IMPACT OF DOPPLER WEATHER RADAR DATA ASSIMILATION ON THE PREDICTIONS OF MESOSCALE CONVECTIVE SYSTEMS

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1. INTRODUCTION

The variational data assimilation approach is one of the most promising techniques available to directly assimilate heterogeneous mesoscale observations in order to improve the estimate of the models initial state. In this study a 3DVAR data assimilation scheme has been used with the Weather Research and Forecasting (WRF) model to assimilate the special observations collected during the STORM Field Experiments. STORM is an acronym for Severe Thunderstorm Observations and Regional Modeling. The STORM Pilot Field Experiment was conducted during April to May 2009 to 2011 jointly with India, Bangladesh, Nepal and Bhutan to study the characteristics of severe thunderstorms (also known as Nor'westers) that affect these countries during the pre-monsoon season.

In order to study the impact of the special observations on forecasts, 2 sets of experiments were conducted to study the episodes of 19 May 2011 thunderstorm. The 1st set of experiments were the control experiments (CTRL) in which 24 hours forecasts were made based on the initial conditions produced by the T254L64 global model of NCMRWF. The 2nd set of experiments (DA) was conducted based on the initial conditions produced by assimilating the special field observations. Results were analyzed and compared for the 2 experiments CTRL and DA. The simulated and assimilated results showed the presence of strong vertical wind shear and an advection of warm air forming a solenoidal field during the Nor'wester (Das et al., 2006). Study of Radar data showed that the Nor'westers propagate in the form of parallel bow shaped squall lines having horizontal length of more than 250 km at 0500 to 1000 UTC. The model underestimated the strength of the squall lines in general in its present configuration.

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2. MATERIALS AND METHOD

The WRF Model has been used over the study domain. The model is run at 9 km resolution with 27 vertical levels using initial and boundary conditions obtained from NCMRWF T254L64 global model. 6 hourly NCEP-FNL Data (1°x1°), GTS data, BMD Khepupara DWR radial wind and reflectivity data are utilized in the Experiments. Kain-Fritsch and Grell-Devenyi (GD) ensemble cumulus scheme have been used in the model run. Realized weather phenomena over Bangladesh and surroundings on 19 May 2011 shown in Table 1. Six persons died due to lightning strike in Orrissa, India at night.

Table 1: Realized weather phenomena over Bangladesh and surroundings on 19 May 2011.

Station	Types	Wind Speed kph	Occurrence Time (UTC)
Chittagong	Squall	56	0100
Ranchi	Squall	44	1655-1657
Alipur	Squall	49	2100-2101
Lengpuri	TS	--	0300-0345
Shillong	TS Rain	--	0310-0930
Tezpur	TS	--	2130-0040

2.1 Synoptic main feature

i) Trough of low lies over North Bay.
ii) Seasonal low lies over South Bay.
iii) The upper air cyclonic circulation over Punjab and neighbourhood in lower levels persists. A trough from this system extends up to Gangetic West Bengal across Haryana,

south Uttar Pradesh, north Madhya Pradesh, Chhattisgarh and Jharkhand.

iv) The upper air cyclonic circulation lies over Assam and neighbourhood in lower levels.

2.2 The 3DVAR System

The three dimensional variational assimilation (3DVAR) is designed for a community data assimilation system flexible enough to allow a variety of research studies apart from its operational utilization. The basic goal of the 3DVAR system is to produce an “optimal” estimate of the true atmospheric state at any desired analysis time through iterative solution of a prescribed cost-function (Ide *et al.,* 1997).

The 3DVAR system consists of the four components (Barker *et al.,*, 2003, 2004): (1) Background Pre-processing, (2) Observation Pre-processing and quality control, (3) Variational Analysis, (4) Updation of Boundary Conditions.

2.3 Updating boundary condition

In order to run WRF forecast model using 3DVAR analysis as initial conditions, the lateral boundary conditions (originally computed from global model data) is updated to reflect the modified fields.

