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IMPACT OF CONVECTIVE PARAMETERIZATION SCHEMES ON THE SIMULATION OF PRECIPITATION OF THE SEVERE CYCLONIC STROM PHAILIN (2013): USING A HIGH-RESOLUTION MESOSCALE MODEL WRF ARW

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ABSTRACT

Numerical weather forecasting of tropical cyclones remains one of the most challenging tasks for numerical weather forecasters. This is because the complexity of numerical models, and the inability to account for all processes occurring in nature, means it is impossible to represent atmospheric events exactly by mathematical models. In present study we tried to investigate the sensitivity to three Convective Parameterization schemes for the Very severe cyclonic storm Phailin (9-14 Oct 2013) of Bay of Bengal using WRF (ARW) model and simulation of No Cumulus Parameterization (No Cu) was also undertaken to test model performance of simulating convection explicitly. All schemes were consistently performing better during the development phase, but as the cyclones matured the KF scheme showed cyclone as the most intense one. There was little separation between the KF, GD, and No CU schemes in terms of the central surface pressure and wind speeds of the simulated cyclones. The cyclone track in each scheme showed no variation in cyclone movement. Except the GD scheme all other schemes namely KF, BMJ, and No CU simulations all produced excess precipitation, especially in the eye wall region.

Keywords: Tropical cyclones, parameterization, precipitation, wind speed, surface pressure.

INTRODUCTION

Tropical cyclones are well known for their devastating nature, and are the most destructive of all-natural disasters in terms of loss of life as well as property. Each year, around 80-100 cyclones occur over the globe (Anthes 1982). Tropical cyclones were the most devastating of all-natural disasters because of the loss of human life they cause and the large economic losses they induce (Gray and Landsea, 1992). There are limitations in the understanding of the dynamics of the tropical atmosphere and the interaction of the tropical cyclone with its surrounding environment. However, a good prediction of the location of the landfall and intensity of the disaster a few days in advance is highly desirable for the planning and implementation of the mitigation measures effectively. With the advancements in high performance computing, and development of nested high-resolution mesoscale models MM5 and WRF the numerical forecasting of tropical cyclones has entered a new phase. The Weather Research and forecast (WRF) model has been developed with better dynamics and physics. Similarly, there are numerous literature/reports evaluating the performance of the Advanced Research WRF (ARW) on various weather phenomena. Michalakes *et al*. (2004) and Skamarock *et al*. (2008) exhaustively explained the equations, physics parameters, and dynamic parameters available in the WRF model. Gilland and Rowe (2007) made a comparison of cumulus parameterization schemes in predicting warm season convection using WRF model. Haghroosta *et al*. (2014) used a suit of physics parameterization options from the WRF model to investigate the performance of this same model in predicting selected parameters, with simulations relating to typhoon Noul in the South China Sea. The ARW model sensitivity to different initial and boundary conditions (Mohanty *et al*., 2010) over the NIO and its performance in capturing the special features of TCs like re-curvature (Pattanaik and Ramarao, 2009) is also studied. Chandrasekhar and Balaji (2012) also investigated the sensitivity of numerical simulations of tropical cyclones to physics parameterizations, with a view of determining the best set of physics options for prediction of cyclones originating in the North Indian Ocean. In the proceeding review shows that the Convective parameterization is one of highly complex processes though an essential component of numerical modelling. The choice of Convective parameterization scheme is important for the environment for which it is being modelled, and for producing a reliable forecast. In the case of tropical

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cyclone, the way convection is accounted for is crucial to the dynamics of the system. The main objective of this study to examining the Impact of convective parameterization schemes on the simulation of precipitation of the tropical cyclones and investigate the parameterization implications for the model forecast. This study made to investigate the sensitivity of model to three CP schemes for the Very severe cyclonic storm Phailin (9-14 Oct 2013) occurred in the Bay of Bengal using WRF ARW Model and simulation of No Cumulus Parameterization (No Cu) was also undertaken to and resolving the convective effects to test the Model performance of simulating cyclone in convection explicitly with the 9km horizontal resolution.

Description of the System

Description of the System is obtained from the IMD's report (http://rsmcnewdelhi.imd.gov. in/images/ pdf/publications/preliminary-report/phailin.pdf). A Very Severe Cyclonic Storm (VSCS) PHAILIN is originated in the Bay of Bengal as the remnant cyclonic circulation from the South China Sea. The Cyclonic circulation formed as a low-pressure system over Tenasserim coast and further intensified into well-marked low-pressure system over north Andaman Sea on 7^{th} October. Then it concentrated into a depression over the same region on 8^{th} October and Moving west-north-westwards, intensified into a deep depression on 9^{th} morning and further developed into a cyclonic storm (CS), and named as 'PHAILIN' for the same day evening the Kalpana-1 visible Satellite imagery at this stage is shown in Figure 1. The Cyclonic Storm PHAILIN Moving north-westwards, it further intensified into a severe cyclonic storm (SCS) in the morning and into a VSCS in the forenoon of 10^{th} October shown in (Fig. 1b) over East Central Bay of Bengal. The VSCS PHAILIN is Crossed the Odisha Coast on 12^{th} Oct, lay cantered at 19.0°N and 84.9°E is shown in Fig 1c at the time of Landfall the system attains the maximum sustained surface wind speed was about 115 knots and the central surface pressure was 940hPa with a pressure drop of 66hPa at the centre compared to the surroundings. It caused very heavy to extremely heavy rainfall over Odisha leading to floods, and a strong gale wind leading to large scale structural damage and storm surge leading to coastal inundation over Odisha.

