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Evaluation of Physics options of the Weather Research and Forecasting (WRF) Model to simulate high impact heavy rainfall events over Indian Monsoon region

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In this paper the performance of Weather Research and Forecasting (WRF) model for simulation of heavy rainfall events in presence of monsoon depressions over the Indian monsoon region is investigated with different physics options. A number of experiments for forecasts up to 72 hours are performed with two nested domains at the resolution of 45 km and 15 km respectively. The study shows that WRF model is sensitive to the choice of convective scheme. Betts-Miller-Janjic (BMJ) cumulus scheme is found to produce better results compared to other cumulus schemes for the Indian monsoon region. The model is capable of capturing the movement of the monsoon depression with a lead time of 72 hours. The model is expected to be very useful for forecasting of rainfall and depression tracks in short range time scales over Indian monsoon region.

Key words: Weather Research and Forecasting model, Monsoon depression, Cumulus convective scheme

1. Introduction

During the summer monsoon season (June-September) the Indian subcontinent receives heavy to very heavy rainfall at different parts of India. There is a pressing need in an operational scenario to provide quantitative precipitation forecast of these events with greater accuracy. But forecasting of these high impacts heavy rainfall events continues to be one of the difficult areas in Numerical Weather Prediction (NWP) due to complex issues which involve: impact of orography, treatment of synoptic scale low pressure system, mesoscale convective systems and lack of good quality mesoscale observations, particularly over the ocean. The problem has wide range of applications starting from farming operation to flood forecasting and has direct relevance to the economy of the region.

Representation of precipitation process in NWP models is known as Cumulus Parameterization (CP). Widely used CP schemes in high resolution models are: Anthes-Kuo (Anthes,1997), Betts-Miller, Betts-Miller-Janjic (BMJ) (Betts and Miller, 1986; Janjic, 1994), Grell scheme (GR) (Grell,1993; Grell et al., 1994) and the Kain-Fritsch scheme (KF) (Kain and Fritsch,1993).

Various studies (Wang and Seaman, 1997; Gallus, 1999; Alapaty et al., 1994a, 1994b) are available demonstrating the performance of CP schemes with mesoscale models over different regions. Alapaty et al. (1994a, b) carried out a comparative study on simulation of orographic and monsoon rainfall over Indian region with a limited area model using KF and Kuo schemes. They came to the conclusion that Kuo scheme performs well over the Indian region during monsoon season. Recently, Vaidya (2006) studied the performance of two convective parameterization schemes KF and BMJ over Indian region using Atmospheric Regional Prediction System (ARPS) model. Rainfall prediction skill is subjectively assessed based on the amount and spatial distribution. The study showed that out of four cases, in three cases BMJ scheme produced better results while in one case KF scheme performed better. Ratnam and Cox (2006) tested GR and KF cumulus schemes using MM5 model for the simulations of the monsoon depression. They found that both the schemes are capable to simulate the large scale features of monsoon depressions, but failed to capture the correct location of depressions at 24 hours and 48 hours forecast. GR scheme tends to overestimate the rainfall. KF scheme could simulate the distribution of rainfall, but location of maximum rainfall was different. These studies conclude that the performance of NWP models depends heavily on initial inputs, model resolution and physics options, especially cumulus parameterizations scheme.

The purpose of the present study is to test the performance of various physics options of Weather Research and Forecasting (WRF) model to simulate heavy rainfall events associated with monsoon depressions over Indian region. The focus will be on cumulus parameterizations and planetary boundary layer options available in WRF.

2. The Model

The Advanced Research WRF (ARW) model is developed by Mesoscale and Microscale Meteorology (MMM) Division of National Center for Atmospheric Research (NCAR), USA. The details descriptions of the model are available in the recent studies (Michalakes et al., 2001; Skamarock, et al. 2005). WRF is a fully compressible non-hydrostatic (with hydrostatic option), primitive equation model with multiple nesting options to enhance resolution over the area of interest. It is a next-generation numerical weather prediction model with advance dynamics, physics, and numeric schemes (Skamarock, et al. 2005). The model uses terrain-following hydrostatic pressure coordinate system with permitted vertical stretching (Laprise, 1992). Arakawa C grid staggering is used for horizontal discretization. The model equations are conservative for scalar variables. The other features of the model are: Eulerian mass coordinates, named as the Advanced Research WRF (ARW), the time-split third order Runge-Kutta (RK3) integration scheme (Klemp and Wilhelmson, 1978; Skamarock and Klemp, 1992; Wicker and Skamarock, 2002) for model integration, higher order advection schemes and complete Coriolis, curvature and mapping terms.

The experiments are carried out in the off-line mode using WRF model version 2.2 (Released December 2006). This version of the WRF consists of two parts: WRF Standard Initialization (WRFSI) and ARW. The SI provides three mandatory inputs for WRF namely, (a) To define and localize the three dimensional grid, (b) To specify the 'static' surface characteristics of land, water and vegetation and (c) To provide the initial and lateral boundary condition by interpolating larger scale model data to the model resolution for the domain of interest.

The model includes three different cumulus parameterization schemes namely, KF, BMJ and Grell-Deveyi (GD)). Two planetary boundary layer (PBL) schemes, the Yonsei University (YSU) and Mellor-Yamada-Janjic (MYJ) schemes were also tested. These parameterizations have not changed too much in the new versions. It is presumed that changes in these physics options since the version 2.2, may affect the details of the results, but probably not the major results about which schemes work the best.

Other physics options of the WRF model are: (a) Micro physics – Lin et al. (1983), (b) Long wave radiation – RRTM scheme, (c) Short wave radiation – Dudhia scheme, (d) Surface layer physics based on Monin-Obukhov with Carslon-Boland viscous sub layer and (e) Land surface – Noah Land surface model (LSM) and number of soil layer 4 for Noah LSM scheme.

3. Design of experiment

For the present study, two-way nesting with horizontal resolution of 45 km and 15 km is used. In the two way nesting each domain takes information from parent domain every time step and runs three time steps for each parent time step before feeding back information to parent domain on the coincident interior points (Skamarock et al., 2005). 31 vertical levels are used for this study. A time step of 180 and 60 seconds respectively is used for the integration of two domains. The model is integrated for forecasts up to 78 hours with output being saved at every 3 hours interval.

In this study, two domains are configured, as shown in Fig. 1. Domain 1 is the coarse domain and has 116 × 111 grid points in north-south and east-west

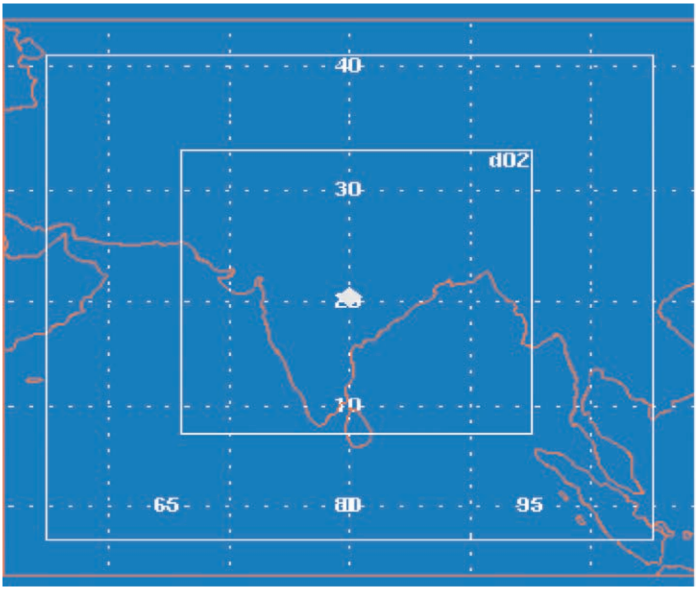


Figure 1. Domain selection for the experiments.

directions, with a horizontal grid spacing of 45 km. Domain 2 is nested domain with 199 × 193 grid points at 15 km grid spacing. Both the domains run together with two-way nested interactions. The initial and boundary conditions are derived from National Centre for Environmental Prediction (NCEP) 6 hourly Global Forecast System (GFS) outputs freely available in the Internet at the horizontal resolution of 1° × 1° lat/long (http://nomad3.ncep.noaa.gov/ncep_data/index.html). GFS data are interpolated to WRF model grid to provide the initial and lateral boundary condition at 6 hour interval for the domain 1. Domain 2 obtains its initial and boundary conditions from domain 1 and provides feedback to domain 1 during the two way nesting run.

In the first step, performance of the model is tested with different cumulus parameterization schemes. The cumulus options of the WRF model that evaluated here are briefly described below:

(a) KF: The KF scheme is basically designed to use in mesoscale models. The convection is determined by convective available potential energy (CAPE) at a grid point. A trigger function is defined based on the resolvable scale vertical motion. When the scheme is activated CAPE is removed by rearrangement of temperature and moisture fields. As the scheme itself removes the CAPE, it is found that this scheme favors explicit rainfall. This scheme utilizes cloud model for cloud-environment, detrainment etc. and parameterizes downdraft.

