRB files "degribs" data and record these data in simple format called intermediate format. These GIRB files contain all time varying meteorological fields and different from another global and regional models such as NAM, GFS or NCEPS's. It has different format to recognize variables and levels in GRIB file. Also it contain tables of these codes Vtables "variable tables" specifically define which fields have taken from GRIB file and write into intermediate format (WRF model Chapter 5; http:// www.mmm.ucar.edu / wrf /users / pub-doc.html).

Program Flow of WRF model

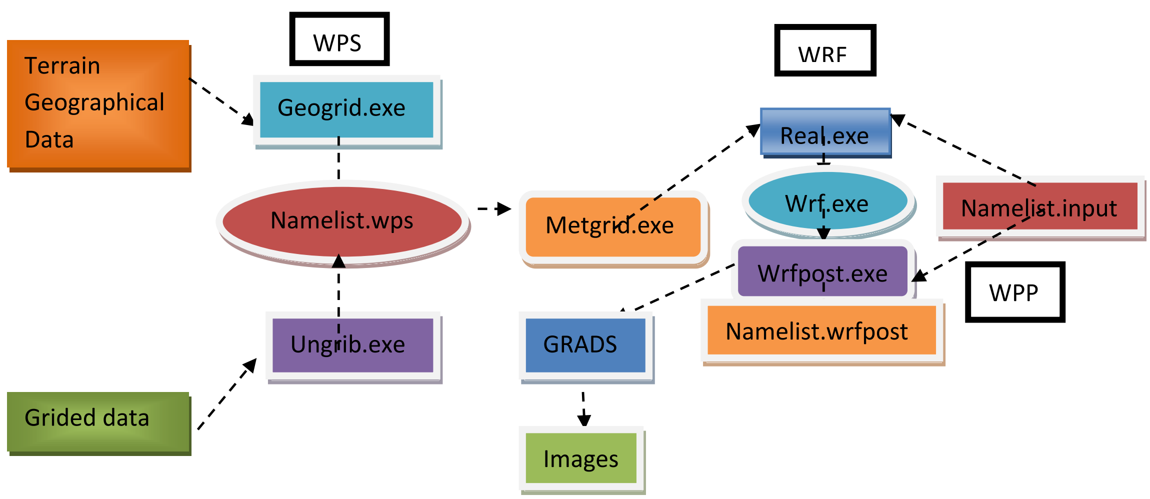


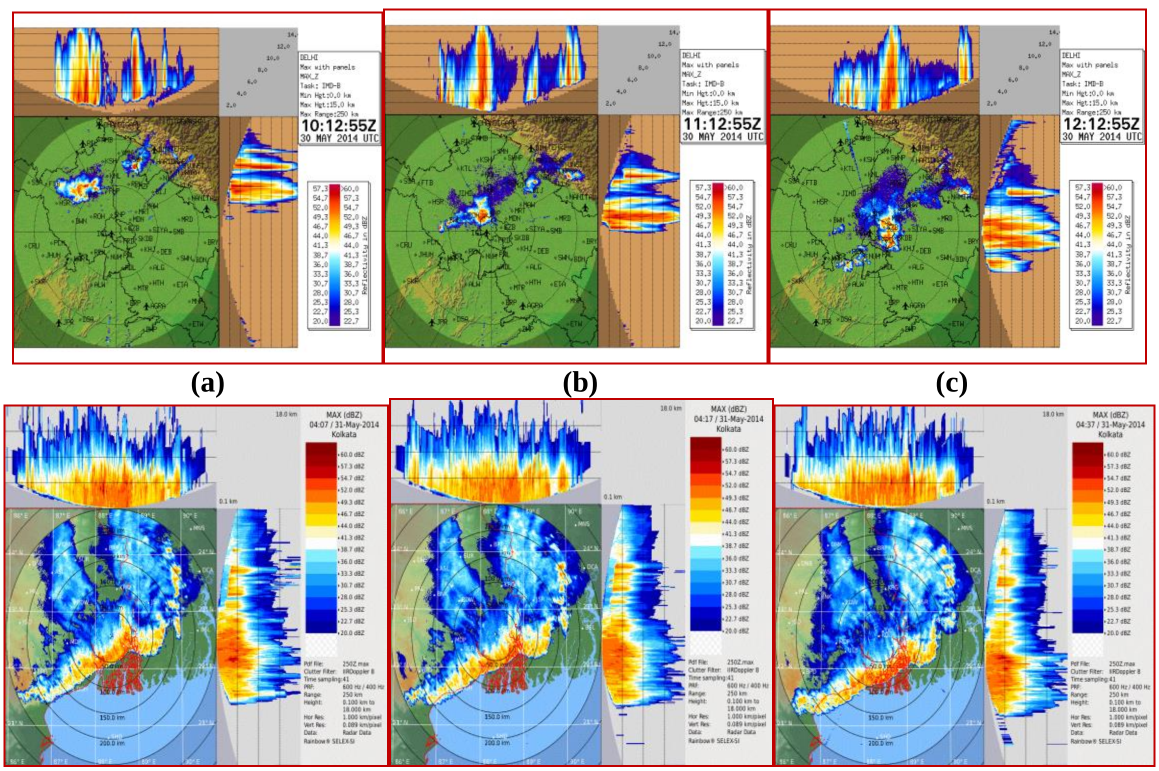
Figure 3: Program flow of WRF model (*Source*: Jaya et al. 2015)