MATERIALS AND METHODS

Experimental Design and Data used

In the present study Weather Research and Forecast (WRF/ARW Version 3.5) model (Wang *et al*., 2010) is used for the simulation of VSCS Phailin with different cumulus convection schemes. Three Convective parameterization schemes, the KF, BMJ, and GD ensemble, were used to examine precipitation resolving processes and test model sensitivity. A simulation of explicit convection (No Cu) was also undertaken to test model performance without the use of Convective parameterization. The model is designed to simulate with the high resolution domain of 9 km (Fig. 2) resolution covering the Bay of Bengal region. The model is integrated for a period of 144 hours. The initial, boundary conditions are derived from NOAA NOMADS GFS data (Table 1). 32 sigma vertical levels are used extending from 1000 hPa to 100 hPa. All the experiments were conducted with physical parameterization schemes of Mellor-Yamada local closure (TKE) scheme, for Planetary Boundary Layer (PBL) Turbulence (Janjic 1990). Thermal diffusion scheme for the land surface processes (Dudhia, 1996), Lin scheme for microphysics (Lin *et al*., 1983), Dudhia/ RRTM schemes for shortwave/long wave processes respectively all the details has given in Table 1. The initial and boundary conditions are taken from GFS high resolution data set in NOMADS (NOAA Operational Model Archive and Distribution System), This is available at 0.5x0.5 degree resolution with 3 hr forecast interval. The model topography and land cover for the 9 km domain regions are obtained from the USGS 5', 2' and 30" data sets. In this study all the simulations have been performed on DESKTOP PC with 8GB RAM in an Intel I3 processor, in a LINUX environment. With the available computational facilities, the experiments of the areas are limited. Due to the Less computational abilities in this study the high resolution 9km domain is used.

The observations of Central Sea Level Pressure (CSLP) and Maximum Sustained Wind (MSW) data were obtained from India Meteorological Department (IMD) annual report. Simulated cloud spatial distribution was compared with the Kalpana-1 satellite images which were obtained from IMD reports. Model track positions and intensity parameters (CSLP, MSW) were compared to the IMD track positions data. The observations of rainfall were taken from the Tropical Rainfall Measuring Mission (TRMM) satellite for comparison with the model simulated rainfall. The daily TRMM data (3B42_V7) is available at a spatial resolution of 0.25^0 x 0.25^0.

RESULTS AND DISCUSSION

A high resolution nested domain of 9 km grid resolution was used in this experiment to study the dynamics and structure of cyclone at the most mature stage. Cyclone intensity is measured in terms of central surface pressure and wind speed. The variation of each scheme is good indication of how different convection schemes affected the spin up of cyclone at various stages.

The model predicted Mean Sea Level Pressure (MSLP) and Maximum Sustained Wind speed (MSW) are shown in Figure 3a,b. In the Figure 3a it is clearly seen that, at the initial stage i.e., 12 hours of forecast time there is only 2-3 hPa difference between each of the scheme. After 30 hours of the simulation the spread of MSLP is quiet evident there is 25hPa differences between the KF and GD, where as the difference between the BMJ and No CU were of the order of 12hPa. The period of intensification which led to mature stage is quite different for each simulation. The performance of convection schemes is compared to the observed MSLP provided by India Meteorological Department. In the development stage of all the schemes are show a reasonable skill. In the mature stage the KF scheme showed an intensification of 924hPa maximum on 0600 UTC of 12/10/2013. While the other three schemes the maximum intensification is 978hPa of 0900 UTC on 12/10/2013 with GD scheme, 958hPa of 21UTC on 12/10/2013 with BMJ scheme and with the No Cu scheme the maximum intensification is 937hPa on 21UTC of 12/10/2013. With the result the KF scheme produced the deepest simulated central surface pressure 924hPa. All the simulations showed an increase of MSLP at the end of forecast which is indicated dissipation after attaining mature stage, of the all four experiments the KF and NOCU near realistic values to the observed MSLP. The results of simulated wind speed (Figure 3b) showed a similar pattern to that of simulated pressure. Firstly, during the development stage, the KF, No Cu, BMJ and GD simulations were in close agreement. These schemes were similar for the first 18 hours and after 24 hours the KF and No Cu schemes varied in speed by 3 to 4 ms^{-1}, although the GD scheme had fallen slightly. The KF predicted an increase in its wind speed of 4-5 ms^{-1}every 6 hours, and reaches a maximum of 80ms^{-1}, as such was the most intense cyclone. The comparison of trends in the simulated wind to those of the observed wind revealed that the model was unable to match observed wind after 24 - 30 hours of simulation.

Track Prediction

The track of the tropical cyclone is much important at the mature and land fall stages for the devastation the location of the maximum rainfall is depends upon the Tropical Cyclone Movement. Track of the Tropical Cyclone Phailin with different convection schemes is compared to the IMD Observed track is shown in Figure 4. the mean track path of the Phailin cyclone and the simulated tracks for each scheme is not much variation at the initial and mature stages the three schemes have showed the North West ward displacement which is in agreement to the observations. The KF, GD and BMJ scheme initially performed well, and was the closest to the observed after 42 hours. At the time of land fall KF and GD makes fewer errors compared with the BMJ schemes. No CU predicted track deviated much showed a much more North ward movement, making each rather inaccurate. The NO CU is showing the much errors and the it is more displacement towards north is the landfall time and showing more rainfall in the South East sector the other convective parameterization schemes are showing SW sector at mature stage.

Convective Parameterization analysis

Having described the effects of the schemes with MSLP and Maximum sustained wind speed, it is time to examine how each convective parameterization schemes performed in relation to CAPE and Precipitation. CAPE is the amount of potential energy available to accelerate a parcel vertically, and is an indicator of atmospheric instability. This is important for tropical cyclogenesis, as an unstable environment will assist convective development. The results of simulated CAPE at the mature stage with all CP schemes are shown in Figure 5 a-d.

The evolution of the vortex is described at the mature stage of all simulated experiments. This is obtained up from the profile of the MSLP where the value attained is Minimum.

