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Improving IMD operational Limited Area Model forecasts

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India Meteorological Department (IMD) has been using a Limited Area Model (LAM) on operational basis for the forecast up to 48 hours with the first guess fields for objective analysis and lateral boundary conditions from the global spectral model (T–80) run of the National Center for Medium Range Weather Forecasting (NCMRWF), New Delhi. In this paper the model code has been modified and made more flexible, delinking it from the NCMRWF (T–80). This has allowed the use of initial and boundary conditions directly from the NCEP Global Forecast System (GFS) products available at the resolution of 1° × 1° lat./long. The main interest in this study is to improve the analysis and forecast in the short range time scale (up to 72 hours) by improving the model (LAM) resolution and using better Initial and boundary conditions from the NCEP GFS instead of the NCMRWF T–80 model. Simulation experiments are performed on wide variety of synoptic situations which occur very often over the Indian sub-continent. The performance evaluation in terms of qualitative comparison between the model simulated outputs against actual observations and the outputs of the operational model indicates that the modified version of the model is capable to provide a improved numerical guidance on the occurrence of heavy rainfall in the 48–72 hours forecast scale.

Keywords: Limited Area Model, monsoon depression, first guess, lateral boundary condition

1. Introduction

Convective heavy rainfall events are one of the most disastrous weather phenomena affecting a large population and of common interest to countries in South Asian Association for Regional Cooperation (SAARC) Region. Accurate forecasts of these events are crucial for the early warning systems in the Region. India Meteorological Department (IMD) has been using a Limited Area Model (LAM) on operational basis for the short range forecasting (forecasts up to 48 hours) since 1995. The horizontal resolution of current version of the operational model is 75 km and 16 sigma levels in the vertical. The input data sets for preparing the initial fields and the lateral boundary conditions required for running the model are obtained from the analyses and forecasts produced by a Medium Range Forecast (MRF) of a Global Model. The original version of LAM operational in IMD is linked to the T–80 global model of the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi. The first guess fields for objective analysis and lateral boundary conditions of the model are derived from the global spectral model (T–80) run of the National Center for Medium Range Weather forecasting (NCMRWF), New Delhi and are updated at every 6 hours interval. In an earlier study, Roy Bhowmik and Prasad (2001) documented the rainfall prediction skill of the LAM using data for the period 1997 to 1999 when the model was run at the horizontal resolution of $1° \times 1°$ lat./long with 12 sigma levels in the vertical. In the year 2001, the model was run at the horizontal resolution of $1° \times 1°$ lat./long. with 16 sigma levels in the vertical. Since 2003, it has been operated at the horizontal resolution of $0.75° \times 0.75°$ lat./long with the same 16 sigma levels. In a very recent study, Roy Bhowmik et al. (2007) showed that the rainfall prediction skill of the model at the horizontal resolution of $0.75° \times 0.75°$ lat./long is not adequate to satisfactorily address detailed aspects of convective features of monsoon system. The study (Roy Bhowmik et al., 2007) concluded that the T–80 (grid spacing of 176 km over the tropics) model of NCMRWF, not being compatible in respect of resolution, is not adequate to provide first guess and boundary conditions of the IMD operational model at the higher resolution.

With the readily availability of inputs through Internet of the real time forecast data sets in regular grid point form at the horizontal resolution of $1° \times 1°$ lat./long, generated by the Global Forecast System (GFS) of National Centre for Environmental Prediction (NCEP) Washington, it is felt motivated to modify the LAM codes so as to prepare the initial and boundary conditions direct from these grid point fields and to delink the model from the spectral form of NCMRWF T–80 inputs, with which the original version is tied up. The GFS data being available on real time basis has the potential to use it for the operational run of LAM.

The main interest in this study is to improve the analysis and forecast in the short range time scale (up to 72 hours) by improving the model (LAM) resolution and using better Initial and boundary conditions from NCEP GFS instead of NCMRWF T–80 model.

2. Global Data Assimilation and Forecast System at NCMRWF

Global Data Assimilation System (GDAS) operational at NCMRWF is a six hourly intermittent three dimensional scheme. The main components of GDAS are (i) Data reception and quality control (ii) Data analysis and (iii) the NWP model. Meteorological observations of various observing platform from all over the globe are received at Regional Telecom Hub (RTH), New Delhi through Global Telecommunication System (GTS) and are available to NCMRWF. The data is assimilated four times a day viz, 00, 06, 12, and 18 UTC every day. Data used in the operational assimilation system of NCMRWF are SYNOP/SHIP, BUOY,TEMP, PILOT, AMDAR/AIREP, SATOB from INSAT, METEOSAT at 0° to 60° E GMS and GOES. The observations falling within 3 hours of the nominal analysis time are used in the assimilation. A six hour prediction from the model, with a previous initial condition, valid for the current analysis time is used as the background field or the first guess field for the subsequent analysis. The analysis scheme used is the Spectral Statistical Interpolation (SSI) technique developed at NCEP (Parrish and Derber, 1992). The spectral model at NCMRWF is a T80/L18 spectral global model, the initial version of which is developed at NCEP (Kanamitsu, 1989). The medium range predictions are prepared by integrating the model for 7 days from 00 UTC of each day.

The resolution of the NCEP GFS is T–254/L64 and the outputs of the model are available in the internet in the GRIB format at the grid resolution of 1° × 1°. The superiority of the NCEP GFS is not only the model resolution, it uses an extensive range of satellite and other conventional and non conventional observations.

3. The Operational Forecast system at IMD

The operational Limited area Analysis and Forecast System (LAFS) of IMD, New Delhi consists of real time processing of data received from Global Telecommunication System (GTS) and objective analysis by three dimensional multivariate optimum interpolation scheme. The forecast model is a semi-implicit, semi-Lagrangian, multi level primitive equation model cast in sigma co-ordinate and staggered Arakawa C-grid in the horizontal. The model consists of the usual equations of motion, thermodynamic energy equation, mass continuity equation, moisture continuity equation, hydrostatic equation and equation of state. The model includes number of physical processes such as cumulus convection (modified Kuo; Krishnamurti et al., 1983), shallow convection, large scale condensation, atmospheric boundary layer (Monin-Obukhov formulation of surface layers with stability dependent vertical diffusion in mixed layer), radiation (Harshvardan and Corsetti, 1984; Lacis and Hansen, 1974) and envelope orography (Wallace et al., 1983)). Further details of the model formulation can be found in Krishnamurti et al. (1989). The orography prescribed in the model is smoothed by a nine point smoother to prevent instability due to steep gradients of terrain over the Himalayan region. The other features of the model include time dependent lateral boundary conditions and dynamic normal mode initialization (Sugi, 1986). The model is run up to 48 hours, twice daily and initialized with 00 UTC and 12 UTC observations. The time step of the model is 600 seconds.