(b) GD: Grell and Devenyi (2002) introduced an ensemble cumulus scheme in which effectively multiple cumulus schemes and variants are run within each grid box and then the results are averaged to give the feedback to the model. In principle, the averaging can be weighted to optimize the scheme, but the default is an equal weight. The schemes are all mass-flux type schemes, but with differing updraft and downdraft entrainment and detrainment parameters, and precipitation efficiencies. These differences in static control are combined with differences in dynamic control, which is the method of determining cloud mass flux. The dynamic control closures are based on CAPE or cloud work function, low-level vertical velocity, or moisture convergence. Those based on CAPE either balance the rate of change of CAPE or relax the CAPE to a climatological value, or remove the CAPE in a convective time scale. The moisture convergence closure balances the cloud rainfall to the integrated vertical advection of moisture. Another control is the trigger, where the maximum cap strength that permits convection can be varied. These controls typically provide ensembles of 144 members. Details of this scheme can be found in Skamarock et al. (2005).

(c) BMJ: This scheme is a lagged convective adjustment scheme. The model temperature and moisture profiles are adjusted towards reference profiles which are in quasi equilibrium state due to deep convection. Details about this scheme can be found in Janjic (2000).

For testing the performance of different cumulus convection schemes, PBL option MYJ is used. In the second step PBL scheme options of the model are tested. For comparison of performance skill of the model, observed gridded rainfall data of India Meteorological Department (IMD) is used (Rajeevan et al., 2006).

4. Results of experiments

Monsoon low pressure system is the main rain producing system of summer monsoon over Indian region which forms over the northwest Bay of Bengal and moves northwest wards across the country giving rise to heavy to very heavy falls during its passage. Along the west coast of India heavy rainfall occasionally occurs during the formation of these low pressure systems. In this section, performance of the model with different physics options over Indian monsoon region in presence of monsoon depression is examined and discussed. The case studies selected for the experiments are:

a) Deep depression of 2–4 July 2006

b) Deep depression of 2–4 August 2006

c) Depression of 29 August–1 September 2006

Track positions of these monsoon depressions are shown in Fig. 2.

a)

b)

c)

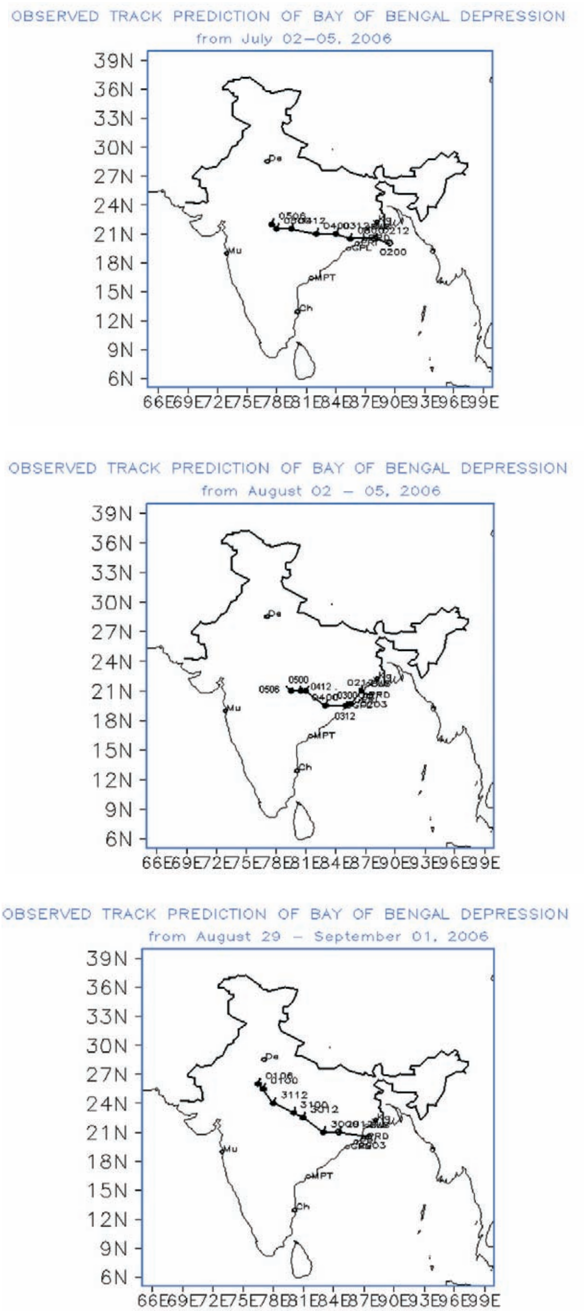


Figure 2. Observed track of monsoon depressions of (a) 2-4 July 2006; (b) 2-5 August of 2006 and (c) 29 August to 1 September 2006.

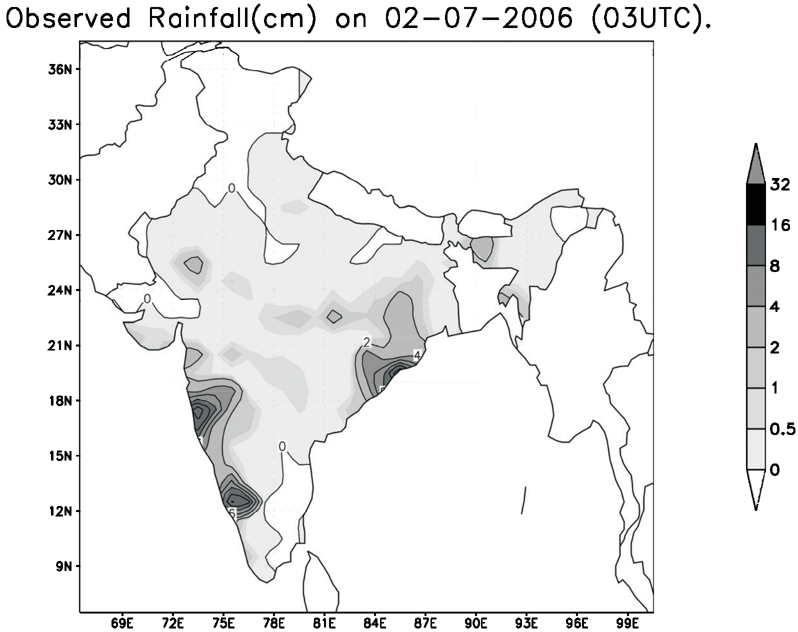


Figure 3. Observed rainfall (cm) for 2 July 2006.

4.1. Results of numerical experiments with different cumulus physics options

For the case 1 (the depression of 2–4 July 2006), the model is run for day-3 forecast (up to 72 hours forecast) with the initial condition of 1 July 2006. Figure 3 presents 24 hours (day-1) observed rainfall (cm) of 2 July 2006. The observed rainfall distribution shows a north-south oriented belt of rainfall of order 2 to 10 cm between lat. 12° N and 21° N with a peak centered near lat. 17° N along the west coast. Another heavy rainfall belt of magnitude 1 cm–17 cm is observed near lat 19° N along east coast over the area of monsoon depression. Rainfall activities are also noticed over east-central India over the domain of eastern end of monsoon trough. Fig. 4(a,b,c) shows corresponding 24 hours forecast (day-1) rainfall of 2 July with cumulus options of BMJ, KF and GD schemes respectively. Both BMJ and KF schemes show large scale rainfall activity over the northwest Bay of Bengal and adjoining east coast of India, along the west coast of India and along the eastern part of monsoon trough region, BMJ scheme produces rainfall of order 2 cm to 16 cm along the west coast and 1 cm to 8 cm over the east coast near lat. 19° N. The GD scheme shows rainfall of order 1 cm to 4 cm along the west coast and 2 cm to 4 cm along the east coast. KF scheme could capture rainfall of order 4 cm to 16 cm along the west coast and 4 cm to 8 cm along the east coast. The rainfall is considerably underesti-

a)

b)