- **Metgrid.exe** – This program interpolate the meteorological data from ungrib.exe. The output from metgrid.exe is used for WRF system. The data must be specified in "share" namelist record of WPS namelist file. It is time dependent and run each time a new simulation (WRF model Chapter 5; http:// www.mmm.ucar.edu / wrf /users / pub-doc.html).

2.2 WRF System–Weather Research and Forecasting system has an initialization program (real.exe) and numerical integration program

Table 1. WRF-ARW Model Configuration

Map projection	Mercator	Mercator	Mercator
Reference latitudeof the domain	22.00^{0}N	28.30^{0}N	28.50^{0}N
Reference longitude of the domain	80.00^{0}E	81.50^{0}E	81.70^{0}E
Number of domain	1	1	1
Number of vertical layers	27 sigma levels	27 sigma levels	27 sigma levels
Horizontal Resolution	9km	3km	1km
Time step	30s	10s	3s
Number of grid points (e-we, e-sn)	360, 360	680, 570	2100, 1700
Resolution of geographical data	5min	1min	30sec
Topography	USGS	USGS	USGS



(a) **(b)** **(c)**

(d) **(e)** **(f)**

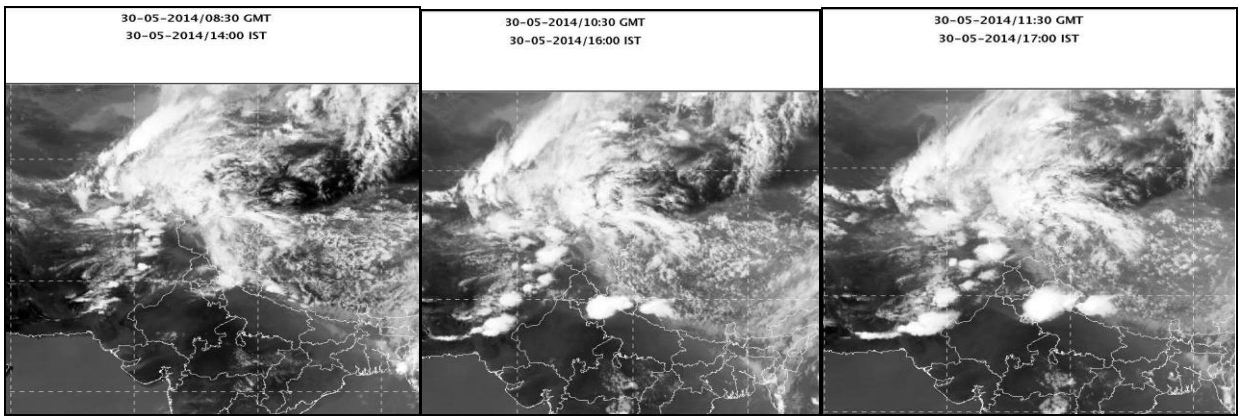
Figure 4: Reflectivity in Doppler Weather Radar
(*Source*: Thunderstorm Report-IMD, 2014)

(wrf.exe). The real.exe generate initial and boundary conditions for wrf.exe which are which are obtained from output files of WPP system(Litta, 2013). This WRF system has the following exercises –