The input data used for the analysis consist of: Surface – SYNOP/SHIP; Upper air – TEMP/PILOT, SATOB; Aircraft reports – AIREP, AMDAR, CODAR. These are extracted and decoded from the raw GTS data sets. All the data are quality controlled and packed into a special format for objective analysis. The methodology applied for objective analysis scheme is the statistical 3-dimensional multivariate Optimum Interpolation (OI) scheme (Dey and Morone, 1985). The scheme is based on applying correction to a first guess, the corrections being the weighted average of (observation-first guess) residuals at the observation locations. The variable analyzed in this scheme is geopotential (z), u and v components of wind and specific humidity. Temperature (T) field is derived from geopotential field hydrostatistically. Analysis is carried out on 12 sigma (pressure divided by surface pressure) surfaces 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.07, 0.05 in the vertical and on $1° \times 1°$ horizontal lat./long. Grid for a regional or limited horizontal domain covering lat. 30° S to 60° N and long. 0° to 150° E.

4. The upgraded version of the model and design of experiments

In this study, the model is further modified increasing the vertical resolution from 16 sigma to 18 sigma levels. The horizontal resolution is increased to $0.5° \times 0.5°$ lat/long. The model code has been made more flexible to allow the use of initial and boundary conditions directly from the NCEP GFS products, decoded from GRIB. The values of geopotential, temperature, zonal and meridional components of wind and relative humidity are picked up at 16 pressure levels upto 10 hPa, including the surface level. The pressure level data on the global grid are then interpolated to the LAM grid in the horizontal resolution of $0.5° \times 0.5°$ lat/long and 18 sigma levels in the vertical to prepare initial field and six hourly boundary conditions. The objective analysis is carried out with the initial fields from the GFS. The model time step is 450 seconds. These steps enabled us to carry out numerical experiments through forecast period of 72 hours. The main focus of the study is to demonstrate the efficiency of the improved limited area model with GFS fields as initial and boundary conditions in forecasting high impact precipitation system.

For both the operational run as well as the experimental run, an objective analysis is carried out with the same observational data set (synoptic, INSAT etc), but with different initial (first guess) and boundary conditions (NCMRWF T–80 for the operational run and NCEP GFS for the experimental run).

5. Results of experiments and discussion

Forecasting of high impact precipitation events is a challenging task in the whole of south Asia where weather systems such as monsoon depression, cyclonic storm, tornado, western disturbance (WD) constitute a major convective system affecting a large population. There is a pressing need in operational scenarios to provide quantitative precipitation forecasts of these events with greater accuracy. The problem has a wide range of applications from farming operation to flood forecasting and has direct relevant to the economy of the region. The main focus of the study is to examine the efficiency of the improved limited area model in forecasting heavy rainfall episodes in presence of various synoptic situations affecting SAARC region. Cases selected for the simulation experiments are:

(a) Monsoon depression of 27–30 August 2006
(b) Exceptionally heavy rainfall event of Mumbai on 27 July 2005
(c) Heavy rainfall episode over northern and east central parts of India in association with Western Disturbance (WD) during April 17–19, 2006
(d) Tornado and heavy rainfall episode over Bangladesh during 7–9 October 2004

5.1. Monsoon depression of 27–30 August 2006

In order to illustrate the performance of the new version of the model with GFS fields as initial and boundary conditions, we select a case study of monsoon depression. The track positions of the system is shown in Figure 1. The system was located as a low pressure area on 27 August 2006 which became well marked on 28 August and concentrated into a depression on 29 August morning. The system crossed east central coast of India around noon of 29 August. After crossing the coast initially the system moved northwest wards, then west-northwesterly and weakened into a low pressure area on 2 September 2006.

At first we examine the impact of the NCEP GFS fields as the first guess to generate the model initial condition (termed as new analysis) incorporating

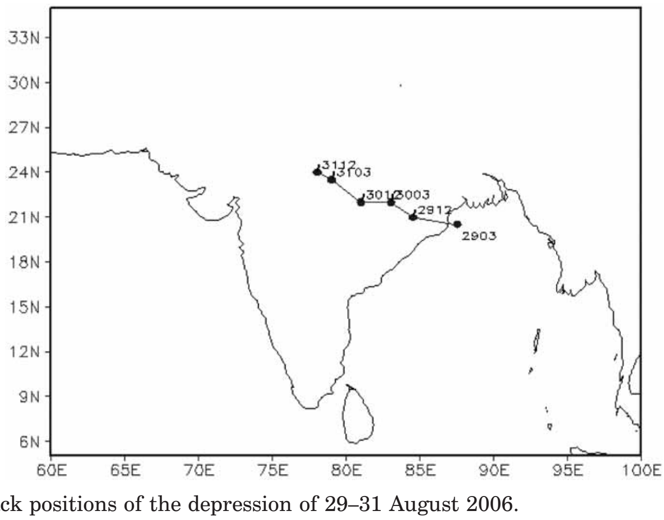

Figure 1. Track positions of the depression of 29–31 August 2006.