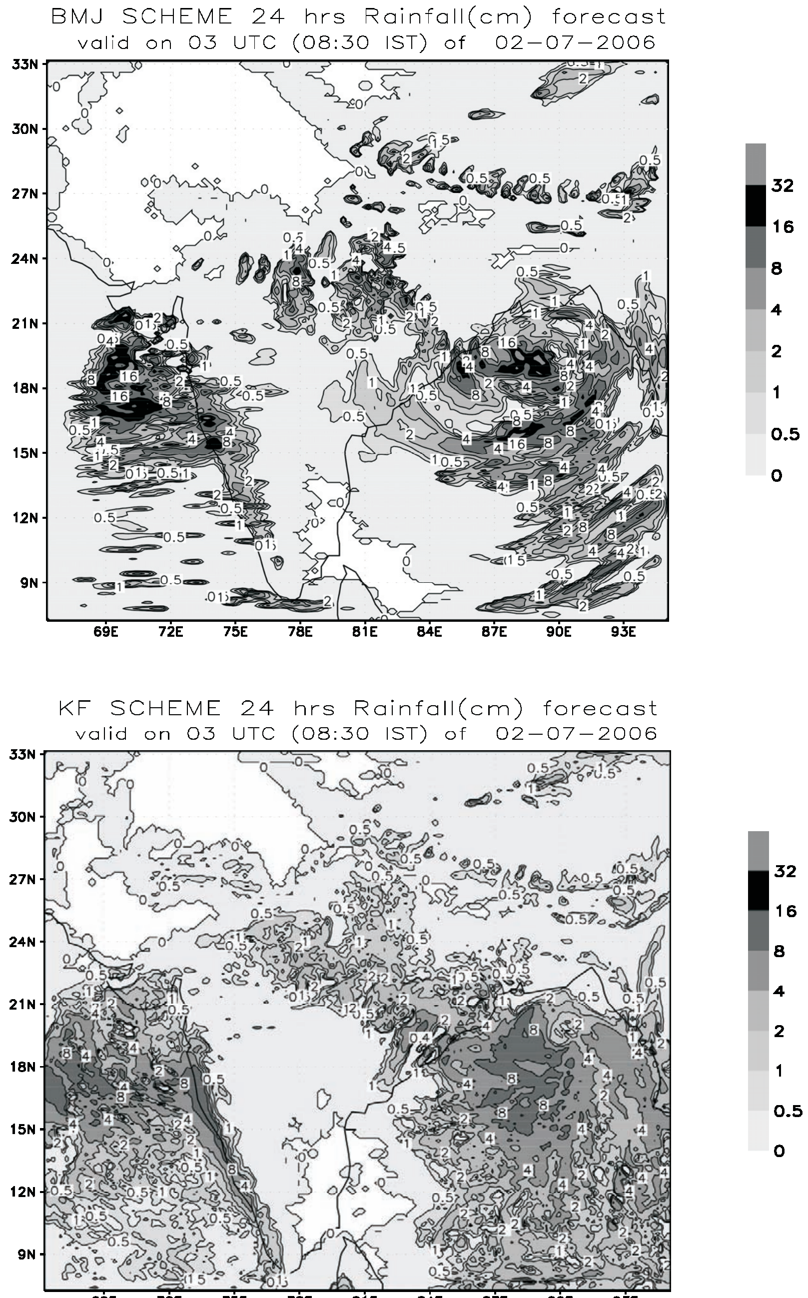
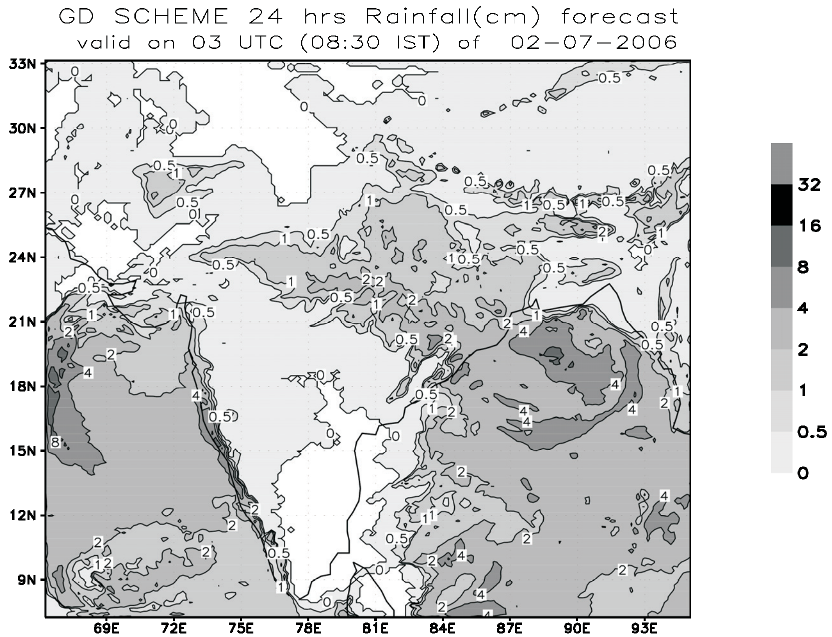


Figure 4. a) BMJ scheme for 24 hours rainfall (cm) forecast (day-1) valid for 2 July 2006.
b) KF scheme for 24 hours rainfall (cm) forecast valid for 2 July 2006.
c) GD scheme for 24 hours rainfall (cm) forecast valid for 2 July 2006.

c)



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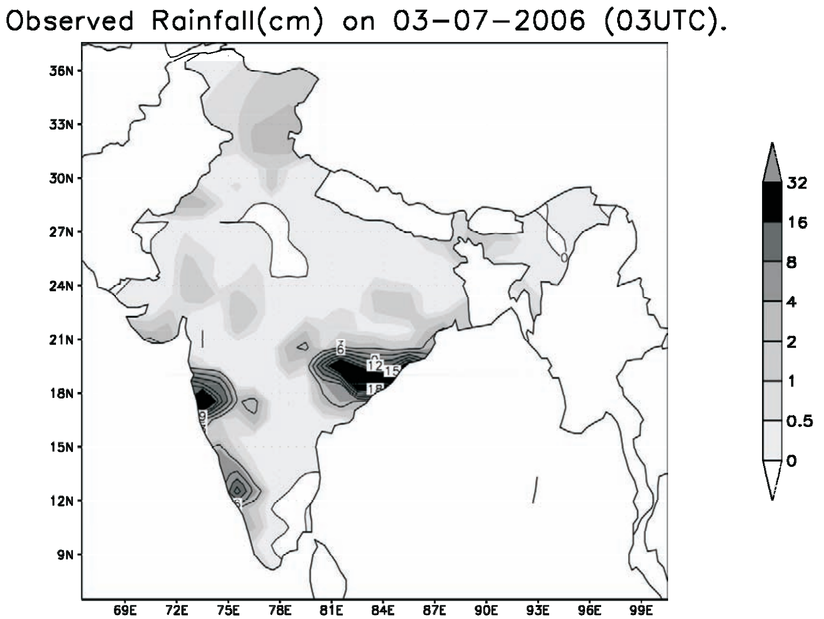


Figure 5. Observed rainfall for 3 July 2006 in cm.

mated by the GD scheme. The rainfall distribution produced by BMJ and KF schemes are broadly close to the observations. The inter-comparison shows that the meso-scale features of monsoon rainfall are better captured by the BMJ scheme. The performance of BMJ scheme at the 24 hours forecast is found to be relatively superior.

Fig. 5 illustrates observed rainfall for 3 July. The observation continues to describe a north-south oriented belt of rainfall of order 4 to 32 cm along the west coast with a peak centered near lat. 19° N and 12° N. The other heavy rainfall belt is located along the east coast over the area of monsoon depression. Fig. 6(a, b, c) presents corresponding model predicted rainfall of 48 hours (day-2) valid on 3 July 2006 based on three schemes BMJ, KF, GD respectively. Both BMJ and KF schemes continue to describe large scale rainfall activities over the north-west Bay and adjoining east coast of India. As the system moved northwestwards over the maritime state, the corresponding forecast could capture the shifting of rainfall belt associated with the monsoon depression. Again BMJ continues to describe the meso-scale rainfall features in a more realistic way. BMJ scheme produces rainfall of order 2 cm to 32 cm along west coast with peak intensity near lat. 20° N. Along the east coast rainfall of

a)