The GD scheme produced a strong rotational vortex at the mature stage in Figure 5(a). The eye was close to neutral stability, with the air mass resolved to be marginally unstable, with a CAPE value of 400 J/ kg. The outer edges of the domain to the east were found to have very unstable air, but this was limited and appeared to be having minimal influence on the cyclone. The circulation was weak and slowly rotating.

The CAPE environment in the BMJ case (Fig. 5b) was significantly more unstable air at the centre of the cyclone. The BMJ scheme represents the CAPE rich environment (2400 J/kg) that produced considerable potential energy for convective development.

The KF Scheme at mature stage (Fig. 5c) is contrast to the GD and BMJ schemes. The centre of eye is marginally unstable. A marginally unstable air is quite common in the tropical cyclone (Anthes, 1982). In the North West periphery of the cyclone is very unstable with a CAPE value of 2700 J/kg. This reflects that the energy is still available from the ocean. This simulation shows that air is flowing north of the cyclone.

The CAPE environment with NOCU in Figure 5d which is similar to that of KF at the mature stage. The centre of the eye was unstable air, at the Northern periphery of the cyclone having the most unstable air with the CAPE is excess of 3000J/kg.

The results of CAPE for the mature stage show the quite differences in the amount and distribution of Potential energy in the cyclone environment for each Convective Parameterization scheme.

Precipitation analysis

The rainfall totals for one hour during mature stage of four experiments is shown in Figure 6a-d. All the schemes show reasonable representation of common precipitation characteristics at the mature stage of the cyclone Phailin. An eye of little to no precipitation was simulated, with a region of heavy precipitation adjacent to the eye representing the eye wall. The rate of precipitation of the eye wall appears to be reasonably similar in the KF, No Cu and BMJ, but not in the GD. It is evident that a maximum hourly total between 30-60mm was simulated by the KF, GD, and No Cu schemes, with only the extent of maximum precipitation coverage varying. While comparing the above values to the TRMM observations (Fig. 7a-c) at the mature phase i.e;12 OCT 2013 (Fig. 7 b), it is clear that the KF, No CU and BMJ schemes have predicted excessive precipitation in the eye wall. This would indicate that these CP schemes were over-active in this environment, and have failed to control the amount of cloud development by the Precipitation Convective Parameterization (PCP) scheme. Finally, while the GD scheme may not have resolved cyclone structure well, it appeared to be the most accurate CP scheme for the high-resolution domain. The rainfall totals for one hour (Fig. 7 b) are quite accurate when compared to the TRMM observations at the mature stage. When examining the area coverage of the cyclone itself, however, the KF prediction is significantly greater than all others. Indeed, a more significant eye wall and eye were simulated.