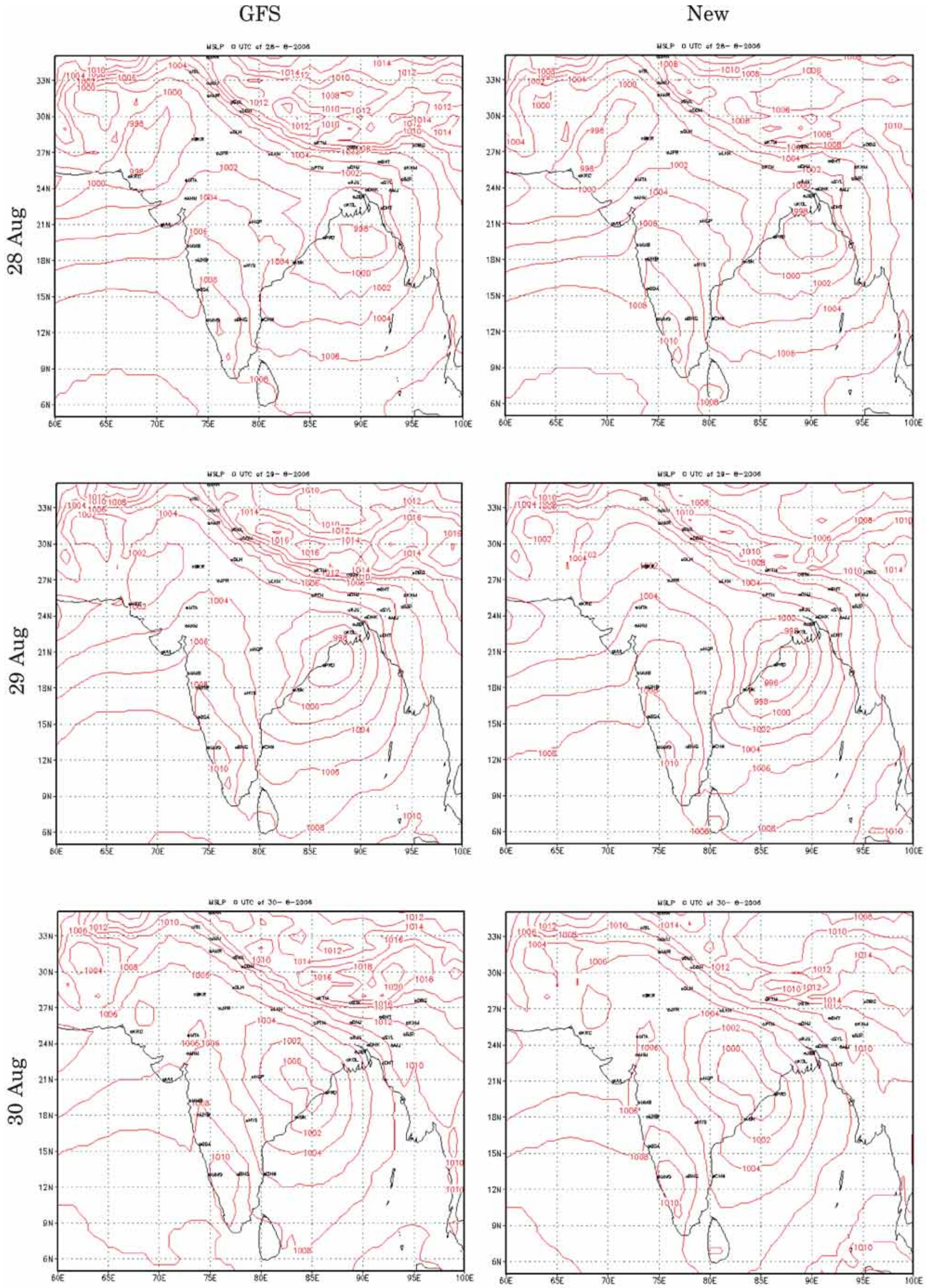

Figure 2. Mean sea level pressure for 28–30 August based on NCEP GFS initial analysis and the new analysis respectively.

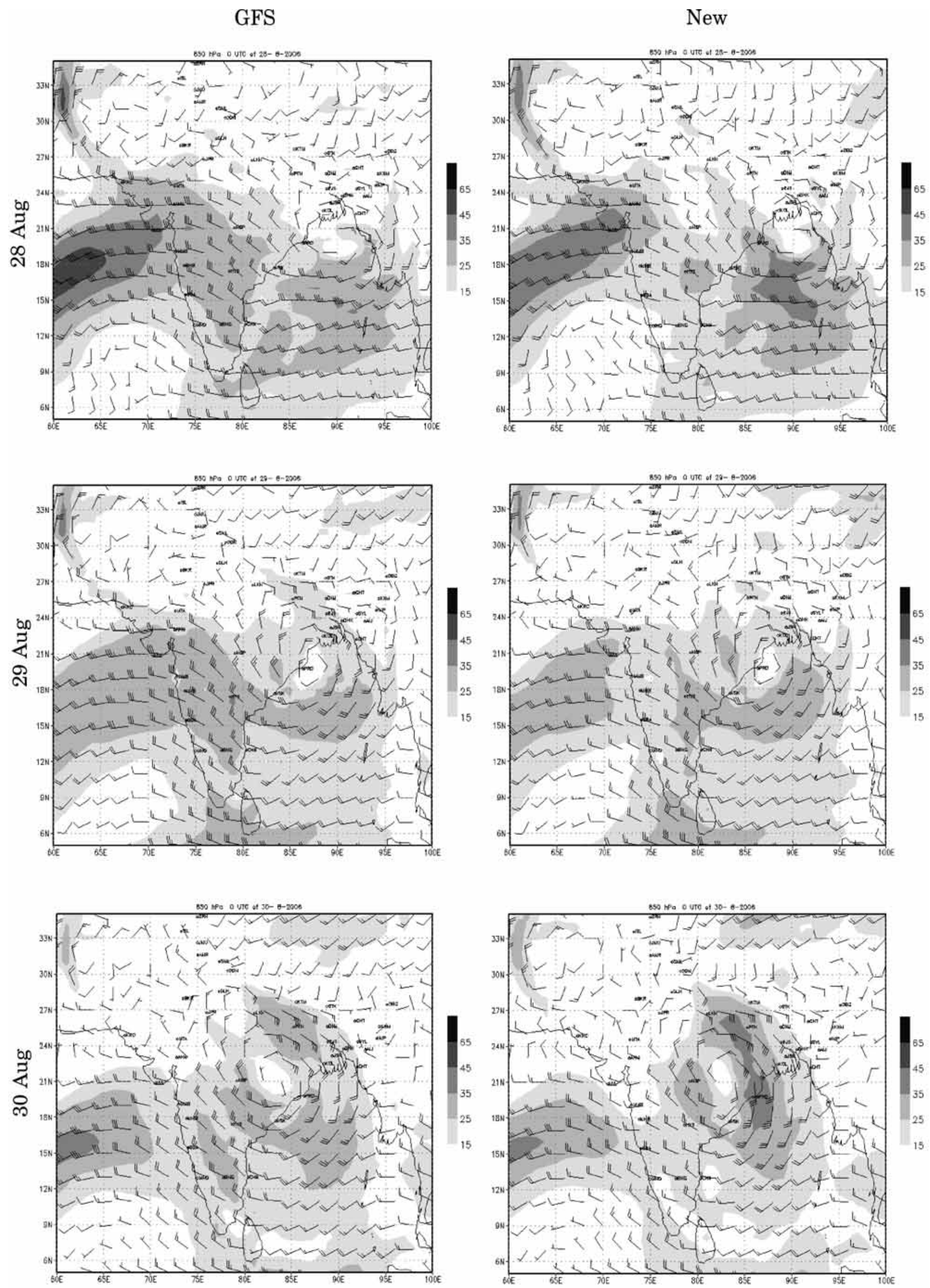

Figure 3. Same as Figure 2 except for the 850 hPa wind fields.

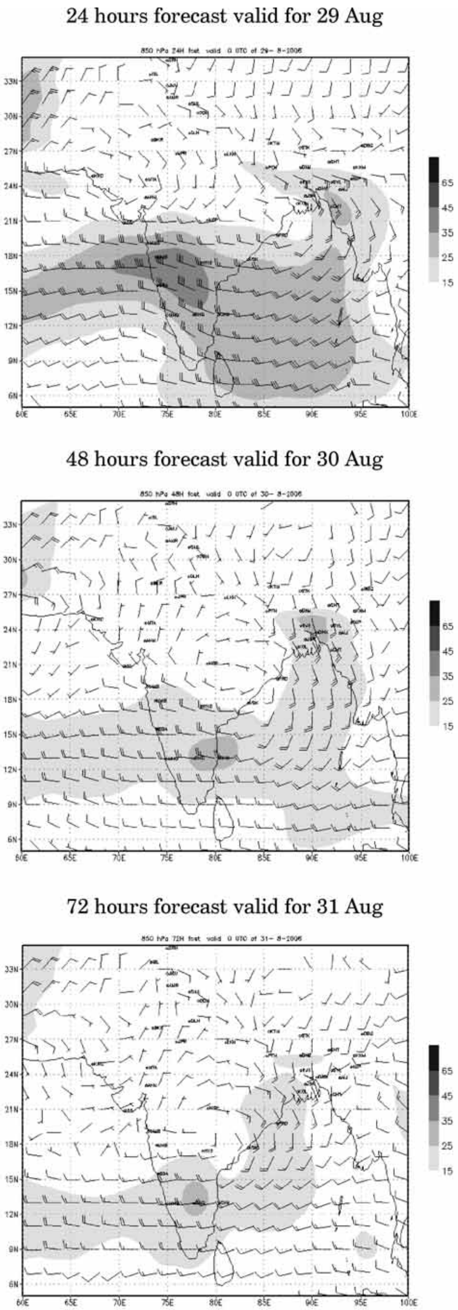

Figure 4. Wind fields at 850 hPa based on 24 hours, 48 hours and 72 hours forecast fields of experimental run valid for 29 to 31 August respectively.

the same observational dataset used for the operational run. Then impact of new analysis in the forecasts is investigated against observations and the corresponding forecasts by the operational Limited Area Model.