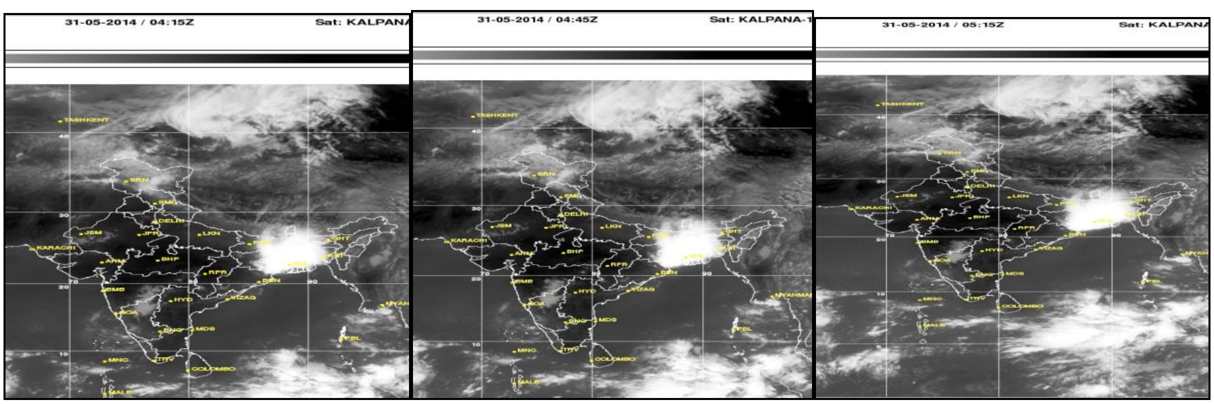
- Read input data file from WPP namelist and compute the variables.

- Create different categories of fields for model (vertical interpolation to requested levels).
- Investigate to confirm sea surface temperature (SST), soil temperature, land use, soil categories, land mask are all consistent with each other and vertically interpolate on model domain.
- It generates the initial and lateral condition file.

2.3 WPP System– WPP system i.e. wrfpost.exe designed to interpolate the WRF-ARW output from their parent grids to different degree levels (height, pressure etc) and different degree output grids (mercator, lambert, conformal) into GRIB format. Also it provides an option to output fields on the different vertical levels of model (Litta, 2013).Its output file can be visualized the data with distinct file format (GRIB, NetCDF, BUFR etc) through Grid Analysis and Display System i.eGrADS (Doty et al, 1995).The initial and boundary conditions are 29052014 at 00 UTC and 31052014 at 00UTC those have been used for experiments. Numerical simulation of this event hadbeen done for 48 hours using different grid resolution domain i.e. 9km, 3km and 1km. The input data is provided by India Meteorological Department-Global Forecasting System (IMD-GFS) at 0.25^0resolution. Topographical informationfor WRF pre processing system (WPS)is being used, based on United State Geographical Survey (USGS)data for 5min, 1min, 30sec at 9km, 3km and 1km respectively.Microphysics (MPs) and cumulus parameterization (CPs) are WRF Single moment 3-Class (WSM3) and Betts-Miller-Janjic schemes for grid size 9km and 3km but in case of Cloud Resolving Scale (grid size 1km) MPs is