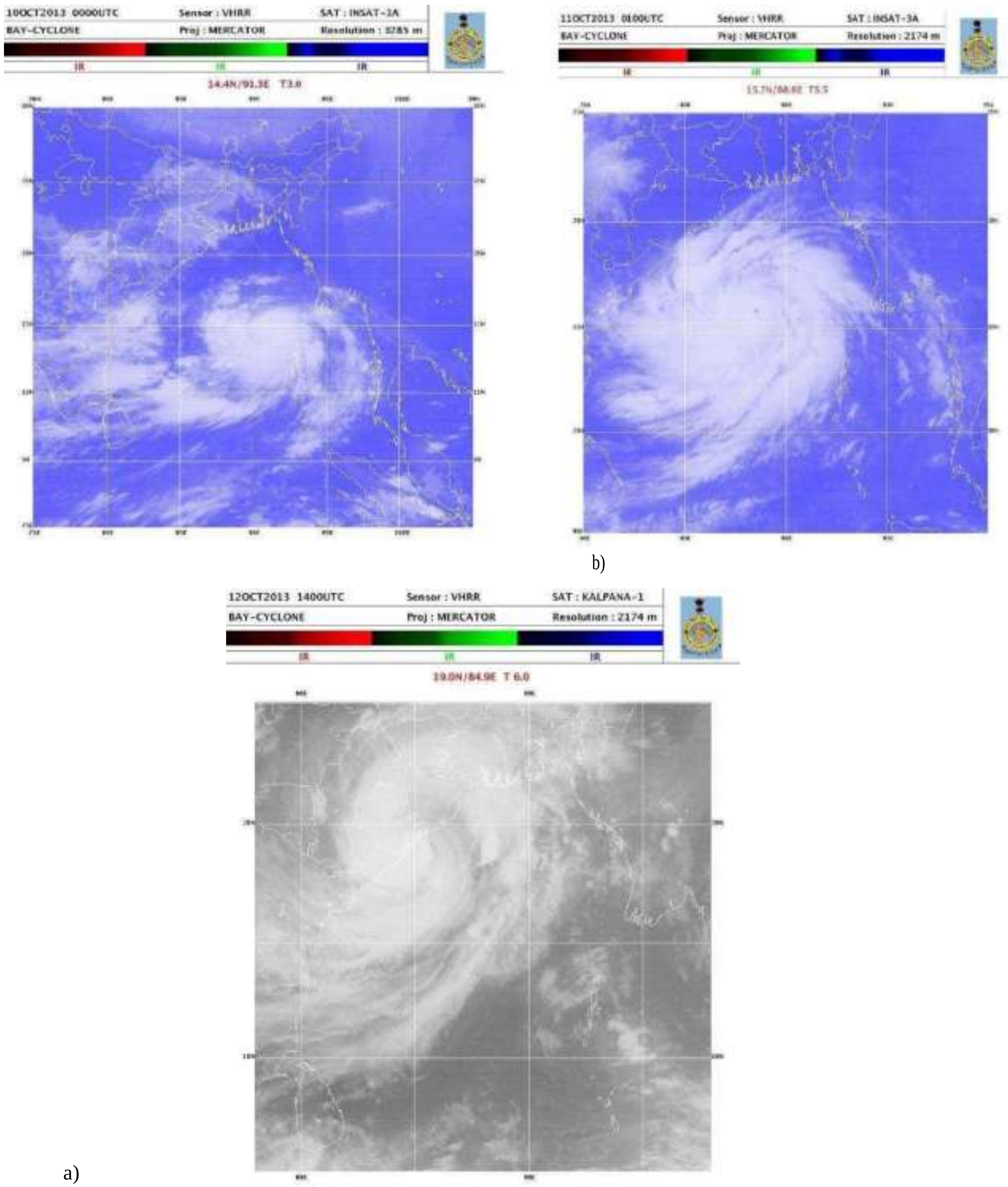
CONCLUSION

A summary of the CP experiments is given in Table 2. The KF, BMJ and No CU simulations all recorded excess rates of precipitation, whereas the GD simulation is realistic. The excess amount of instability removed from the environment by the KF and BMJ schemes, indicates that these CP schemes were over efficient. Modelling of convection explicitly in the No CU simulation also resulted in excess instability removal and over-vigorous convection. The GD scheme removed a realistic amount of instability in some regions, and was less efficient in other regions. In the article a study is made to investigation of three CP schemes for the Very severe cyclonic storm Phailin (9-14 Oct 2013) of Bay of Bengal. Three Convective parameterization schemes, the KF, BMJ, and GD ensemble, were used to examine precipitation resolving processes and test model sensitivity. A simulation of No CP scheme (No Cu) was also undertaken to test model performance of simulating convection explicitly.

The results of the Mean sea level pressure and wind speed indicate that the GD scheme was found to be the weakest of all simulated cyclones. All schemes were consistently performing better during the development phase, but as the cyclones matured the KF cyclone became the most intense. There was little separation between the KF, GD, and No CU schemes in terms of the central pressures and wind speeds of the simulated cyclones. The cyclone tracks for each scheme show that no variation in cyclone movement. The three schemes have showed the North West ward displacement which is accurate to compare with the observed track. The results of CAPE for the mature stage show the quite differences in the amount and distribution of Potential energy in the cyclone environment for each Convective Parameterization scheme. Except the GD scheme The KF, GD, and No CU simulations all produced excess precipitation, especially in the eye wall. The KF, BMJ, and No CU simulations all produced well developed cyclones at the maturity stage. In detail, an eye, eye wall, and feeder bands appeared to be present. Despite the GD scheme producing the most accurate precipitation rates throughout the simulation, it failed to accurately predict the intensity of the Cyclone.

Table 1. Brief description of WRF model configuration.

Model	WRF V3.5
Model type	Primitive equation, Non-hydrostatic
Map Projection	Mercator
Initial Time of Integration	00UTC of 9^{TH} OCT 2013 for all convective schemes
Domain	Lat:4N-26N; Lon: 76E-99E
Resolution	9KM
No. Of Vertical levels	32 σ Levels
Radiation Scheme	Dudhia's short wave/RRTM long wave
PBL Scheme	Yonsei-University (YSU) scheme
Convection	Grell–Devenyi, Betts Miller Janjic, and Kain-Fritsch
Micro Physics	Lin *et al*. Scheme



a) b) c)

Fig. 1(a-c): Satellite images during cyclone Phailin on
a) 10th OCT 0000UTC
b) 11th OCT 0700UTC
c) 12th OCT 1400UTC 2013.

Table 2. Summary of CP scheme Performance.

Scheme	Type of Scheme	Closure adjustments	Precipitation Rate(mm/hr) at mature stage	Overall CP scheme performance
KF	Mass-Flux	CAPE removal	44-70	Exercise; Over-active — KF scheme removed too much instability which resulted in excess
BMJ	Adjustment	Sounding adjustment	30-42	Excessive; Over-active — KF scheme removed too much instability which resulted in excess precipitation
GD	Mass-Flux	Various — CAPE, moisture convergence, vertical velocity	10-25	Realistic; Mixed — CP realistic in some regions; underactive in others. In under-active regions the PCP was unable to produce deep convection.
No Cu	Explicit	None (direct representation)	32-55	Excessive; Explicit convection removed too much instability which resulted in excess precipitation