(a) Impact of GFS inputs in the model initial condition

The mean sea level pressure fields on the basis of GFS initial analysis and new analysis at 00 UTC of 28–30 August 2006 are shown in Figure 2. An inter comparison reveals that though the isobaric pattern and location of the system, in general, remain similar, isobars appear to be more smooth in the new analysis. On 29 August when the system was intensifying into a depression, the deepening of the system is better reflected in the new analysis.

The corresponding wind fields at 850 hPa on the basis of initial analysis and new analysis at 00 UTC of 28–30 August are shown in Figure 3. No appreciable difference in the location of the depression is noticed between these two analysis. In the GFS analysis, stronger winds are noticed over a larger domain in the land, particularly on 28 and 29 August when the system lay near the east central coast of India. In the new analysis stronger winds prevailed over the Arabian Sea extending up to the west coast of India. The strong winds are also noticed over the south and south-west sector of the depression centre. The pattern in the new analysis is found to be more realistic.

(b) Impact of GFS inputs in the model forecasts

Figure 4 shows 24 hours, 48 hours and 72 hours forecast wind fields of 850 hPa valid for 29–31 August at 00 UTC based on initial condition of 28 August. Though the model shows the depression slightly mis-located to the south, it is interesting to notice that model could retain the vortex up to 72 hours of forecast. In the operational run, the model failed to retain the vortex after 24 hours (Figure not shown).

24 hours accumulated rainfall based on the objective analysis, 24 hours forecast rainfall valid for 29 August as obtained from the experimental run and the corresponding 24 hours forecast rainfall on the basis of the operational run are shown in Figure 5. The objective analysis of rainfall is carried out at the resolution of $1° \times 1°$ lat/long merging raingauge observations and satellite (INSAT) derived quantitative precipitation estimates following the technique as described by Roy Bhowmik and Das (2007). The study (Roy Bhowmik and Das, 2007) showed that the analysis with the use of high dense land raingauge observations, is superior to other rainfall products like, Climate Prediction Centre (CPC) Merged Analysis of Precipitation (CMAP), Global Precipitation Climate Product (GPCP) data to bring-out characteristic features of Indian monsoon. Figure 5 shows a belt of heavy rainfall of order 20 mm over the east central India, in the domain of monsoon depression. Along the Western Ghats of India, rainfall of order 10 mm is observed. Over the foot hills of Himalayas, a few pockets of heavy rainfall are noticed. The inter-comparison reveals that the experimental run could capture the three belts of

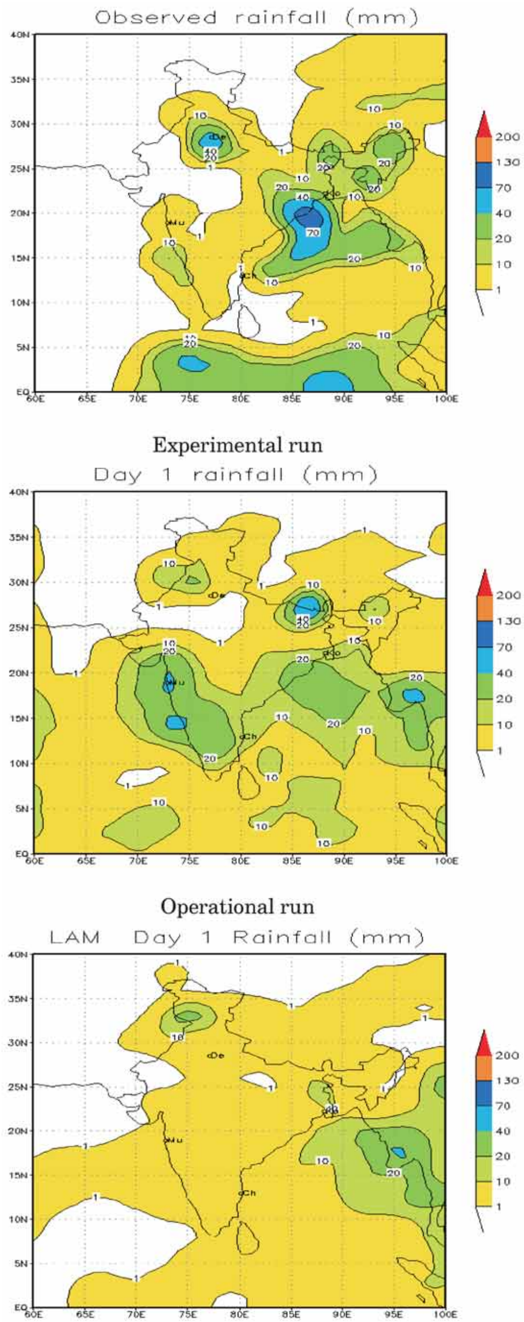

Figure 5. Rainfall analysis (24 hours cumulative rainfall in mm), 24 hours forecast rainfall based on the experimental run and the corresponding operational run valid for 29 August 2006.

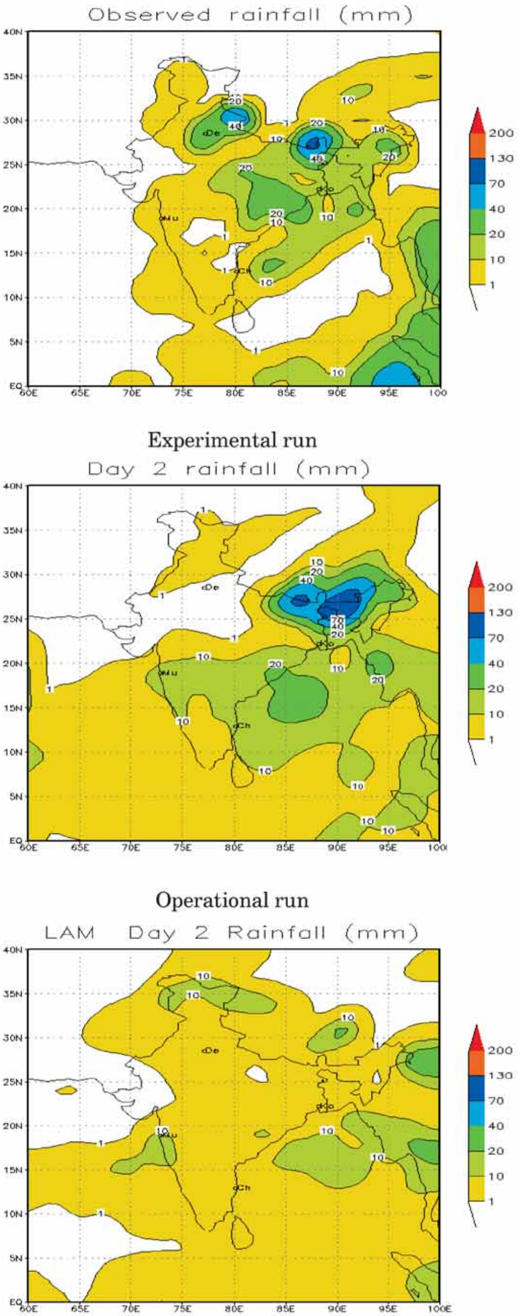

Figure 6. Rainfall analysis (24 hours cumulative rainfall in mm), 48 hours forecast rainfall based on the experimental run and the corresponding operational run valid for 30 August 2006.