(a) **(b)** **(c)**

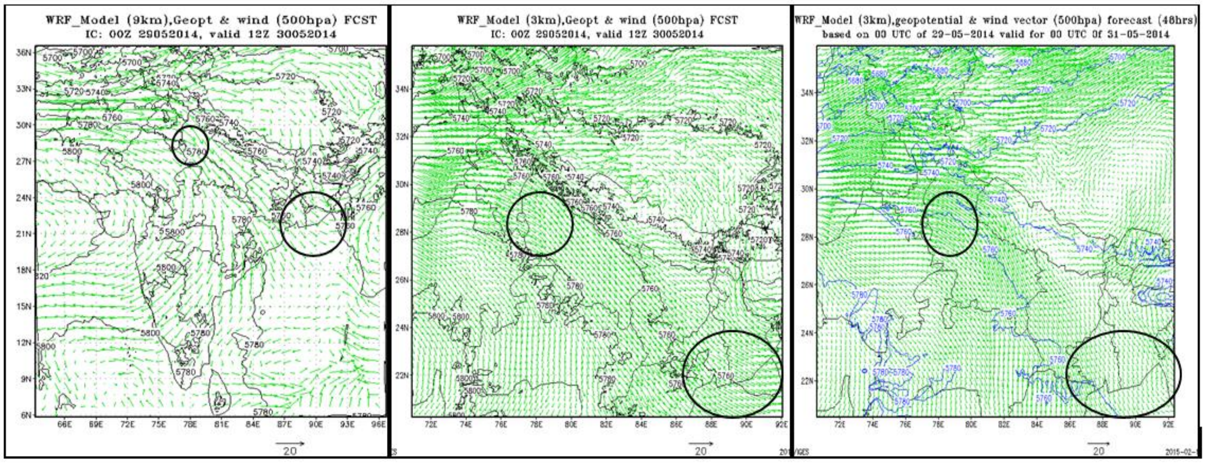


(d) **(e)** **(f)**

Figure 5: Movement of convective clouds as seen in INSAT-3D, TIR-2
(*Source*: Thunderstorm Report-IMD, 2014)

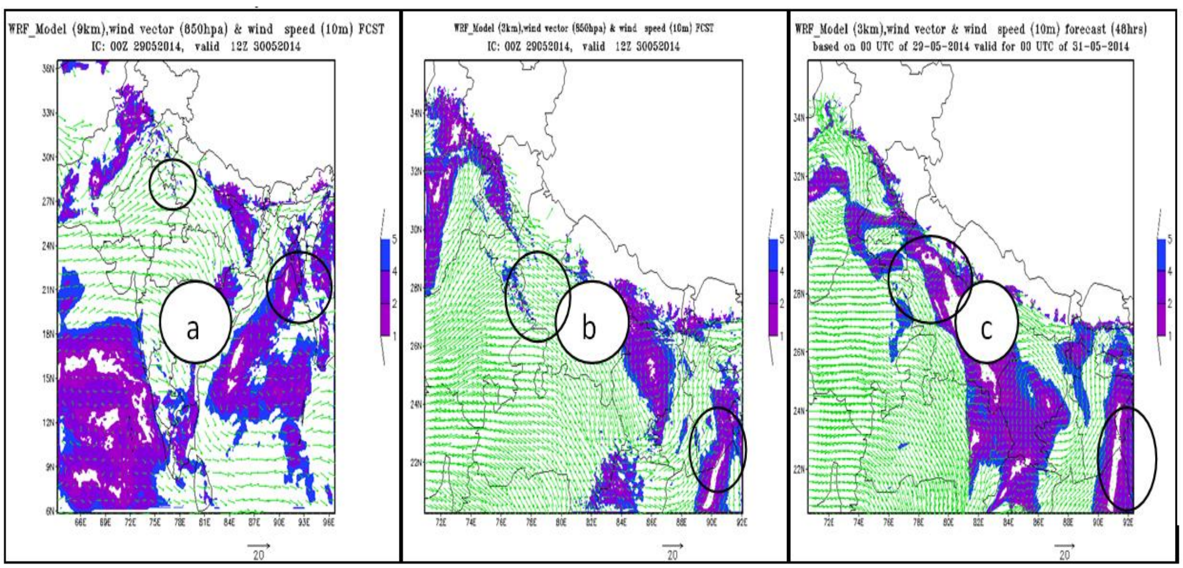
same and CPs has become zero (not necessary to include). The description of model configuration is given in Table (1).

May 2014. The recorded max wind speed was very high (> 121kmph). It reflects that a very high dust storm was occurred Figure(4 a-c). The



(a) **(b)** **(c)**

Figure 6: Simulated Geo-potential and Wind vector at 500hPa valid at 0417 UTC, 31052014 based on IC: 00 UTC 29052014, using WRF model at 9km, 3km and 1km respectively



(a) **(b)** **(c)**

Figure 7: Simulated Wind vector at 850hPa and Wind speed at 10m valid at 0417 UTC, 31052014 based on IC: 00 UTC 29052014, using WRF model at 9km, 3km and 1km respectively

3. Results and Discussion

Intensity of reflectivity (> 55dbz) has estimated by DWR from NWdirection near Patiala at 1430 hrs. It encountered NCR Delhi by 1730 hrs of 30

intensity of echoes was maintained as it moved eastwards. It covered across U.P, Bihar, and entered Kolkata by 1414 hrs of 31 May 2014. Reflectivity (> 54.7 dbz) and max wind speed (>