Three-dimensional observations are mainly centered on the main synoptic hours (0000, 0600, 1200, 1800 UTC) of observation. Keeping this in mind, the present assimilation system is designed as a 6-hrly intermittent assimilation scheme, where analysis is performed four times a day i.e. at 0000, 0600, 1200, 1800 UTC. The control analysis consists of the global data received through GTS/internet, which are ingested in the system at the analysis time with ±3 hours time window. Modules have been developed for reading the decoded observed data from NCMRWF’s operational data sets and for packing in LITTLE-R format, required for ingesting in 3DVAR observation preprocessor. In the present study, two experiments have been conducted. The first one is a control run (CTRL) in which the analysis produced by the NCMRWF global model (T254L64) is used for initial and boundary conditions to run the WRF model. In the second experiment (DA), continuous data assimilation (cyclic run) is carried out using the observations collected during the SAARC STORM Pilot Field Experiment of 2011 (mainly the AWS and SYNOP). In the cyclic run, the boundary conditions for WRF run are taken from global model analysis. However, the lateral boundary conditions are updated after each analysis. Subsequently, after each analysis, six-hour forecasts are made using WRF model. The 6-hour forecast of each run (valid for next analysis time) is used as the first guess for the next analysis (Parish *et al.,* 1992). The assimilation started at 06Z of 19 May 2011 and completed at 06Z of 20 May 2011. Subsequently, 24 hours forecasts were made for the event of widespread thunderstorms (discussed in the next section) based on the CTRL and DA run.

3. RESULTS AND DISCUSSION

The impact of 3DVAR assimilation upon the first guess is studied here. It is seen that the experimental (DA) runs have simulated 10m wind speed of about 12-24 m/s in big patches in the West Bengal and northwest region. Whereas the control run has produced 10m wind speed greater than 12 m/s over the region. High shear regions are wide spread in the West Bengal and Bihar region in the experimental forecasts whereas, the control forecasts have small wind shear restricted over a small region (Barker *et al.,* 2004). Fig. 1 presents the reflectivity, for forecasts valid at 0855 UTC of 19 May, 2011. 850hPa horizontal winds in the experimental forecasts are having higher gustiness over the region of the observed system compared to the control forecasts.

3.1 T- Φ gram analysis

Dhaka T- Φ gram indicated K index 42.7 and Totals Totals Index 47.8 at 0000 UTC. The total precipitable water content stayed at 71.87 mm favouring convective activity.

Kolkata T- Φ gram indicated K index 37 and Totals Totals Index 46.3 at 0000 UTC. The total precipitable water content stayed at 58.37 mm favouring convective activity.

Mohanbari T- Φ gram indicated K index 38.2 and Totals Totals Index 48.3 at 0000 UTC. The total precipitable water content stayed at 57.53 mm favouring convective activity.

Agartala T- Φ gram indicated K index 38 and Totals Totals Index 46.80 at 0000 UTC. The total precipitable water content stayed at 54.82 mm favouring convective activity.

Patna T- Φ gram indicated a low CAPE (636.96 J/kg) at 0000 UTC. The total precipitable water content stayed at 58.94 mm favouring convective activity.

Guwahati T- Φ gram indicated K index 35.30 and Totals Totals Index 52.20 at 0000 UTC. The total precipitable water content stayed at 43.28 mm favouring convective activity.

Bhubaneshwar T- Φ gram indicated a very high CAPE (4036 J/kg) and low CINE (-151 J/kg) at 0000 UTC. The total precipitable water content stayed at 50.02 mm favouring convective activity.

3.2 Doppler Weather Radar and Kalpana-1 Satellite Analysis

Doppler Weather Radar (DWR) Kolkata recorded the vertical extent of the system of about 16 km and the RADAR reflectivity 45 dBz. Fig. 1 showed an echo to the east of India at 0855 UTC, which intensified into a squall line of 300 km length by 1000 UTC. Kalpana-1 satellite imagery (Fig. 2) showed strong convection over eastern India (Cloud Top Temperature, CTT = -70^{0}C), moving southeastwards it expanded into Bangladesh and merged with convection over Jharkhand, Orissa and West Bengal (CTT = -80^{0}C). Moving south it dissipated over the sea after 2330 UTC. Convection persisted over northwest Bay.