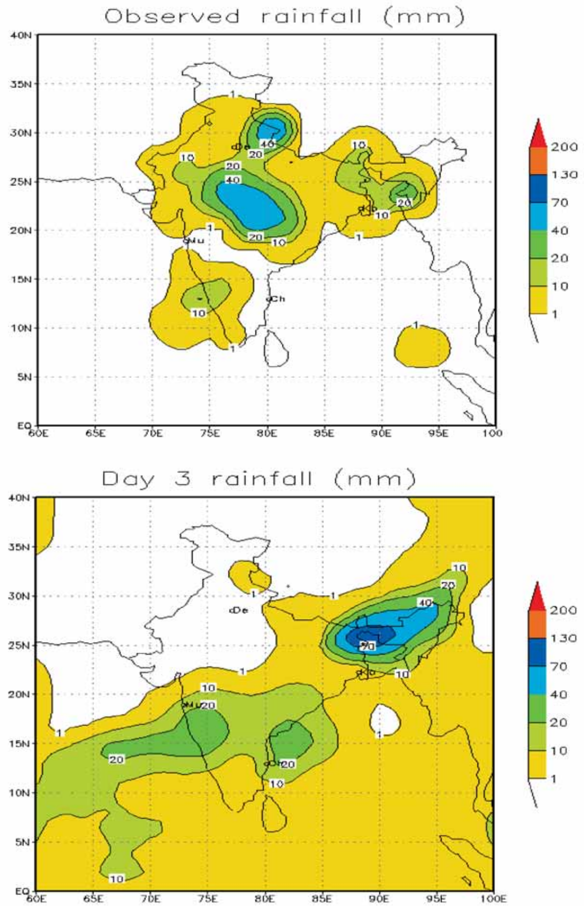

Figure 7. Rainfall analysis (24 hours cumulative rainfall in mm) and 72 hours forecast rainfall based on the experimental run valid for 31 August 2006.

heavy rainfall over the domain of monsoon depression, orographic rainfall along the western ghats and along the foot hills of Himalayas. Some variations in the magnitude are noticed. The corresponding operational run fails to capture these precipitation systems and overall the amount is significantly underestimated. Though the rainfall distribution from the experimental run underestimated rainfall amount at the landfall of monsoon depression (70 cm) and over the equatorial Indian Ocean (20 cm), it could clearly capture these rainfall belts (20 cm) and (10 cm) over these areas which are missing in the operational run. The Figure 6 shows corresponding rainfall for 48 hours forecasts against observation. The observed rainfall of 31 August and the corresponding 72 hours forecast rainfall of experimental run are shown in Figure 7. The new version of the model could broadly capture the rainfall belts over north-east India and over the central parts of the country.

These results clearly show that forecasts generated by experimental run is superior to that of the operational run. The improvement in the forecast arises mainly due to two factors viz, enhanced resolution of the upgraded model (LAM) and use of the first guess and boundary conditions from the NCEP GFS. The NCEP GFS is significantly more advanced with the use of an extensive range of satellite and other conventional and non conventional observations. The limitation of the NCMRWF outputs as the first guess and boundary condition mainly arises due to coarser resolution and ingestion of much less data as compared to NCEP GFS.

5.2. Exceptionally heavy rainfall event of Mumbai on 27 July 2005

The state of Maharashtra on the west coast of India experienced a disastrous rain spell resulting from vigorous monsoon conditions during 25–27 July 2005. The city of Mumbai was devastated. A number of stations reported exceptionally heavy rainfall exceeding 30–40 cm in a 24 hour period in Konkan and Goa and the interior parts (Figure 8). Unprecedented rainfall measuring 94 cm in 24 hours occurred at Mumbai (Santacruz) and 81 cm at another station Bhandup on 27 July. Widespread flooding due to inundation was reported. Synoptically, this exceptionally heavy rainfall event was in association with a well marked offshore trough along the west coast of India and a low pressure

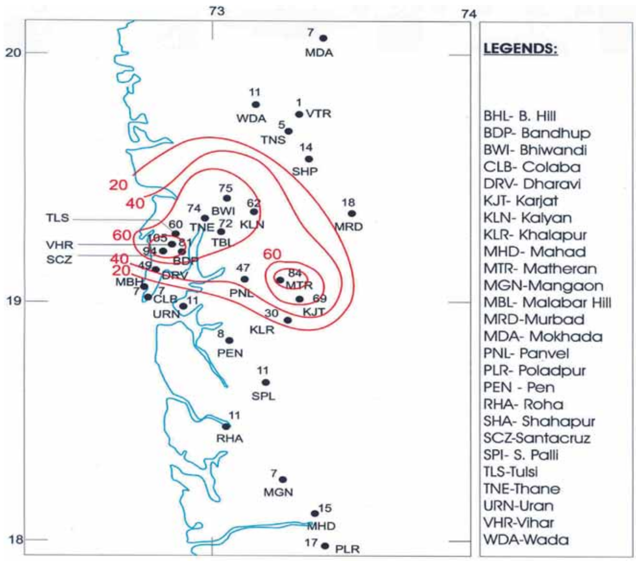

Figure 8. 24 hours observed rainfall (cm) ecoded at 03 UTC of 27 July 2005.

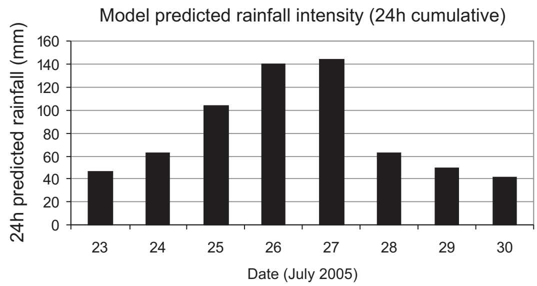

Figure 9. Model predicted rainfall intensity (24h cumulative) based on the initial conditions of dates shown on abscissa at a grid point close to Mumbai.

system which was located over Central India. This type of synoptic pattern is very common during the monsoon season. Lal et al. (2006) made a detailed documentation on the performance of some operational NWP models in predicting this heavy rainfall episode over Mumbai. The study showed that the NCMRWF operational global model (T–80) could capture only about 2 cm of rainfall over Mumbai with a 4 cm core region much south of Mumbai in the 24 hours prediction valid at 03 UTC of 27 July. The NCEP GFS showed 24 hours rainfall amount of 12–16 cm, with the peak located to the north of Mumbai. The operational LAM could produce 4–8 cm rainfall for the 24 hours forecast valid at 00 UTC of 27 July.