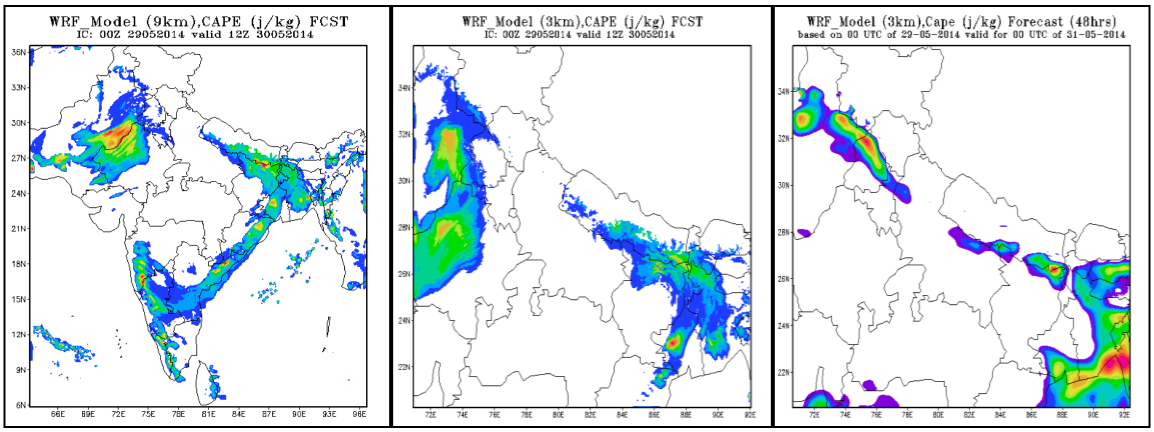
52 kmph) shows a high intensity of squall line Figure (4 d-f).

Scattered convective clouds have been recorded by INSAT 3-D TIR-2 to the north of New Delhi at 1330 hrs of 30 May 2014. It further became intense and covered NCR region (CTT, -50). The cell moved eastward and grew with more intensity over Kolkata at 1145 hrs of 31 May 2014 (CTT, -70) Figure (5 a-f).

Fig (6 a-c) demonstrate WRF model simulated geo-potential and wind vector at 500 hpa, at 9km, 3km and 1km resolution respectively. The model initial condition was 00 UTC of 29 May 2014 and valid for 31 May 2014. The results indicate northwesterly winds which pass over Delhi and surrounding region and moves towards West Bengal. It can be seen, highest resolution (1km) result has given the better structure of convergence zone as compare to coarser resolutions (9km and 3km).

Wind vector at 850 hpa and wind speed at 10m has been simulated at different grid resolution (9km, 3km and 1km) with initial condition of 00 UTC, 29 May 2014 and valid for 00 UTC, 31 May 2014. It has been seen that northwesterly flow of wind fields and wind speed is captured over south of Delhi and eastern part of the India. The results are more towards reality in the 1km resolution which is not seen at 9km and 3km resolutions Figure (7 a-c).

Figure (8 a-c) indicates the simulated results of CAPE at different grid resolution (9km, 3km and 1km) based on 00UTC of 29 May 2014 initial condition and valid to 00UTC of 31 May 2014. The highest value of CAPE has been seen over northwestern part and eastern part of India, is greater than 2400 (j/kg) in the 1km higher resolution which is not seen well by lower resolutions (9km and 3km) model results.