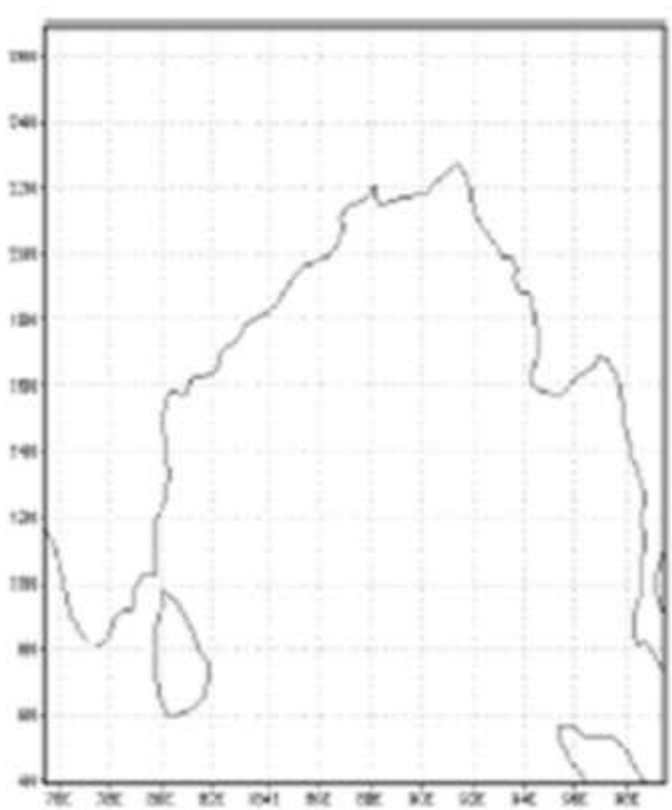
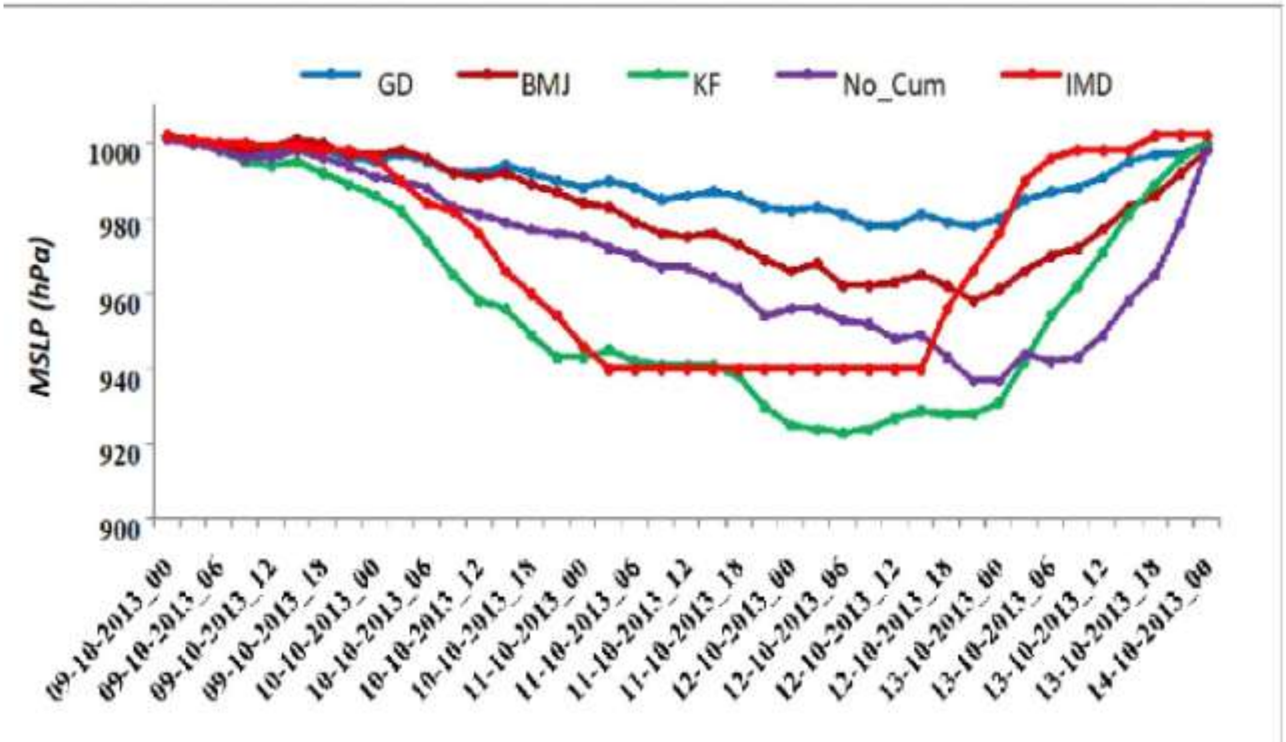


Fig. 2. Domain Study.



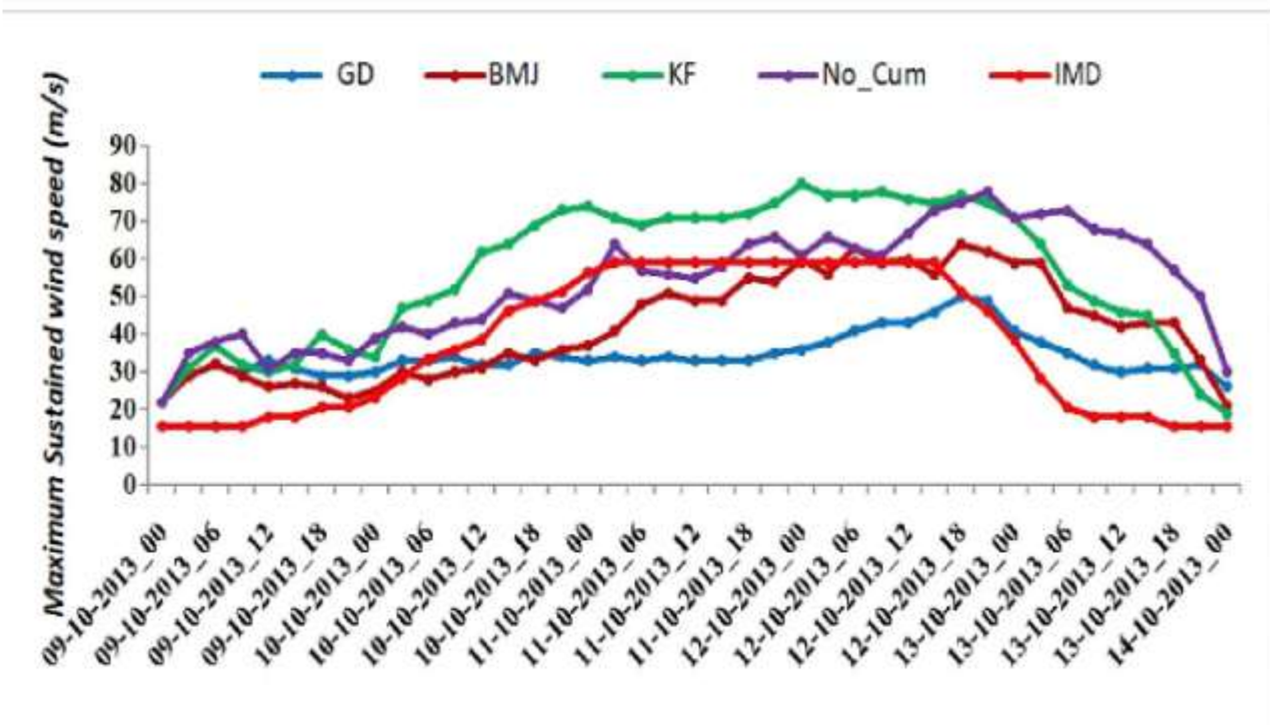


Fig. 3a,b. Time variation of Minimum Sea Level Pressure and Maximum wind speed with 9 km horizontal resolution.