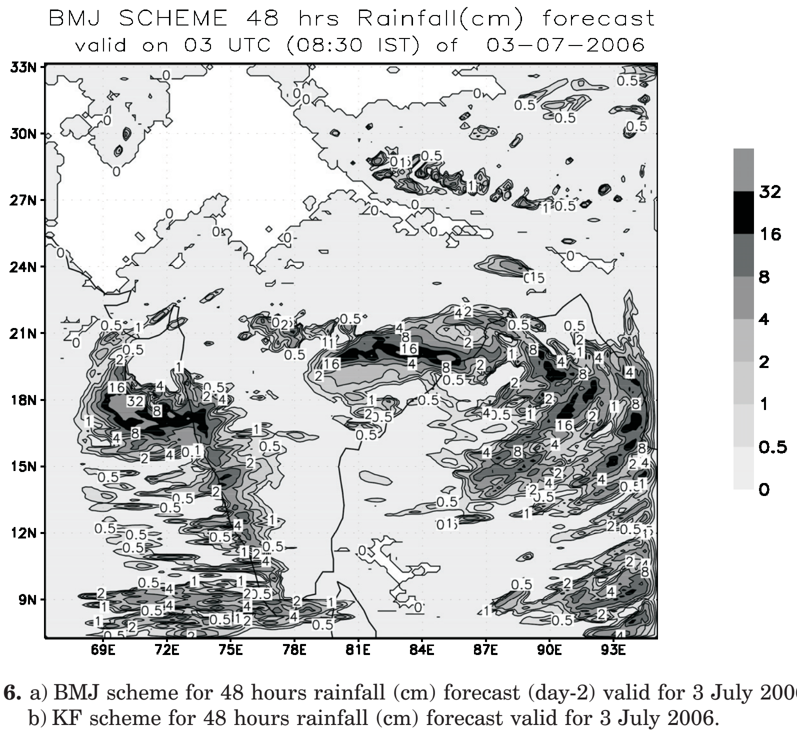
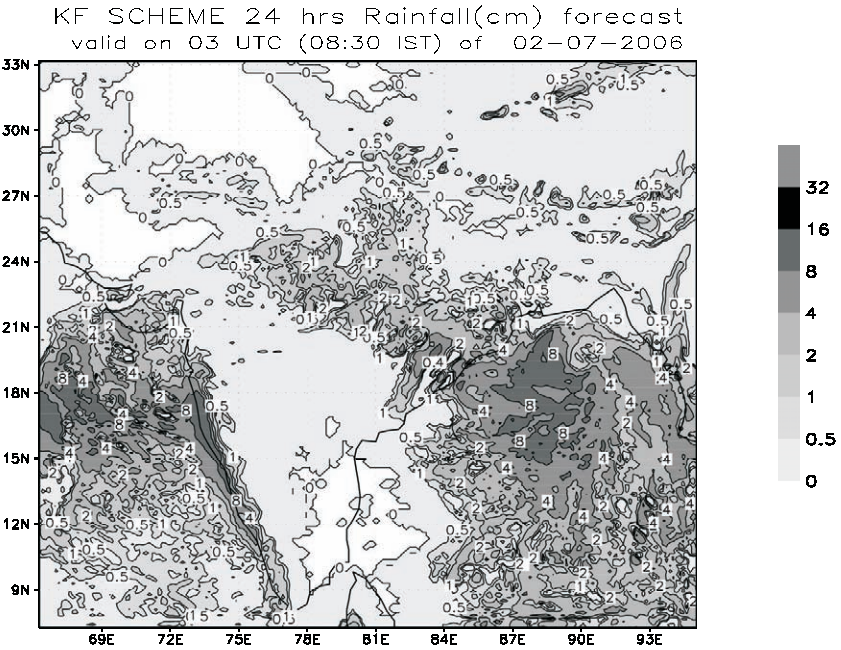


Figure 6. a) BMJ scheme for 48 hours rainfall (cm) forecast (day-2) valid for 3 July 2006.
b) KF scheme for 48 hours rainfall (cm) forecast valid for 3 July 2006.
c) GD scheme for 48 hours rainfall (cm) forecast valid for 3 July 2006.

b)



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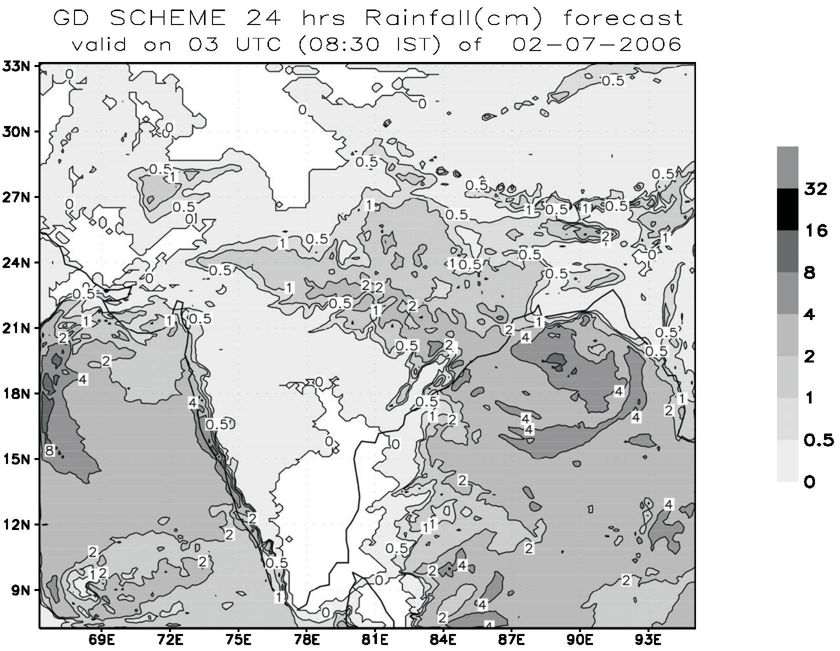

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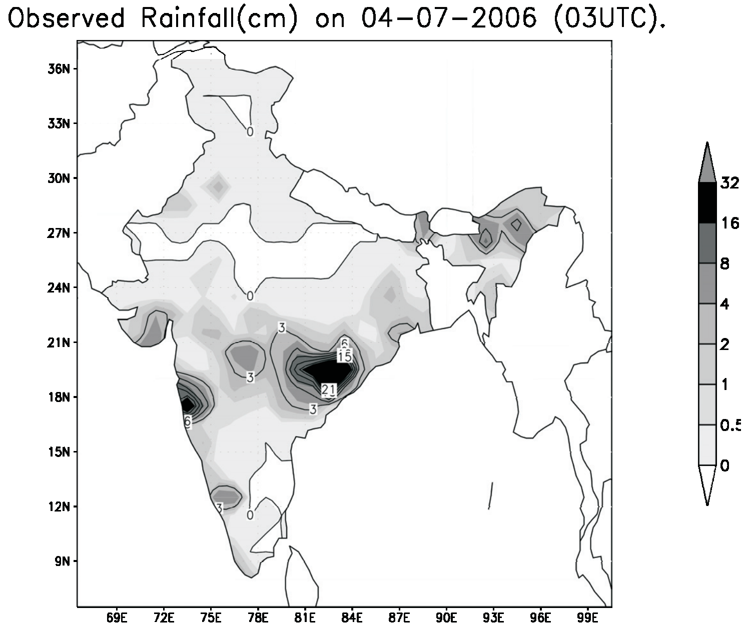
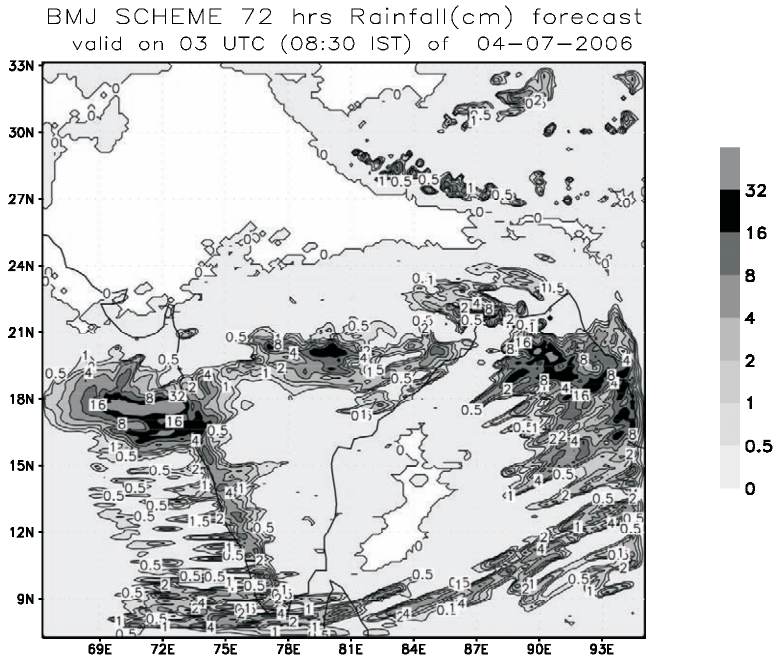


Figure 7. Observed rainfall for 4 July 2006 in cm.

order 4 cm to 32 cm is noticed. The KF scheme produces rainfall of order 4 cm to 16 cm rainfall along west coast and 12 cm to 32 cm rainfall along east coast of India with a peak magnitude of 32 cm near latitude 18° N. GD cumulus scheme produces rainfall in the range of 4 cm to 16 cm along the west coast and 12 cm to 32 cm over east coast of India. All the three experiments captured the distribution of rainfall over the east coast, over the area of monsoon depression. But along the west coasts of India forecast rainfall by BMJ scheme is found to be more realistic compared to other two schemes. Spatial pattern of rainfall in BMJ scheme is in agreement with observed rainfall pattern.