Figure 9 contains the time series plot of the 24 hours model predicted rainfall intensity at the selected grid point from 23–30 July. The model could produce 14.5 cm rainfall on 27 July. The model predicted rainfall of order 25–30 cm

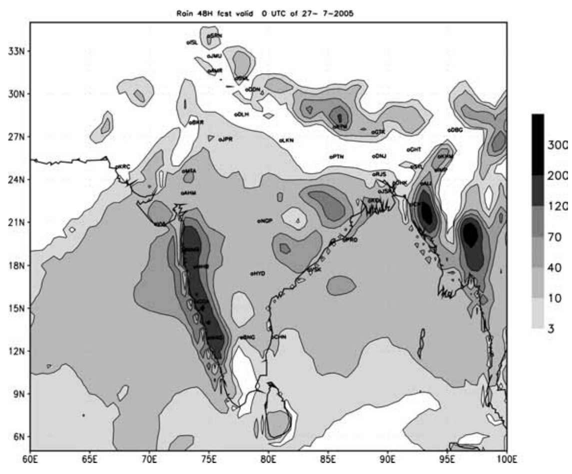

Figure 10. 48h forecast precipitation (mm; cumulative) based on initial conditions of 25 July 2005, valid on 00 UTC of 27 July.

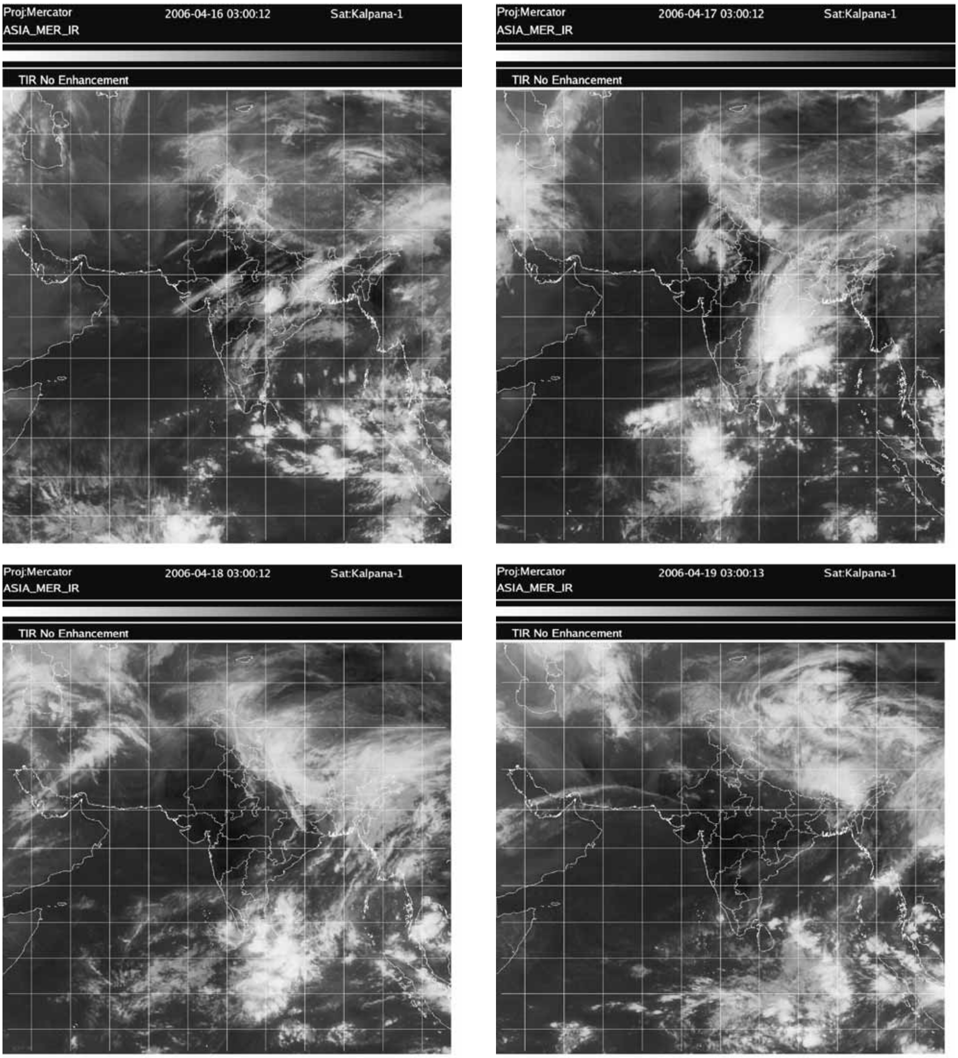

Figure 11. INSAT cloud imageries of (a) 16 April, (b) 17 April (c) 18 April and (d) 19 April 2006.

(48 hours cumulative) based on the initial conditions of 25 July is shown in Figure 10. The rainfall magnitudes are much underestimated as compared to observations. However, the fact is to be noted that the model has been able to capture the rise in the rainfall intensity, to reach the peak level on 26 and 27 July, and the heavy rainfall belt along the west coast and the adjoining interior parts. These results show that the experimental model is clearly superior to the operational LAM to simulate this heavy rainfall episode.

5.3. Heavy rainfall episode in association with Western Disturbance (WD) of April 17–19, 2006

A western disturbance (WD) as an upper air trough was seen over north Pakistan and adjoining northwest on 14 April. The system was gradually moving eastwards and became deep further during 17 to 19 April 2006. During the passage of this system northern as well as eastern parts of India experienced widespread pre-monsoon. thunderstorm activities. According to the reports of India Meteorological Department rainfall of order 7 cm to 12 cm was observed over the eastern part of India. The corresponding satellite (INSAT) imageries of 16 to 19 April are shown in Figure 11(a–d).

The 48 hours forecast rainfall valid for 17 April is shown in Figure 12. The 24 hours forecast rainfall field valid for 18 April and 19 April are shown in Figures 13–14. The inter comparison with the observations reveals that the model could well capture the rainfall activities during this WD episode. Thus, this case study demonstrated the suitability of the model for operational implementation for the real time forecast.

5.4. Tornado over Bangladesh during 7–8 October 2004

According to the report of Dhaka local newspaper, a mighty tornado battered many areas of Bangladesh on 7 October 20004 killing ten people, injuring 500 and leaving a trail of devastation in different parts of the country. According to the newspaper report of Kolkata, heavy rain paralyses life in West Bengal killing 4 people due to heavy downpour during 7–9 October. This event was in association with a low pressure system over the north Bay of Bengal.

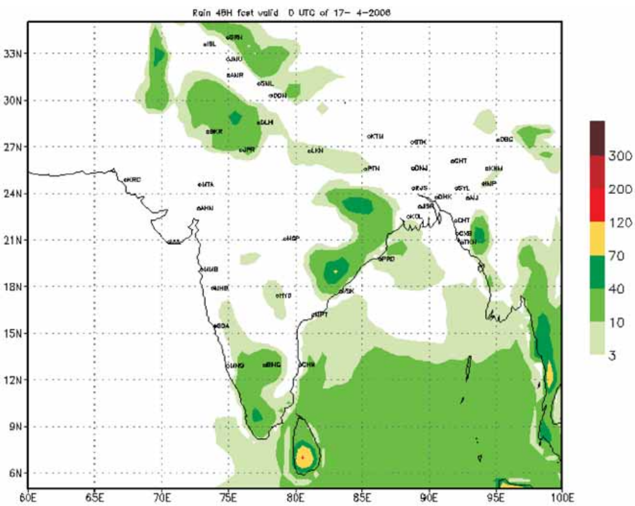

Figure 12. 48 hours predicted rainfall (mm) valid for 17 April 2006.