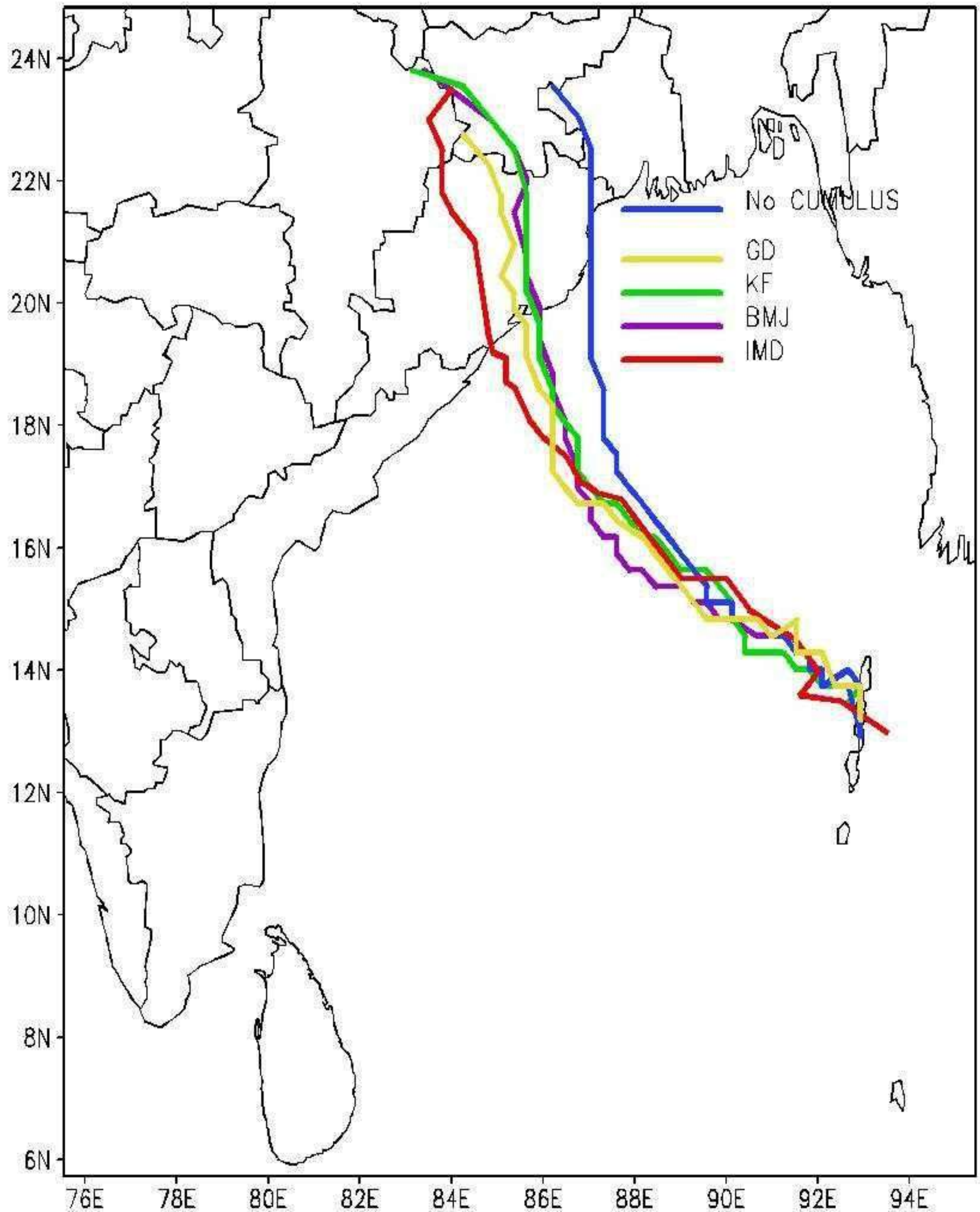


Fig. 4. Comparison of tracks on simulations with different CP schemes to that of the IMD Observed track.