The TRMM plot shows (Fig. 3) rainfall above 64 mm over eastern parts of Bangladesh and above 128 mm at most places in eastern ghat of India.

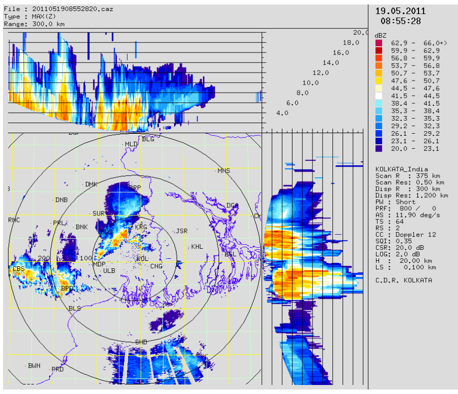


Fig. 1: Observed Reflectivity on 19 May 2011 at 0855 UTC.

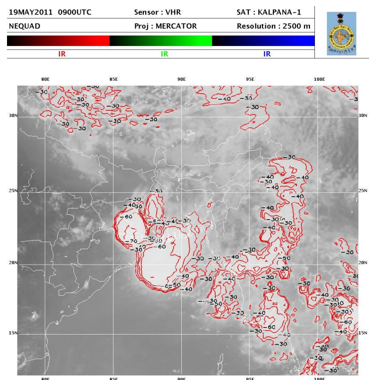


Fig. 2: Observed CTT on 19 May 2011 at 0900 UTC.

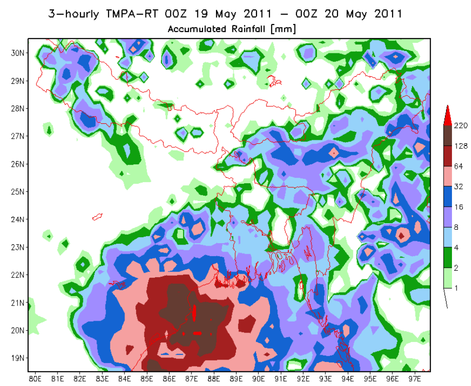


Fig. 3: TRMM precipitation accumulated for 24 hours (00Z of 19 May to 00Z of 20 May 2011).

3.3 Impact of assimilated data on the forecast fields

The 19 May 2011 episode of thunderstorms was simulated using both CTRL and DA analyses. The model was integrated for 24 hours for the case. Results of simulations and the impact of data assimilation on the case are described below.

3.3.1 Convective parameterization schemes (CPSs)

The state-of-the-art mesoscale model (WRF–NMMV2.2) was used by Litta and Mohanty (2008) to study the performance of cloud-resolving simulation of the cloud ensemble scheme for cumulus parameterization. The first simulation used the Kain-Fritsch scheme (KF), based on Kain (Kain, 2004) and Kain and Fritsch (Kain and Fritsch, 1993). The second one used Grell-Devenyi ensemble (GD) parameterization, based on Grell and Devenyi (Grell and Devenyi, 2002).

A particular convective scheme may work for a particular event or Idealized case convective environment, but may not work in others. The initialization effectiveness of a particular scheme to simulate the convection depends on the design aspects of the scheme that includes its triggering function, closure assumption, and precipitation scheme. However, the assumption and simplification of a particular convective scheme has basically limited its effectiveness.

The choice of schemes was based on a prior experiment for which the results were reported elsewhere. To compare the differences among the CPSs, simulations are performed for a particular time period utilizing the same initial and boundary conditions (BC) and other physical parameterizations for each CPSs and then model outputs are compared with observation. An attempt is made to examine different stability indices obtained from simulations with different CPSs on 19 May 2011 at 0900 UTC over Dhaka (23.76^0 N, 90.38^0 E). Observed data is used for the validation of model simulated stability indices (Table 2).

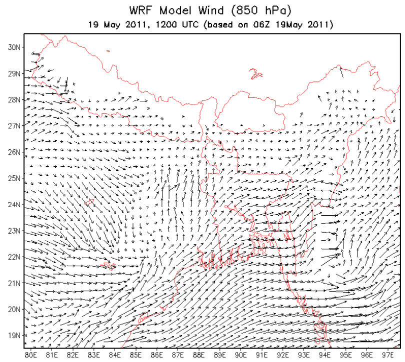
Table 2. The inter-comparison of Observed at 0000 UTC and model simulated stability indices with different CPSs and DA run over Dhaka valid for 19May 2011 at 0900 UTC.