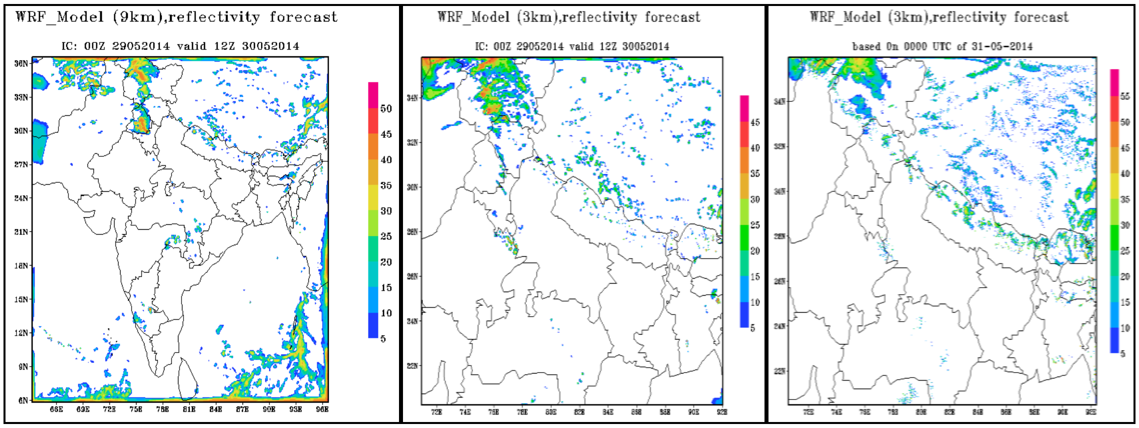
(a) **(b)** **(c)**

Figure 8: Simulated CAPE valid at 00 UTC, 31052014 based on IC: 00 UTC 29052014, using WRF model at 9km, 3km and 1km respectively

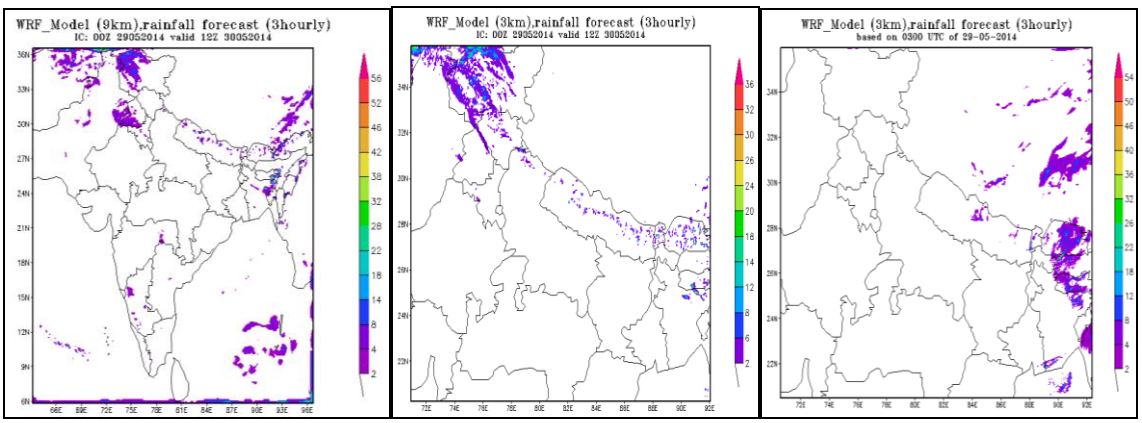
Simulated reflectivity shows some echoes over south of Delhi and near Kolkata region by 1km grid resolution result. The echoes can also be seen over south of Delhi at 3km but in case of Kolkata region, it is not shown better result as compare to 1km grid resolution. Whereas 9km resolutionresult does not show fine results as compare to 3km and 1km higher resolution results fig (9 a-c). Rainfall forecast by model results is not simulated well as in fig (9 d-f). It may be happen because observed rainfall was very low.

4. **Conclusions**

Investigation of severe thunderstorm/dust storm has been made using WRF-ARW V-3.6.1 model. This thunderstorm affected NCR Delhi and surrounding regions at 1430 hrs of 30 May 2014 from northwest direction and moved eastward. It encountered Kolkata by 1414 hrs of 31 May 2014. Its severity was influenced by vertical extension of wind shear causing loss of life and damage to property. Sensitivity



(a) (b) (c)



(d) (e) (f)

Figure 9: Simulated reflectivity and rainfall valid at 0844 UTC, 31052014 based on IC: 00 UTC, 29052014, using WRF model at 9km, 3km and 1km respectively

experiments are conducted to perform the higher grid resolutions (9km, 3km and 1km) model results. The simulation predict better results of wind flow characteristics at lower level 850 hPa and wind speed at 10m of the event at 1km grid resolution as compare to 9km and 3km resolution results.However more experiments need to be conducted by using nested domain, different parameterization schemes for better prediction in terms of precise time, location and intensity. So that an early warning can be issued for the safety of life.