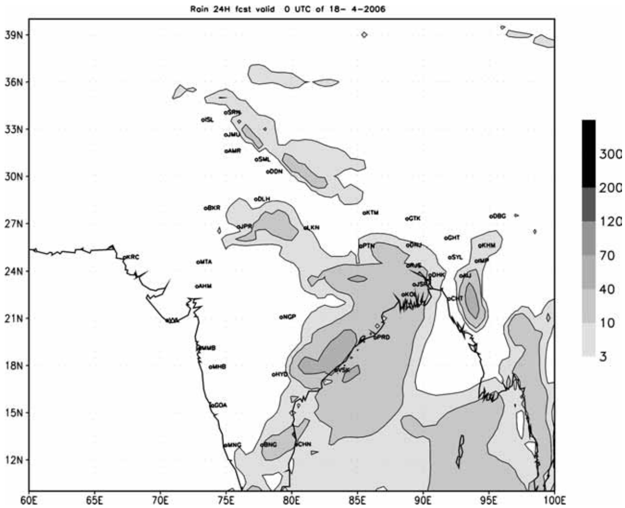

Figure 13. 24 hours predicted rainfall (mm) valid for 18 April 2006.

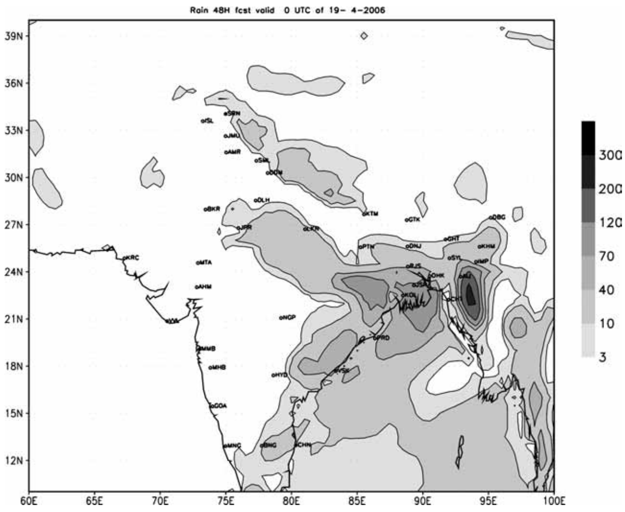

Figure 14. 48 hours predicted rainfall (mm) valid for 19 April 2006.

The system was initially located as a well marked low pressure area over southeast Bay of Bengal on 1st October. It concentrated into a depression on 2nd over the same area. It moved northwestwards and lay over west central Bay of Bengal on 3rd. It moved along the east central coast of India on 6th and persisted over the same area on 7 October.

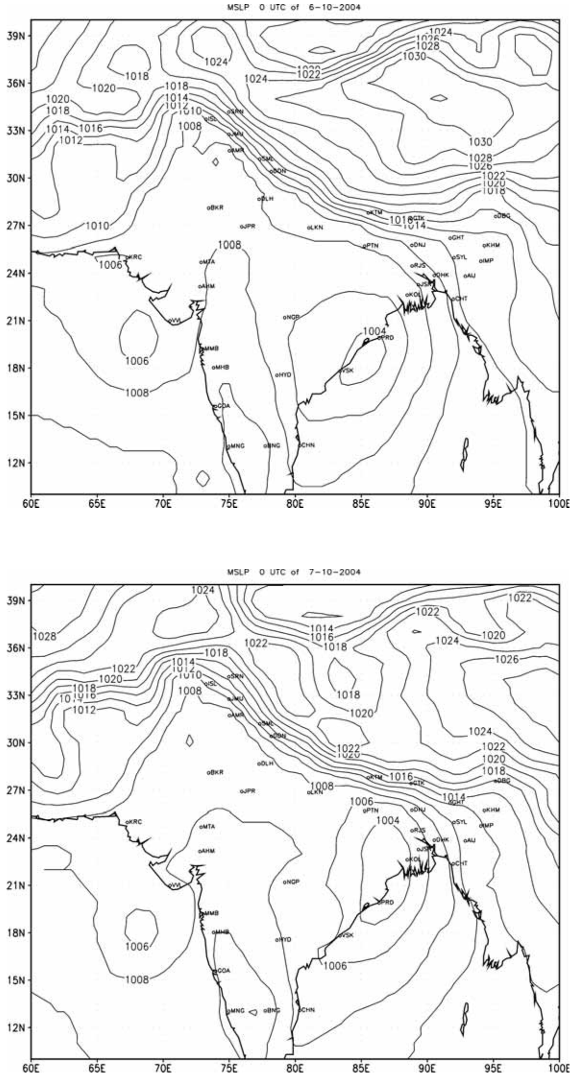

Figure 15. Mean sea level pressure analysis (hPa) of (a) 6 October and (7) October 2004.

Figure 15 (a,b) show the mean sea level pressure analysis field on 6 and 7 October 2004. Build up of the pressure gradient is noticed to the north-eastern sector of the system during 6 and 7 October as the system was moving northwards along the east coast. This caused strengthening of southerly wind along Bangladesh and over the eastern parts of India and incursion of adequate moisture in the lower tropospheric levels. Figure 16 display corresponding 48 hours accumulated forecast rainfall distribution valid for 00 UTC of 6, 7 and 8

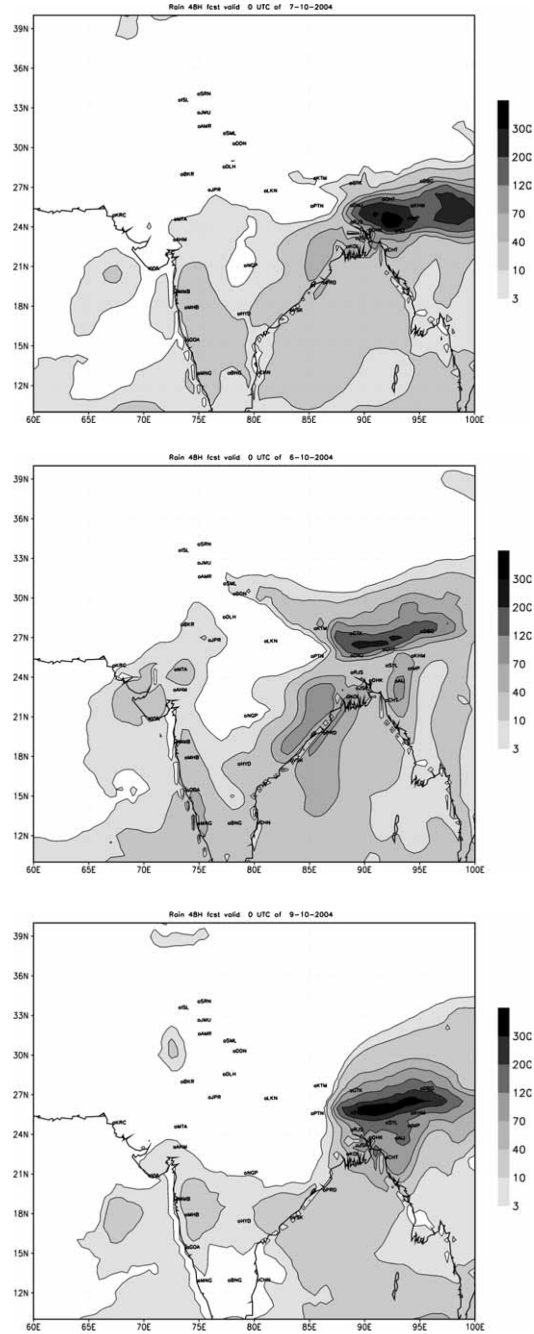

Figure 16. 48 hours predicted rainfall (mm) valid at 00 UTC of (a) 7 October, (b) 8 October and (c) 9 October 2004.