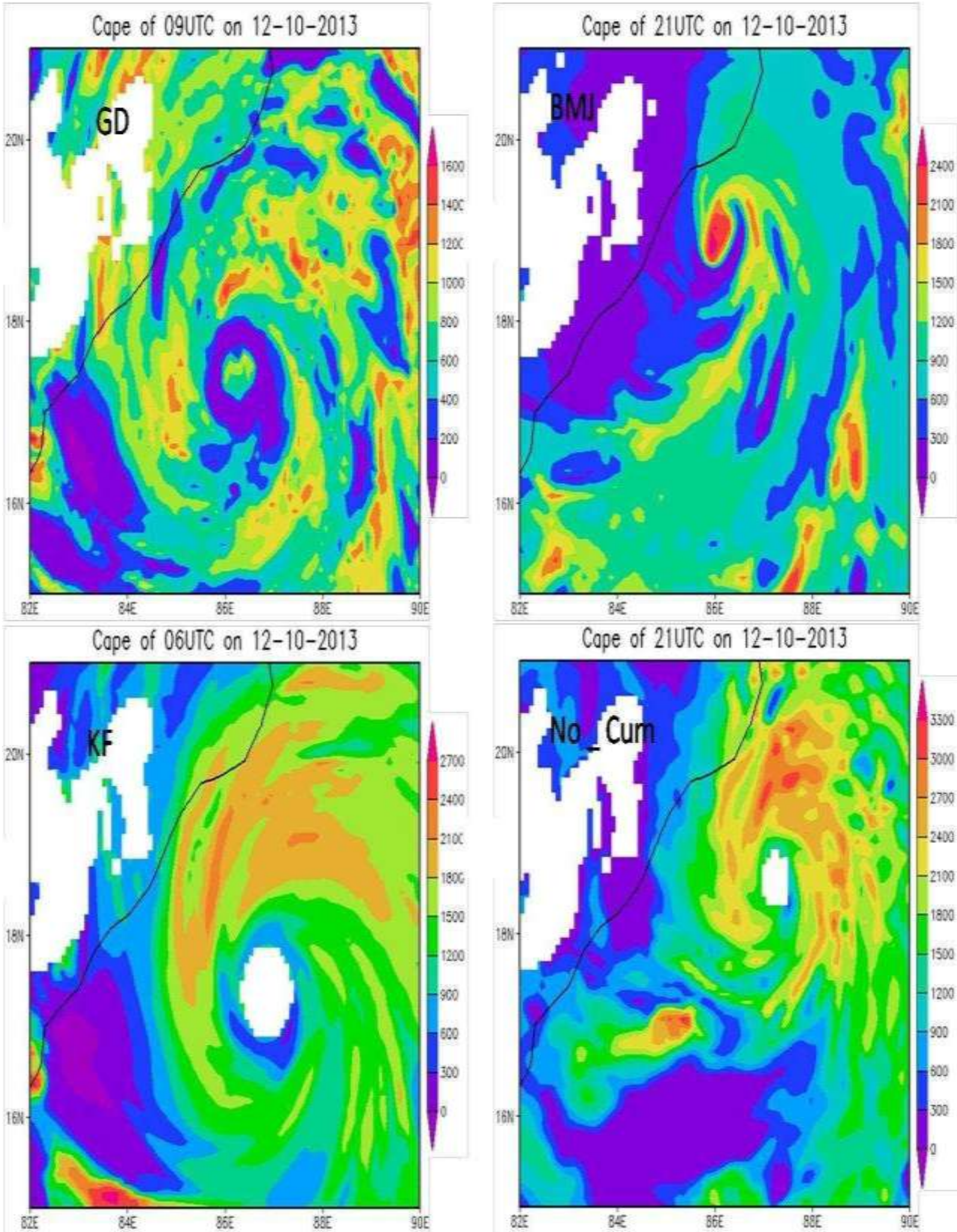


Fig. 5. Simulated CAPE in J kg-1 during the maturity phase for (a) GD at 09UTC on 12/10/2013 (b) BMJ at 21UTC on 12/10/2013 (c) KF at 06UTC on 12/10/2013, and (d) No Cu at 21UTC on 12/10/2013.