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References

Ahrens, C.D., Meteorology today: An introduction to weather, Climate and the environment. Ninth Edition. Brooks/cole, Pacific Grove, California, 2009.

Alvi, S.M.A. and Punjabi, K.G., Diurnal and seasonal variations of squalls in India. Indian J. Meteor. Gepphys., 1966, 7, 206-216.

Anthes., Recent Applications of the Penn State/NCAR Mesoscale model to Synoptic, Mesoscale and Climate Studies. Americ. Meteor. Soc., 1990, 71, 1610-1629.

Cotton, W. B., Thompson, T and Mielke. P.W., Real time mesoscale prediction on workstations. Bulletin Americ. Meteor. Soc., 1994, 75, 349-362.

Doty, B and Kinter III, J.L., Geophysical Data Analysis and Visualization Using GrADS. Visualization Techniques in Space and Atmospheric Sciences, eds. E. P. Szuszczewicz and J. H. Bredekamp. NASA, Washington, D.C, 1995, 209-219.

Dudhia., A Nonhydrostatic version of the Penn State-NCAR Mesoscale model: Validation Tests and Simulation of an Atlantic Cyclone and Cold Front. Americ. Meteor. Soc., 1993, 121, 1493-1513.

Jaya Singh, Ajay Gairola, Someshwar Das., "Numerical Simulation of a Severe Thunderstorm over Delhi using WRF model" International Journal of Scientific and Research Publications, 2015.

Joseph, P.V., Raipal, D.K and Deka, S.N., Andhi the convective duststorm of northwest India. Mausam., 1980, 31, 431- 442.

Litta, A.J., Computational models for the prediction of severe thunderstorms over east Indian region. PhD thesis, Cochin University of Science and Technology, India. 2013.

Litta, A.J., Mohanty, U.C and Idicula, S.M., The diagnosis of severe thunderstorms with

high-resolution WRF model. J. Earth Syst. Sci., 2012, 121, 297–316.

Maddox, R. A., Hoxit, L.R and Chappell, C.F., A study of tornadic thunderstorm interactions with thermal boundaries. Mon. Wea. Rev., 1980, 108, 322– 336.

Miller, B. I., On the maximum intensity of hurricanes. J. Met, 1958, 15, 184-195.

Mohanty, U.C., Mandal, M and Raman, S., Simulation of Orissa super cyclone (1999) using PSU/NCAR mesoscale model, Natural Hazards, 2003, 31, 373-390.

PURDOM, J.F.W., Some uses of high-resolution GOES imagery in the mesoscale forecasting of convection and its behavior. Mon. Wea. Rev., 1976, 104, 1474-1483.

PURDOM, J.F.W., Satellite imagery and severe weather warnings. Preprints 7th Conf. Severe Local Storms. Amer. Meteor. Soc., 1971, 120-137.

Rao, K.N. and Raman, P.K., Frequency of days of thunder in India, Indian J. Met. Geophs., 1961, 12, 1, 103–108.

SAARC STORM PROJECT-2014, Government of India, Ministry of Earth Sciences, India Meteorological Department, New Delhi, 2014.

Salvador, Rosa., Calbo, Josep and M, M. Millan., Horizontal grid size selection and its influence on mesoscale model simulations. J. Appl. Meteor., 1999, 38, 1311-1329.

Saxena, R., Bhan, S.C and Yadav, B.P., Analysis of squalls over New Delhi and

forecasting of maximum probable gust speed. Vayumandal., 2009-2010, 35&36, 92-96.

Science Plan 2005 Severe Thunderstorms – Observations & Regional Modeling (STROM) Programme; Department of Science & Technology, Government of India, New Delhi, December 2005.

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Dudha, M.G., Huang, X., Wang ,W and Powers, Y., A Description of the Advanced Research WRF Version 30. NCAR Technical Note NCAR/TN-475+STR, Mesocale and Microscale Meteorology Division, National Centre for STORM Science Plan, Dept. of Science & Technology, Govt. of India, 2008, 118.

Ludlam, F.H., Clouds and Storms. Pennsylvania State University Press, University Park, PA. 1980, 405.

WRF model Chapter 5, Available at: http:// www.mmm.ucar.edu / wrf /users / pub-doc.html (Accessed: 20 June 2014).