October. In the forecast of 6 October, rainfall amount of order 12 cm to 20 cm is noticed along the east central coast extending northeast wards. Due to a strong pressure gradient, a heavy rainfall belt of order 12 cm to 20 cm is located over north-east India. In the forecast of 7 October the heavy rainfall belt (of order 20–30 cm) is found to shift over Bangladesh. Over the eastern parts of India forecast rainfall has been of the order of 12 cm to 20 cm. This heavy rainfall activity over Bangladesh and eastern parts of India also continued in the forecast field of 9 October.

As the low pressure system was located quite far from the land during 6–7 October, synoptically it might be very difficult to predict this heavy rainfall episode over the eastern parts of India and over Bangladesh. But the case study shows that the model has simulated this heavy rainfall episode reasonably well.

6. Concluding remarks

Convective heavy rainfall events are one of the most disastrous weather phenomena affecting a large population and of common interest to countries in SAARC Region. Accurate forecasts of these events are crucial for the early warning systems in the Region. The main objective of this study is to improve the analysis and forecast in the short range time scale (up to 72 hours) over the SAARC region by improving the resolution of the Limited Area Model of IMD and using better Initial and boundary conditions from NCEP GFS instead of NCMRWF T–80 model. The limitation of the NCMRWF T–80 model arises due to the coarser resolution and ingestion of much less data as compared to NCEP GFS. The use of NCEP GFS data is of particular significant in view of its potential in the real time forecasting operations. The important task of this study was to modify the model codes to receive inputs from NCEP GFS at the resolution of $1° \times 1°$ lat./long. This task has been successfully accomplished. Simulation experiments are performed on wide variety of synoptic situations which occur very often over this region. The performance evaluation in terms of qualitative comparison between the model simulated outputs against actual observations and the outputs of the operational model indicates that the modified version of the model is capable to provide a improved numerical guidance on the occurrence of heavy rainfall in the 48–72 hours forecast scale. The improvement in the prediction in the experimental run arises due to the improved resolution of the model and use of better initial and boundary conditions from NCEP GFS. Further improvement is possible with the use of better quality dense conventional and non conventional observations as expected to be available in the near future under the modernization programme of IMD.

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References

Dey, C.H. and Morone, L. L. (1985): Evolution of the National Meteorological Center Global Data Assimilation System, January 1982 – December 1983, *Mon. Weather. Rev.*, **113**, 304–318.

Harshvardan and Corsetti, T. G. (1984): *Long wave radiation parameterization for ULCA/GLAS GCM*. NASA Tech. Memo No. 86072, 51 pp.

Kanamitsu, M. (1975): *On numerical weather prediction of a global tropical belt.* Department of Meteorology, Florida State University, Rep. No. 75–1, 282 pp.

Kanamitsu, M. (1989): Description of the NMC global data assimilation and forecast system, *Weather Forecast*., **4**, 335–342.

Krishnamurti, T. N. and Low-Nan and Pasch, R. (1983): Cumulus parameterization and rainfall rates II, *Mon. Weather. Rev*., **111**, 815–828.

Krishnamurti, T. N., Kumar, A., Yap, K. S., Davidson, D. and Sheng, J (1989): A documentation of FSU Limited Area model, FSU Rep. No. 89/4 Florida State University, USA.

Lacis, A. A. and Hansen, J. E. (1974): A parameterization for the absorption of solar radiation in the earth's atmosphere, *J. Atmos. Sci*., **31**, 118–133.

Lal, B., Jayanthi, N., Prasad, T., Rajeevan, M., Sunita, D., Srivastava, A. K. and Pai, D. S. (2006): Monsoon 2006 – A report, IMD Met Monograph No. 3/2006, IMD Pune, 81 pp.

Parrish, D. F. and Derber, J. C. (1992): The National Meteorological Centre's Spectral Statistical Interpolation analysis system, *Mon. Weather. Rev*., **120**, 1747–1763.

Roy Bhowmik, S. K. and Prasad, K. (2001): Some characteristics of limited area model precipitation forecast of Indian monsoon and evaluation of associated flow features, *Meteorol. Atmos. Phys*., **76**, 223–236.

Roy Bhowmik, S. K. and Das Ananda, K. (2007): Rainfall Analysis for Indian monsoon region from merged dense raingauge observations and satellite estimates – Evaluation of monsoon rainfall features, *J. Earth Syst. Sci*., **116**(3), 187–198.

Roy Bhowmik, S. K., Joardar, D. and Hatwar, H. R. (2007): An evaluation of precipitation prediction skill of IMD operational NWP system, *Meteorol. Atmos. Phys*., **95**(3), 205–221.

Sugi, M. (1986): Dynamic Normal mode initialization, *J. Meteorol. Soc. Jpn*., **64**, 623–636.

Wallace, J. M., Tihaldi, S. and Simon, J. (1983): Reduction of systematic forecast errors in the ECMWF model through introduction of envelope orography, *Q. J. Roy Meteor. Soc*., **109**, 683–718.

SAŽETAK

Poboljšanje IMD prognoza operativnog regionalnog modela

S. K. Roy Bhowmik i Kanti Prasad

Indijska meteorološka služba (IMD) koristi operativno regionalni model (LAM) za 48-satne prognoze s inicijalnim poljima za objektivnu analizu i graničnim uvjetima iz globalnog spektralnog modela (T–80) pokretanog na Nacionalnom centru za srednjoročnu prognozu (NCMRWF) u New Delhi-ju. U ovoj je studiji kôd modela modificiran, te je napravljen mnogo fleksibilnije u odnosu na NCMRWF (T–80) model. To je omogućilo upotrebu početnih i graničnih uvjeta direktno iz NCEP produkata Globalnog Forecast System (GFS) koji su dostupni na rezoluciji od 1° × 1° zemljopisna širina / zemljopisna dužina. Glavni je interes ove studije bio da se poboljša analiza i 72-satna prognoza poboljšavajući rezoluciju regionalnog modela te koristeći bolje početne i granične uvjete iz NCEP GFS umjesto onih iz NCMRWF T–80 modela. Izvedeno je mnoštvo eksperimenta uvažavajući razne sinoptičke situacije koje se učestalo događaju nad indijskim pod-kontinentom. Procjena performansi pomoću kvalitativne usporedbe između rezultata modela i stvarnih opažanja te rezultata operativnog modela naznačila je da je modificirana verzija modela sposobna omogućiti poboljšane smjernice u slučaju pojave obilnih oborina za 48 do 72-satne prognoze.

Ključne riječi: Regionalni model, monsuni, početno (inicijalno) polje, granični uvjet

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