Stability Index	KF	GD	DA Run	Observed
K	24	27	30	42.7
TT	40	41	45	47.8

3.3.2 Simulated Characteristic

Fig. 4 presents the 850 hPa horizontal wind, for forecasts valid at 1200 UTC of 19 May, 2011. 850hPa horizontal winds in the experimental forecasts are having higher gustiness over the region of the observed system compared to the control forecasts. There is a strong trough at 850 hPa simulated by the DA; this is absent in the CTRL run. The 700 hPa horizontal wind shows a trough and high wind velocity over the thunderstorm location. The phenomena are stronger in the DA run (Dasgupta *et al.,* 2005).

(a)



(b)

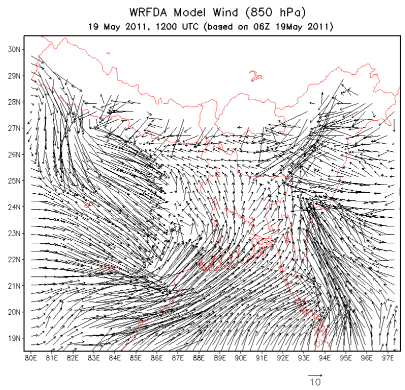
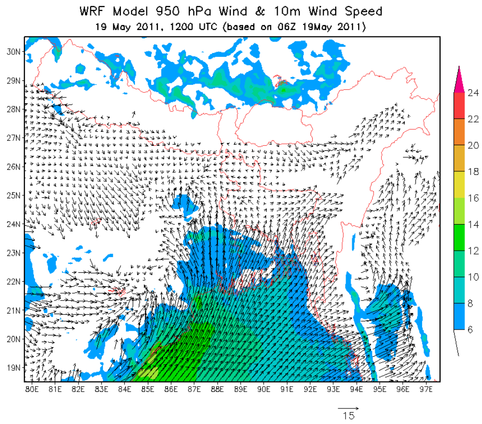


Fig. 4.: 850 hPa Wind Vector forecasts valid at 1200 UTC of 19 May 2011 (a) CTRL and (b) DA run.

Fig. 5 presents the 10 m wind speed and vector wind at 950 hPa, for CTRL and DA valid at 1200 UTC of 19 May, 2011. It is seen that in the region 18.5^0 - 22.5^{0}N and 83^0 - 88^{0}E, the DA runs have simulated more than 22 m/s of 10 m wind speed. The value simulated by the control run is quiet less (about 14-16 m/s) and in the region 18^0 - 22.5^{0}N and 84^0 - 88^{0}E. The control and DA run has also simulated high 10m wind speed along the coastal belt of West Bengal. Wind shear significantly improved over the region of northeast India and the eastern region of the study domain.

(a)



(b)

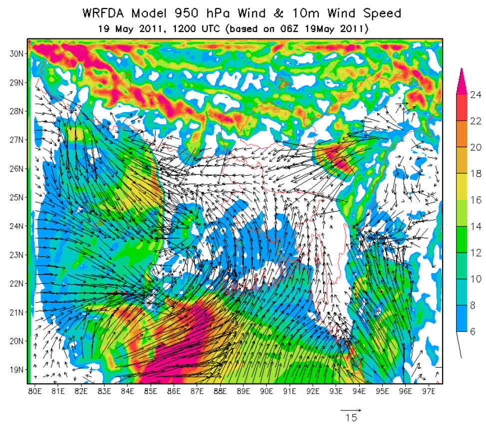
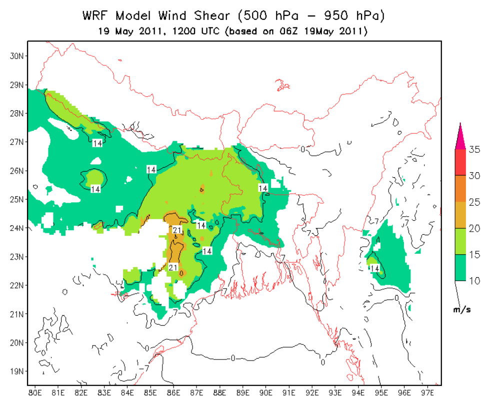


Fig. 5: Vector Wind at 950 hPa and 10 m wind speed (m/s) forecasts valid at 1200 UTC of 19 May 2011 (a) CTRL and (b) DA run.