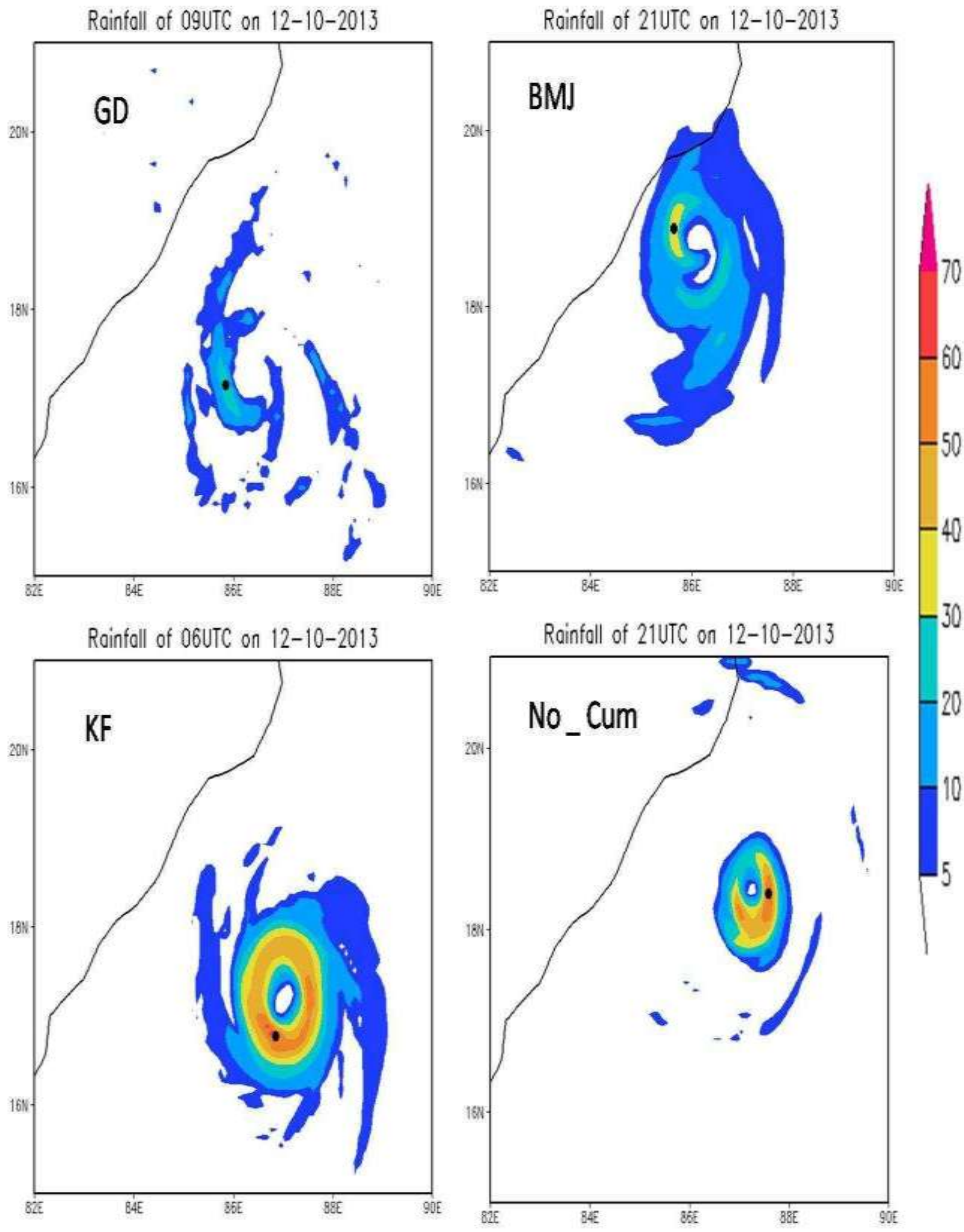


Fig. 6. Simulated rainfall total for one hour during the mature stage for (a) GD at 09UTC on 12/10/2013 (b) BMJ at 21UTC on 12/10/2013 (c) KF at 06UTC on 12/10/2013, and (d) No Cu at 21UTC on 12/10/2013.

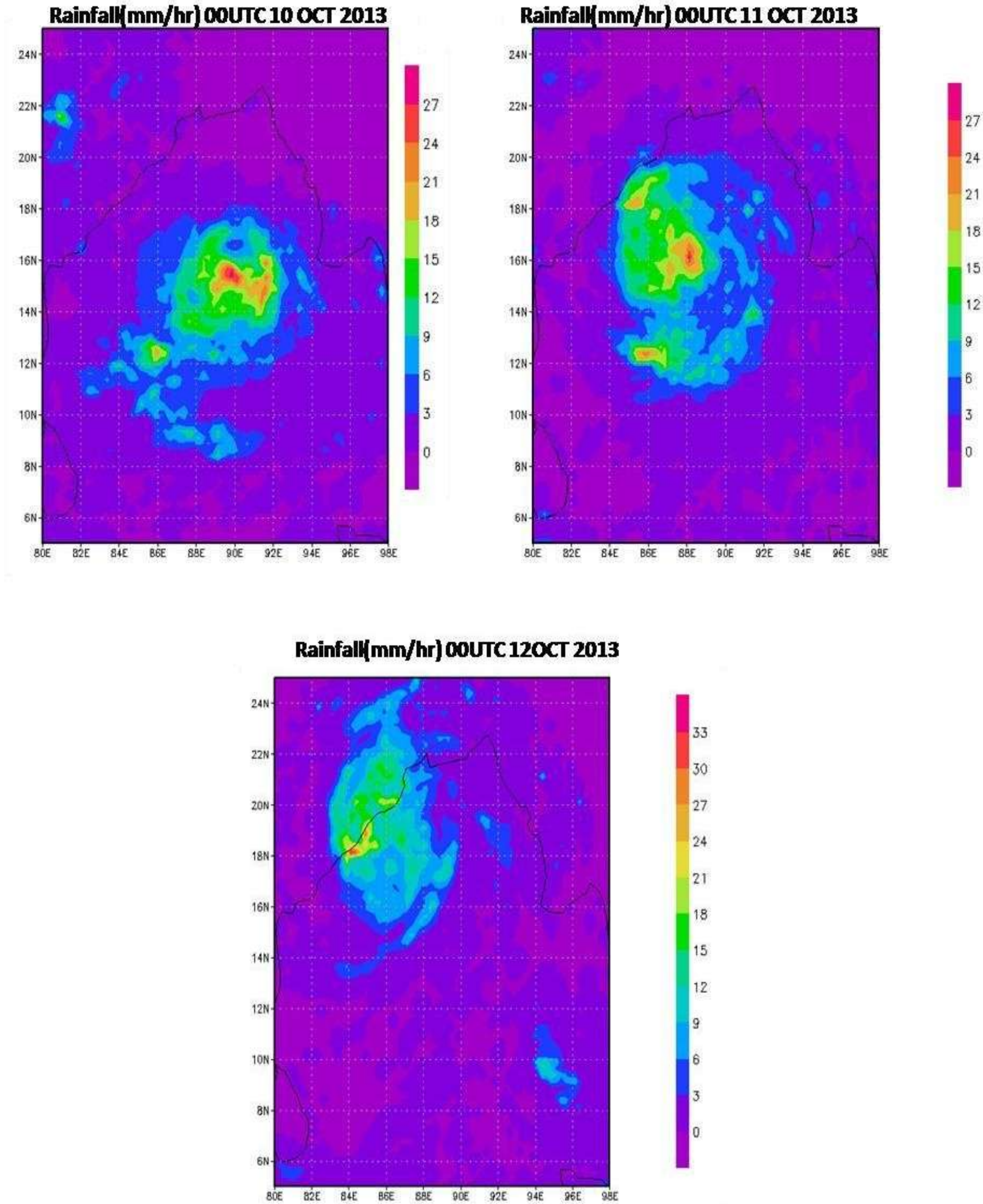


Fig. 7. The TRMM rainfall(mm/hr) for initial (10 OCT 2013) b) Mature stage (11 OCT 2013) c) landfall (12 OCT 2013).

Abbreviations

ARW	Advanced Weather Research Prediction
BMJ	Bettes Miller Janjic
CAPE	Convetive Available Potential Energy
CP	Convective Perameterization
EU	Eulerian Mass
ESRL	Earth System Research Laboratory
GD	Grell Devenyi
IMD	India Meteorological Department
KF	Kain Fritsch
MSLP	Mean Sea level Pressure
MSW	Maximum Surface Wind Speed
MRF	Medium Range Forecasting
MYJ	Miller- yemada- Janjic
MM5	Mesoscale Model
NCEP	National Center for Environment Prediction
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NO CU	No Cumulus Parameterization
NOMADS	NOAA Operational Model Archive and Distribution System
WRF	Weather Research Forecast

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