Fig. 7 shows the observed rainfall of 5 July 2006. It is clear from the figure that maximum rainfall occurred near latitude 17° N along west coast and near 19° N in the east coast of India. The corresponding rainfall of 72 hours (day-3) forecast by these three schemes are shown in Fig 8 (a,b,c). The KF scheme considerably overestimates rainfall (~32 cm) over the central parts of country, over the area of monsoon depression and along the west coast compared to BMJ scheme. The GD scheme shows under-estimation of rainfall over the land areas. It is evident from this inter-comparison that BMJ scheme persistently showed better performance at day-1, day-2 and day-3 forecasts. Large scales as well as mesoscale features of rainfall in presence of monsoon depression, particularly the orographic rainfall along the Western Ghats of India are better captured by the BMJ scheme.

a)



b)

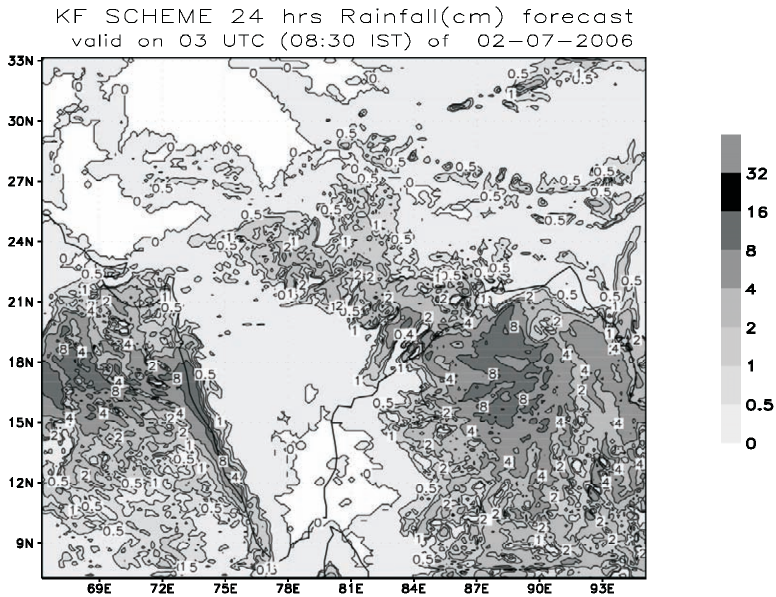
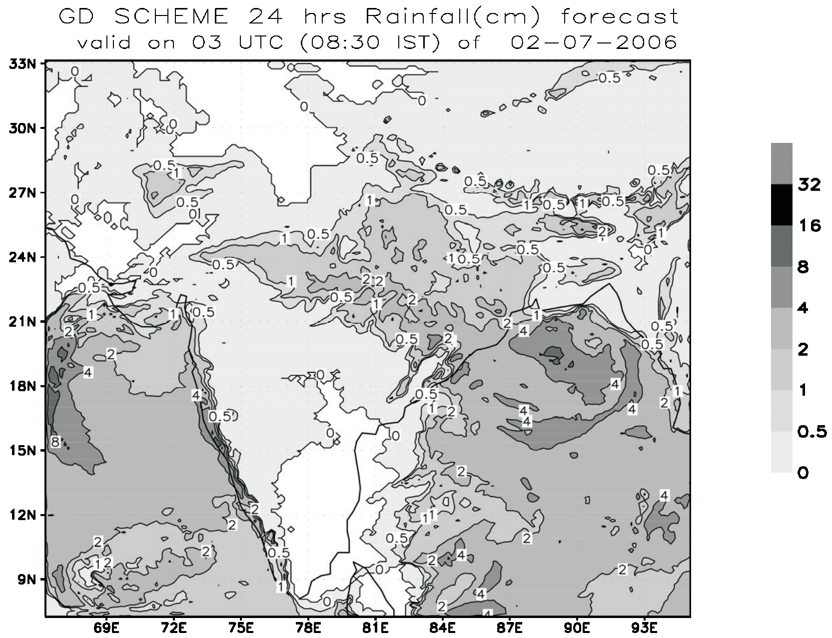


Figure 8. a) BMJ scheme for 72 hours rainfall (cm) forecast (day-3) valid for 4 July 2006.
b) KF scheme for 72 hours rainfall (cm) forecast valid for 4 July 2006.
c) GD scheme for 72 hours rainfall (cm) forecast valid for 4 July 2006.

c)



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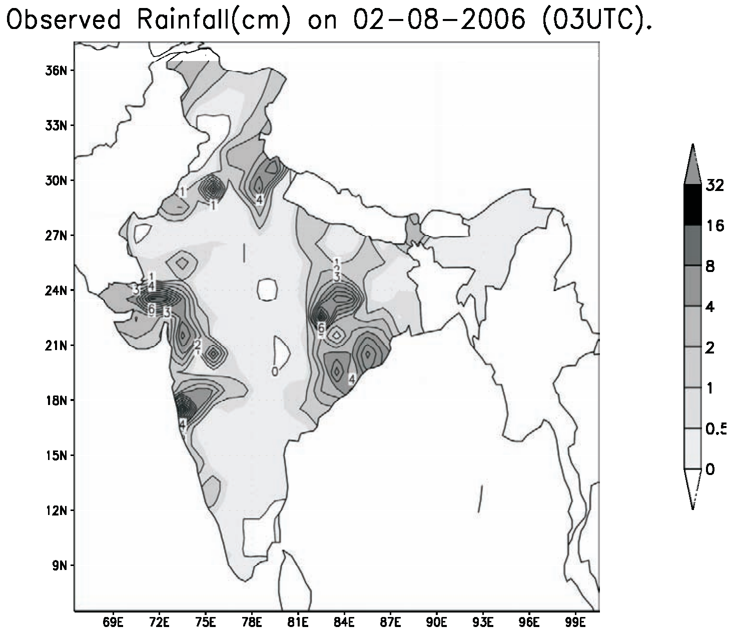


Figure 9. Observed rainfall (cm) for 2 August 2006.

Next experiment is carried out for the case 2 (depression of 2–5 August 2006). The model is run with the initial condition of 1 August 2006 and integrated for 48 hours forecast (up to day-2 forecasts). Fig. 9 shows the observed rainfall of 2 August 2006. The amount of observed rainfall along west coast ranges from 1 cm to 16 cm with a peak near lat. 18° N. Rainfall of order 3 cm to 16 cm is observed over Gujarat region. Over the east central India rainfall of order 4 cm to 16 cm is noticed. Fig. 10 (a, b, c) shows the corresponding 24 hours forecast rainfall valid on 2 August 2006 based on these three different cumulus convection schemes.

All the three schemes show large scale rainfall activities over the northwest Bay of Bengal and adjoining east coast of India in association with this system. Rainfall activities are also noticed along the west coast of India and over the area of monsoon trough region. The inter-comparison reveals that rainfall along the west coast and over the Gujarat region is better captured by the BMJ scheme. These rainfall activities are under-estimated by the GD scheme and KF schemes. The rainfall activity realized over the northwest India (in the observation near latitude 30° N) is found to be under-estimated by all the schemes. The rainfall patter over the east central India produced by the BMJ scheme is in well agreement with the observed one.

a)