Signal of severe thunderstorm activity over the observed region is present in the model simulated Mean CAPE (J/kg) and Mean CINE (J/kg) for forecasts valid at 1100 UTC of 19 May, 2011. Fig. 6 presents the wind shear between 500 and 950 hPa pressure levels for forecasts valid at 1200 UTC of 19 May, 2011.

Regions having the shear values above 10m/s have been shaded. Both the simulations are able to produce maxima in shear (> 10 m/s) in the region of the max. dBZ as simulated by the model. High shear regions are wide spread in the West Bengal, Bihar and northwest of Bangladesh region in the CTRL and DA run.

(a)



(b)

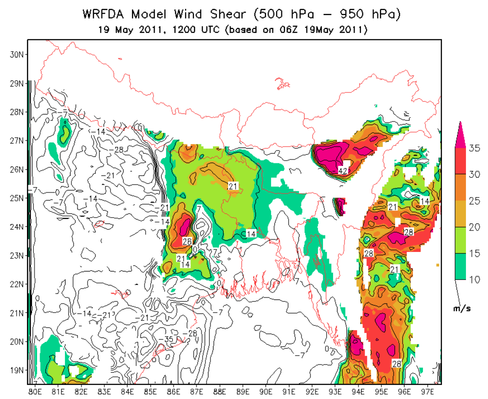


Fig. 6: Wind Shear of [500 – 950 hPa] (m/s) forecasts valid at 1200 UTC of 19 May 2011 (a) CTRL and (b) DA run.

3.3.3 Sea Level Pressure (SLP) Time Series

An attempt has been taken to plot time series of sea level pressure (SLP) after Data Assimilation over Chittagong (22.22^0 N, 91.80^0 E), Bangladesh, Alipore (22.32^0 N, 88.20^0 E), India, Ranchi (23.19^0 N, 85.19^0 E), India and Shillong (25.34^0 N, 91.53^0 E), India.

Sea Level pressure seems to be less than 1003 hPa over the West Bengal and adjoining regions compared to other areas (Fig. 7), due to existence of heat low during the pre-monsoon.

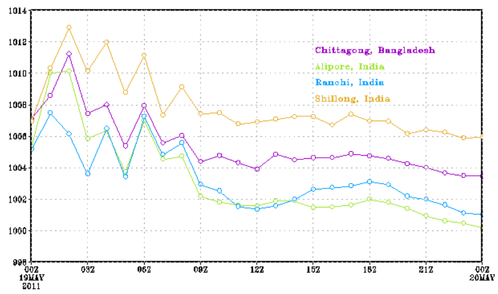


Fig. 7: Time Series of SLP at Chittagong, Alipore, Ranchi and Shillong.

4. CONCLUSION

The impact of data assimilation is very clearly highlighted as the experimental simulations from the WRF-3DVAR are able to capture the thunderstorm closer to the observations compared to the control run. The position and intensity of the simulated thunderstorms in the experimental runs is close to the observed values, as compared to the DWR images.

The thunderstorm event from the model simulation is best highlighted from the spatial distribution of 10 m wind speed and maximum reflectivity. They are in turn supported by the wind shear within 500 to 850hPa pressure level. It is observed that the signature of the thunderstorm activity is well represented in the model generated CAPE and CINE distributions. The 850 and 700hPa wind fields also reflects the system captured by the model simulations.

The model is still not able to accurately produce the exact location and time of occurrences of the thunderstorms. The genesis and growth of cells, their horizontal distribution, vertical structure, the direction and speed of their movement and time of dissipation are still some of the challenges unresolved by the model.

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