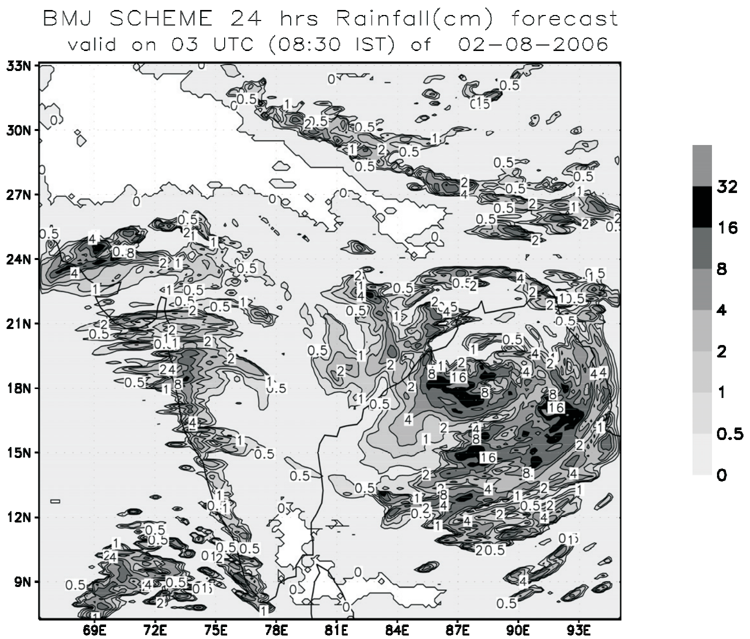
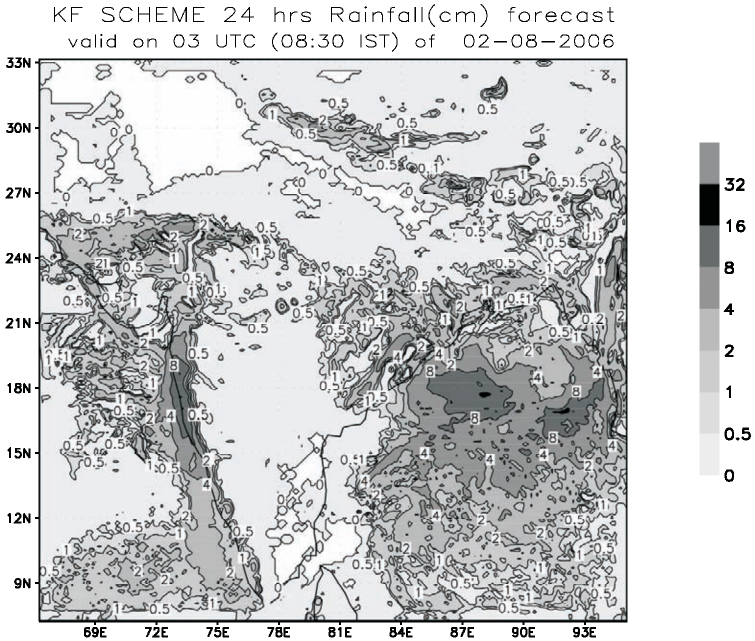


Figure 10. a) BMJ scheme for 24 hours rainfall (cm) forecast valid for 2 August 2006.
b) KF scheme for 24 hours rainfall (cm) forecast valid for 2 August 2006.
c) GD scheme for 24 hours rainfall (cm) forecast valid for 2 August 2006.

b)



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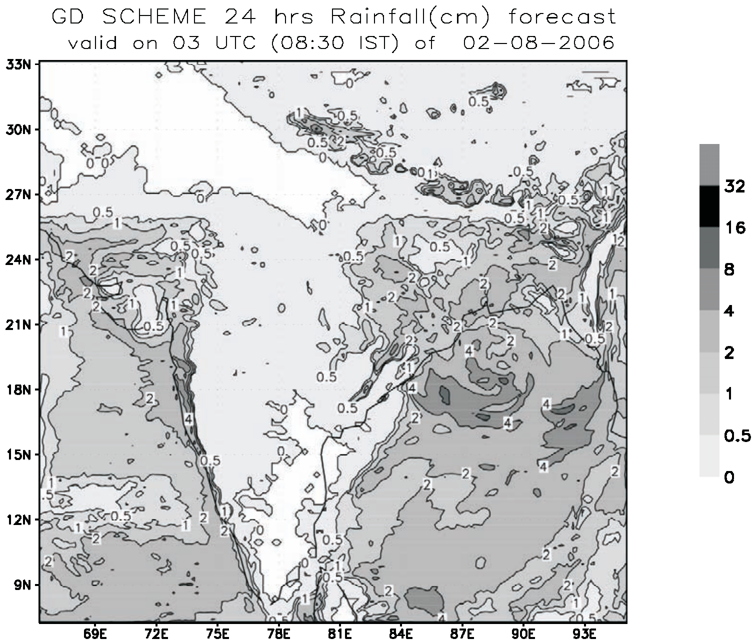


Figure 10. Continued.

Fig. 11 and 12 (a, b, c) illustrate the observed and the corresponding day-2 forecast rainfall on 3 August 2006. The inter-comparison reveals that KF and BMJ schemes perform better as compared to GD scheme. The observed rainfall pattern is in well agreement with that of BMJ scheme. The performance of BMJ cumulus scheme is found to persistently better at all the forecast hours (day-1 to day-2).

Better performance of BMJ scheme to reproduce more realistic rainfall forecast may be because of reference profiles it uses are closer to the observed one. In a tropical country like India rainfall from mesoscale convective systems are very common weather phenomena. Roy Bhowmik et al. (2008) made a detailed seasonal and spatial analysis of CAPE and Convective Inhibition Energy (CIN) in relation to convective activities over Indian region. They found that convective rainfall during pre-monsoon season over East-central Indian region is associated with higher value of CAPE (2400 J kg^{-1}) with CIN value close to 0 J kg^{-1}. The magnitude of CAPE during monsoon season shows decreasing trend (1500 J kg^{-1}) over East-central India. But magnitude of CIN is generally very high (negative) during this season. Thus dynamic condition such as low level convergence, rising motion are necessary for the effective release of environment energy (Cohen and Frank, 1989). The monsoon synoptic scale systems like monsoon depression play a dominant role to provide dynamical support for rising of moist air. Thus it appears from the result of this study that

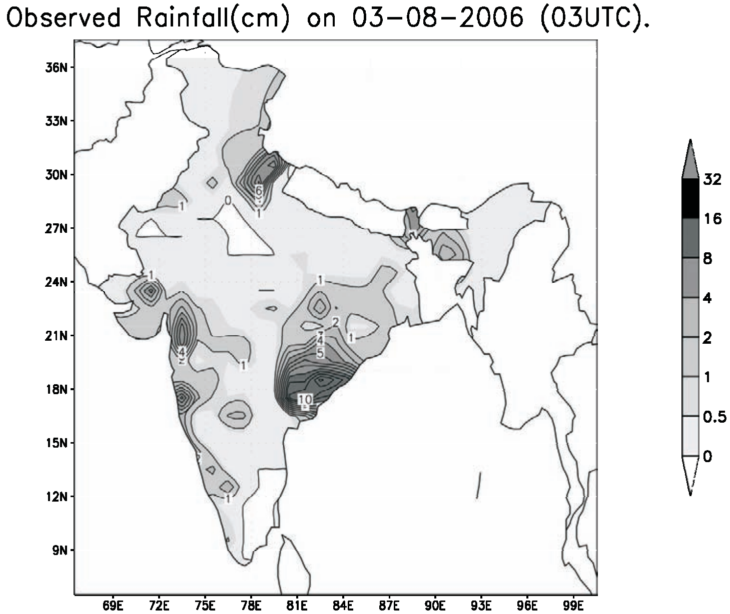


Figure 11. Observed rainfall (cm) for 3 August 2006.

a)

b)

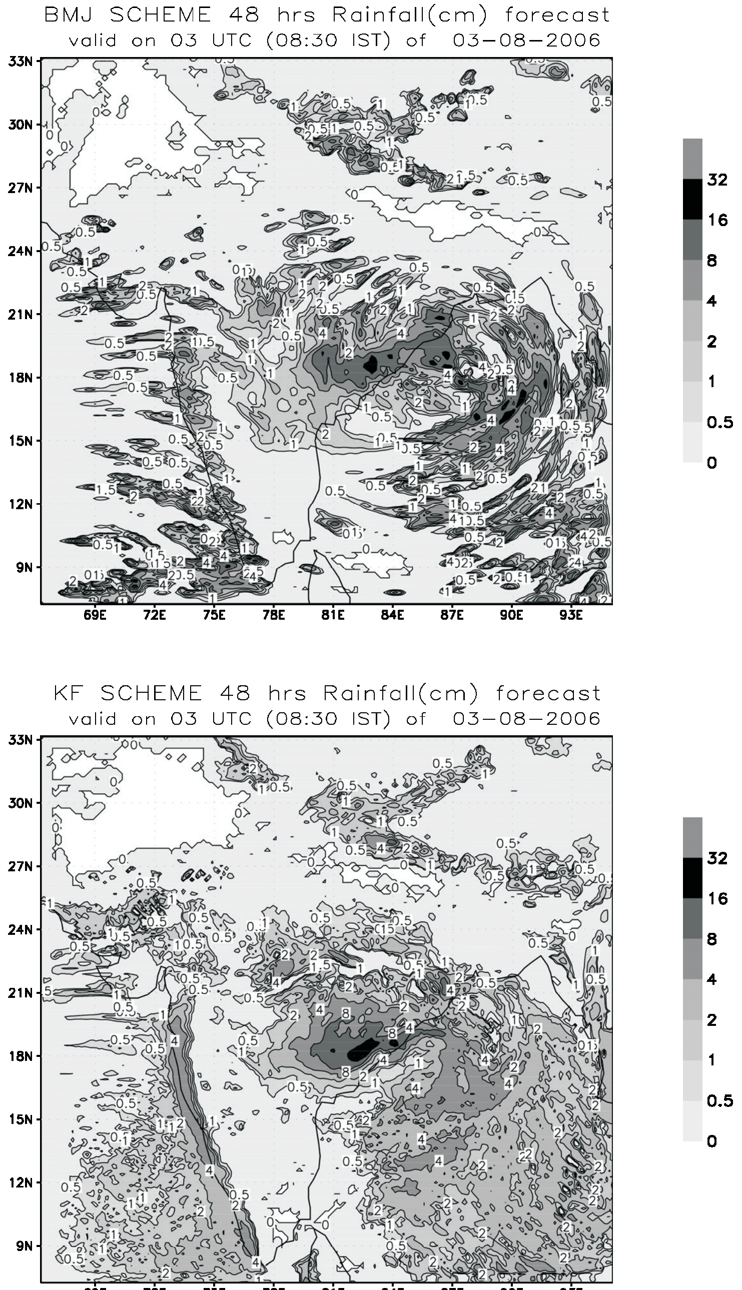


Figure 12. a) BMJ scheme for 48 hours rainfall (cm) forecast valid for 3 August 2006.
b) KF scheme for 48 hours rainfall (cm) forecast valid for 3 August 2006.
c) GD scheme for 48 hours rainfall (cm) forecast valid for 3 August 2006.

c)

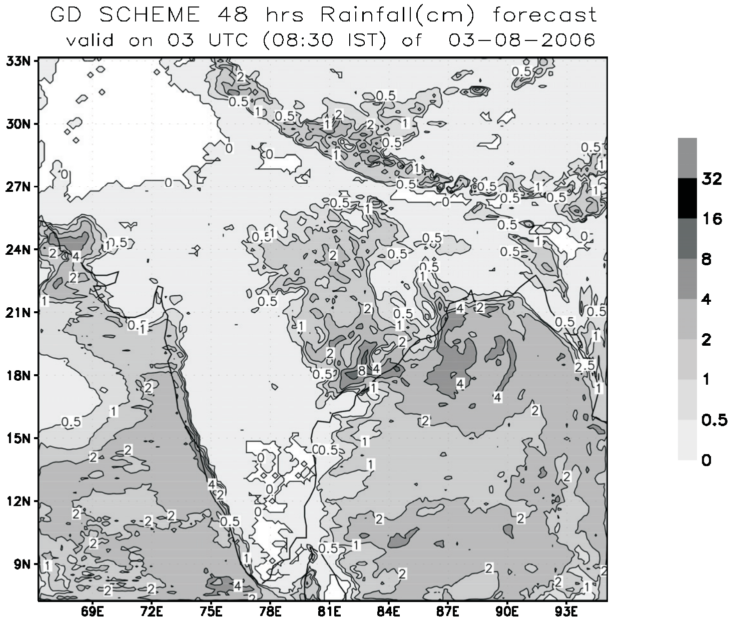


Figure 12. Continued.

CP scheme of KF and GD which are based on certain assumptions of CAPE may not be that relevant in case of monsoon depression. Whereas the BMJ scheme which is based on convective adjustment assumption is more relevant for the case of monsoon depression.

4.2 Experiments with PBL options

The model is again tested for the depression of July 2006 (case-1) with two different PBL schemes namely, MYJ and YSU. In these experiments, CP option BMJ is used. Fig. 13 (a, b) shows corresponding 24 hours forecast rainfall valid on 2 July 2006. The result shows that the MYJ scheme is able to capture the maximum rainfall along the west coast around 18° N. Rainfall prediction by MYJ scheme along the west coast varies from 2 to 16 cm which is similar to observed rainfall (Fig. 3). Similarly heavy rainfall along the east coast of India is well predicted by this scheme. This scheme performed well for 24 hours forecast. It is seen from Fig. 13 (b), that rainfall predicted by the YSU scheme along the west coast varies from 2 cm to 8 cm. The spread of heavy rainfall along the west coast is less as compared to MYJ scheme. This scheme underestimates rainfall along the east coast as compared to MYJ scheme.

Fig. 14 (a, b) shows the performance of both PBL schemes for 48 hour forecast valid on 3 July 2006. From Fig. 14 (a) it is evident that MYJ scheme produces rainfall in the range of 2 cm to 32 cm near the latitude 17° N, and 2 cm

a)

b)

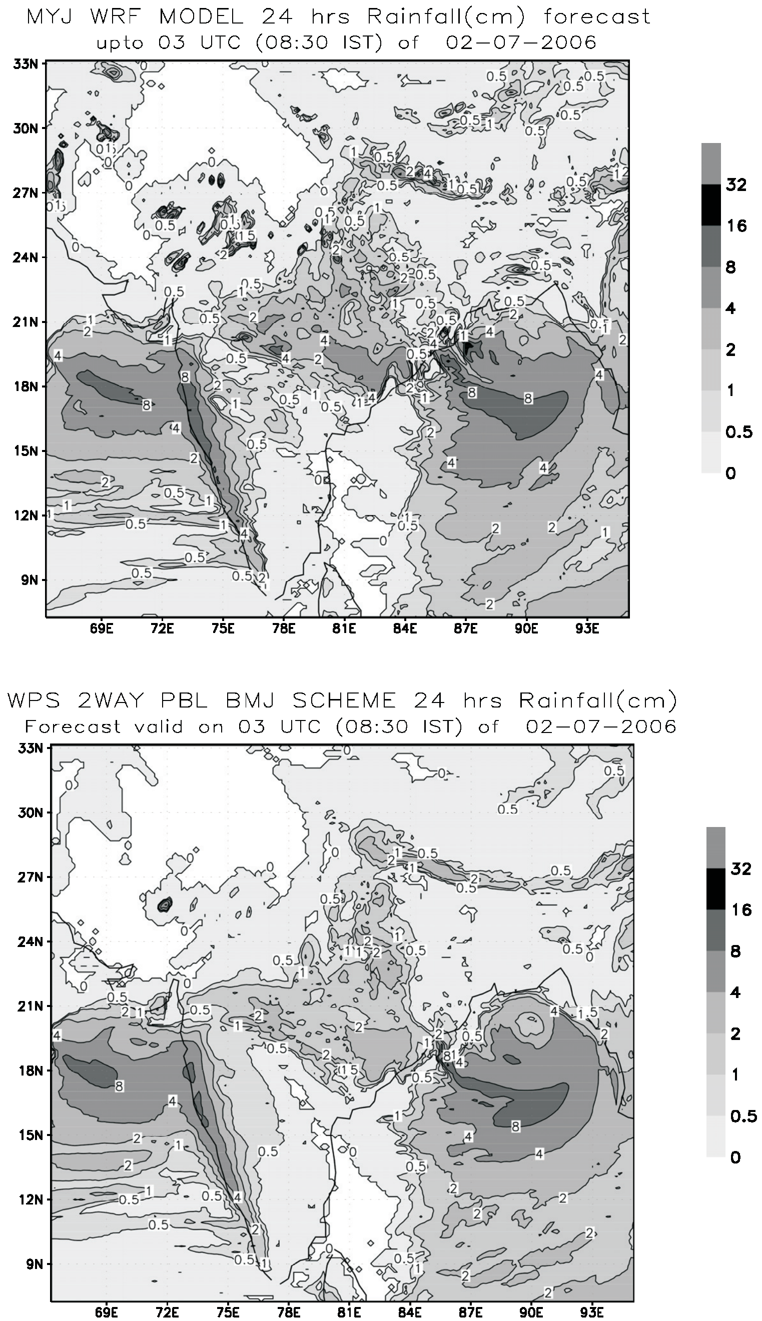
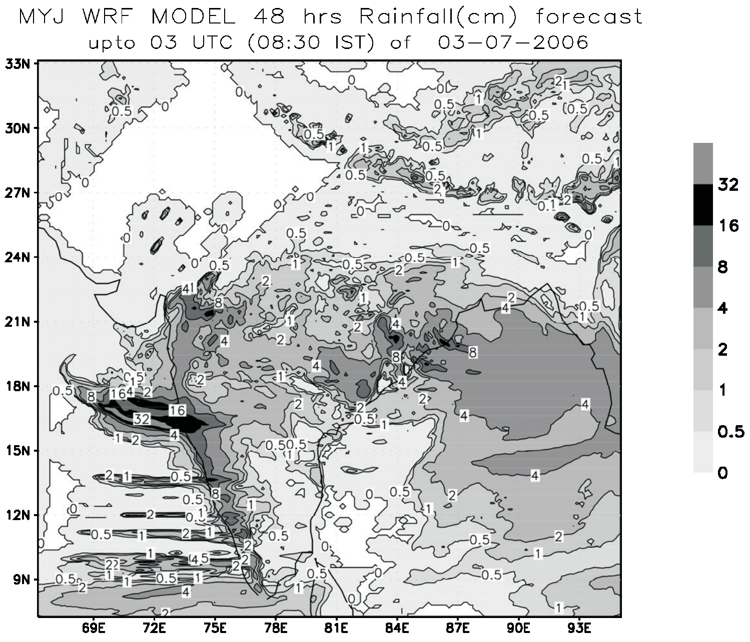


Figure 13. a) MYJ PBL scheme for 24 hours rainfall (cm) forecast valid for 2 July 2006.
b) YSU PBL scheme for 24 hours rainfall (cm) forecast valid for 2 July 2006.

a)



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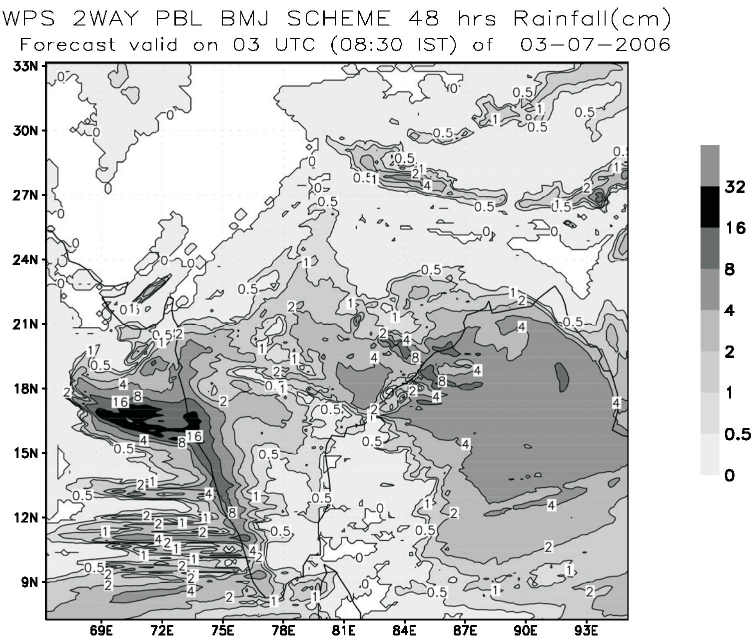

Figure 14. a) MYJ PBL scheme for 48 hours rainfall (cm) forecast valid for 3 July 2006. b) YSU PBL scheme for 48 hours rainfall (cm) forecast valid for 3 July 2006.

to 16 cm near the latitude 12° N, along the east coast rainfall produced by this scheme varies from 2 cm to 16 cm near 19° N. The observed rainfall along the east coast varies from 2 cm to 32 cm along the east coast. YSU scheme (Fig. 14 b) produces rainfall in the range 2 cm to 8 cm along the east coast near latitude 19° N, whereas rainfall produced by this scheme along the west coast varies from 2 cm to 32 cm near 16° N. Rainfall along the latitude 12° N produced by this scheme varies from 2 cm to 8 cm. From Fig. 14 (a, b) it is evident that YSU PBL scheme underestimates rainfall as compared to MYJ scheme. Same situation was repeated for 72 hour forecast (Results not shown here). The intercomparision shows that for 24 and 48 hour forecast MYJ PBL scheme performed better as compared to YSU scheme. Similar exercise is repeated for another run based on the initial condition of 2 August 2006. The results show that that MYJ scheme performs persistently better as compared to the other PBL scheme.

4.3 Track Prediction

Track of monsoon depressions produced by the WRF model has been compared against the observed track as finalized by IMD. For comparison of re-

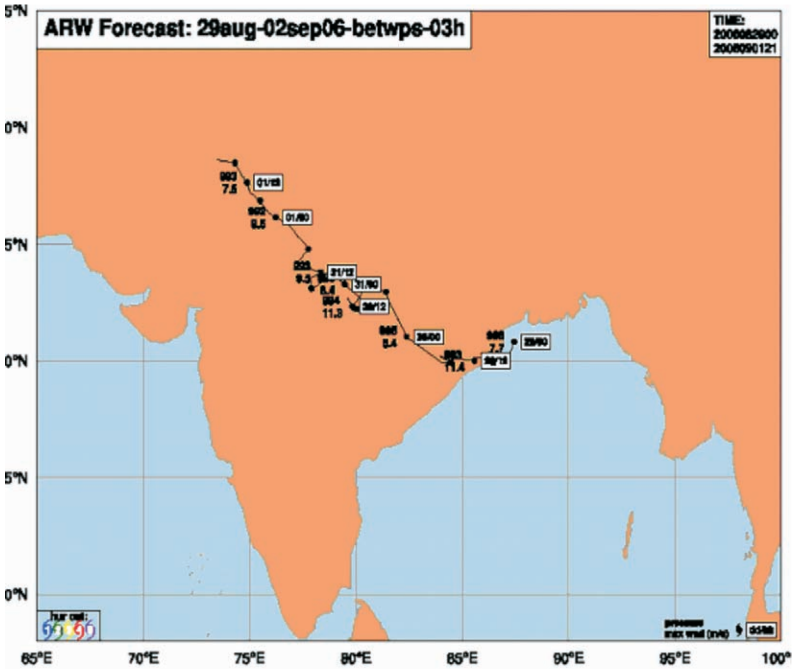

Figure 15. Forecasted tracks of the monsoon depression of 29 August to 1 September 2006 produced by the WRF model. Model run started from 00 UTC of 8 August 2006.

sults, the WRF model is run using CP scheme as BMJ and PBL as MYJ with the initial condition of 00 UTC of 28 August 2006, integrating 78 hours for the forecast up to 06 UTC of 1 September 2006. Fig. 15 shows the track produced by the WRF model for the period from 29 August to 1 September 2006. The result reveals that the forecast track was almost in good agreement with the observed track (Fig. 2c) and the model is capable of capturing the movement of monsoon depression for the forecast up to 78 hours.

5. Concluding Remarks

During recent years the WRF model has become very popular for studying meso-scale weather systems. It is mainly because of three reasons: (a) The model is very user friendly to select various physics options, (b) The model can be operated on a personal computer and (c) Freely availability of NCEP GFS outputs in the Internet to use as initial and boundary conditions. Before the model is used for operational applications, it is necessary to identify the best physics option applicable for the specific region, depending on the geographical, topographical and seasonal characteristics of synoptic and thermodynamical features. In this paper, this exercise is carried out over Indian region for the monsoon season 2006.

The study reveals that for the Indian monsoon domain rainfall forecast by WRF model is sensitive to the choice of cumulus scheme. Out of three cumulus options, the BMJ scheme is found to be relatively better compared to other two cumulus options. The scheme is capable to capture large scale as well as meso-scale features of monsoon precipitation system. The PBL option MYJ produced better rainfall forecast as compared to YSU scheme. The WRF model is capable to capture the movement of monsoon depression with a lead time up to 78 hours.

Better performance of BMJ scheme to reproduce more realistic rainfall forecast may be because of reference profiles it uses are closer to the observed one. It appears from the result of this study that CP scheme of KF and GD, which are based on certain assumptions of CAPE may not be that relevant in case of monsoon depression, where dynamic forcing is more dominant for rising of moist air. The BMJ scheme which is based on convective adjustment assumption appears to be more relevant for the case of monsoon depression.

It is worth to be mentioned that very recently IMD has implemented NCEP based GFS T382 with Grid Statistical Interpolation as the 3 DVAR data assimilation for the forecasts up to 7 days. Using the initial and boundary conditions of this model, WRF (ARW) with 3DVAR data assimilation scheme is made operational using two way nesting at the resolution of 27 km for the outer domain and at the 9 km resolution for the inner domain. Forecast products are made available in the IMD web site: www.imd.gov.in. The very high resolution WRF at 3 km resolution is made operational in the test mode at ten regional centres. The study reported in this paper could be expanded to identify the season as well as region specific best physics options for operational use at IMD.

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SAŽETAK

Procjena fizikalnih parametrizacija u WRF modelu prilikom simuliranja značajnih obilnih oborina nad područjem indijskog monsuna

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U radu se ispituju performanse WRF modela pri simuliranju obilnih oborina na području indijskog monsuna u vrijeme monsunske depresije za različite odabire fizikalnih shema. Napravljen je veći broj prognostičkih eksperimenata u trajanju do 72 sata, s dvije ugniježđene domene s rezolucijama od 45 km i 15 km. Studija pokazuje da je WRF model osjetljiv na izbor konvektivne sheme. Za područje indijskog monsuna Betts-Miller-Janjic (BMJ) kumulusna shema daje bolje rezultate u odnosu na druge kumulusne sheme. Model je uspio uhvatiti pomicanje monsunske depresije u trajanju do 72 sata. Model može biti vrlo koristan za područje indijskog monsuna u kratkoročnim prognozama prognozu oborine i putanja monsunske depresije.

Ključne riječi: WRF model, monsunska depresija, kumulusne konvektivne sheme.

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