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SIMULATION OF ENVIRONMENTAL HEAVY RAINFALL EPISODES DURING JUNE AND JULY 2006 – A CASE STUDY

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ABSTRACT

Mesoscale systems play an important role in giving heavy rainfall episodes across India during the onset phase of southwest monsoon; these incidents are very crucial to start agriculture operations. An attempt is made in this numerically simulated study to identify intense environmental precipitation events due to mesoscale systems using a high-resolution mesoscale model (MM5) over some parts of Andhra Pradesh during 29 June to 4 July 2006. In this model authors made use of Grell cumulus parameterization, Medium Range Forecast (MRF) Planetary Boundary Layer (PBL), Explicit micro physics and five layer soil schemes are used. The model results highlight that the simulated heavy rainfall events over the study region are predicted promisingly and it is upto 80% of observational data; these rainfall amounts are further compared with 3B42RT precipitation data. Thus MM5 control simulation indicates that the intense precipitation is due to advected warm moist air at low levels onto the coast and is enhanced by the formation of a meso-beta scale low-pressure system just off the East Coast of India.

Keywords: Mesoscale systems, MM5, Onset, rainfall, convection

INTRODUCTION

The Indian community generally regards rainfall as the most prime meteorological parameter, which has socio-economical importance and its observations are needed to support a range of services extending from prediction of flood events to climatological studies of drought. The environmental mesoscale monsoon disturbances are characterized by frequent heavy to very heavy rainfall events (24 hours rainfall ≥ 125 mm) leading to floods over different regions of India in general and Andhra Pradesh (AP) in particular in the Onset phase to start agricultural operations. Dhar and Nandergi (1993 and 1993a) have pointed out severe rainstorms events, which do not occur uniformly over India during southwest monsoon season. The monsoon rainfall received from meso-scale weather systems at many locations can range from 125 mm to 900 mm in one day, which can have sizable contribution to their total annual rainfall (Rakhecha and Pisharoty, 1996) and such occurrence of rainfall extremes has practical implications to water resources and dam design projects during the advance period of Indian summer monsoon.

There are several studies relating to different aspects of Onset and advance of summer monsoon, which are very pivotal to start the agricultural operations throughout the country. The Onset of monsoon in meteorological parlance has been associated with the heralding of monsoonal rains over the Kerala coast of India (Ananthkrishnan, 1988); mesoscale systems in the form of trough of low, Onset vortex and offshore vortex etc., play an important role in giving rainfall (normal to heavy). Though the normal date of Onset over Kerala coast is 1 June, it varies from 11 May in 1918 to 18 June in 1972. The Onset of monsoon is sometimes associated with the active phases of Madden-Julian Oscillation also. The maximum value of total precipitable water in the 10° N –15° N latitude zone is seen to appear 7–12 days prior to the monsoon Onset over Kerala coast for the formation of mesoscale systems. Surges in the strength of monsoon flow over central Arabian Sea are important parameters to be monitored in short range forecasting for the monsoon mesoscale activity including its Onset over India, while surges in the Bay of Bengal cause good amount of rain through mesoscale systems over coastal AP during Onset phase. There are several studies connecting to Onset and advance of monsoon features with mesoscale systems (Ramamurty and Keshavamurty, 1964; Pant, 1964, Ananthkrishnan *et al.*, 1968; Yadav and Kelkar, 1989; Kung and Sharif, 1980, 1982; Bhanu Kumar, 1981; Bhanu Kumar and Dey 1982; Sikka and Gadgil, 1980).

During the last two decades, weather forecasting all over the world has greatly benefited from the guidance provided by Numerical Weather Prediction (NWP). Significant improvement in accuracy and reliability of NWP products has been driven by advances in numerical techniques, explosive growth in computer power and by the phenomenal increase in satellite-based soundings. However, limitations remain in the prediction of severe weather events, which have a very short life but still cause

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extensive damage. The main objective of this paper is to simulate the severe rainfall episodes occurred during the Onset phase using the mesoscale model (MM5) in order to identify the factors relating to mesoscale systems contributing to the heavy rainfall events.

Study Area

Andhra Pradesh state situated on the east coast of India near the Bay of Bengal consists of three meteorological subdivisions namely coastal AP, Telengana and Rayalaseema (Fig. 1a). During the Onset phase some parts of study region normally receive normal to heavy rainfall events due to mesoscale systems traveling from the Bay of Bengal during June/July. Though the normal annual precipitation over Andhra Pradesh is 938 mm, the major portion of the rain (624 mm) is obtained during June through September. Generally summer monsoon advances over study region during second/ third weeks of June in every year; the monsoon advance shows pulsatory nature and it covers whole of India in three/four pluses during the Onset phase (Subbaramayya and Bhanu Kumar, 1978; Subbaramayya *et al*., 1984; Subbaramayya *et al*., 1987). A great proportion of variability of rainfall in Andhra Pradesh is related to the occurrence and intensity of extremely heavy rainfall events due to mesoscale systems. There is a pressing need to predict magnitude of heavy rainfall events over different parts of Andhra Pradesh for probable planning. Recent Mumbai heavy rainfall (94cm on 26-27th July 2005) episode in the monsoon period was simulated and discussed at length by many modelers and they suggested the pressing need to simulate similar rainfall events over the other parts of India during the summer monsoon season (Joseph, 2006; Kalsi, 2006; Gairola, 2006; Mohanty, 2006; Ashrit, 2006; Simon, 2006). Hence discussions on heavy rainfall events

Table 1. IMD rain gauge and model rainfall data (in brackets simulated heavy rainfall events).

Region	ID	Stations	IMD Rainfall (mm)					
			29 Jun	30 Jun	1 Jul	2 Jul	3 Jul	4 Jul
Coastal A.P	a	Komarada	20 (17)				190 (**150**)	
	b	Patapatnam				30 (24)	190 (**150**)	20 (13)
	c	Veeraghattam	20 (15)			20 (15)	150(**110**)	
	d	Palakonda	30 (24)			20 (17)	140(**100**)	
	e	Palasa				60 (49)	130(**100**)	
		Mandasa					110 (98)	
		Tekkali	50 (42)	80 (73)		20 (14)	110 (100)	
		Parvathipuram	60 (53)			20 (17)		
Telengana	f	Asifabad	20 (15)					190(**150**)
	g	Sirpur						170(**120**)
	h	Adilabad	70 (64)	50 (39)	20 (15)			125(**100**)
		Kaleswaram		50 (43)	20 (17)			100 (93)
		Banswada	50 (40)				30 (22)	10 (6)
		Sriramsagar	50 (44)	10 (7)	10 (6)			10 (8)

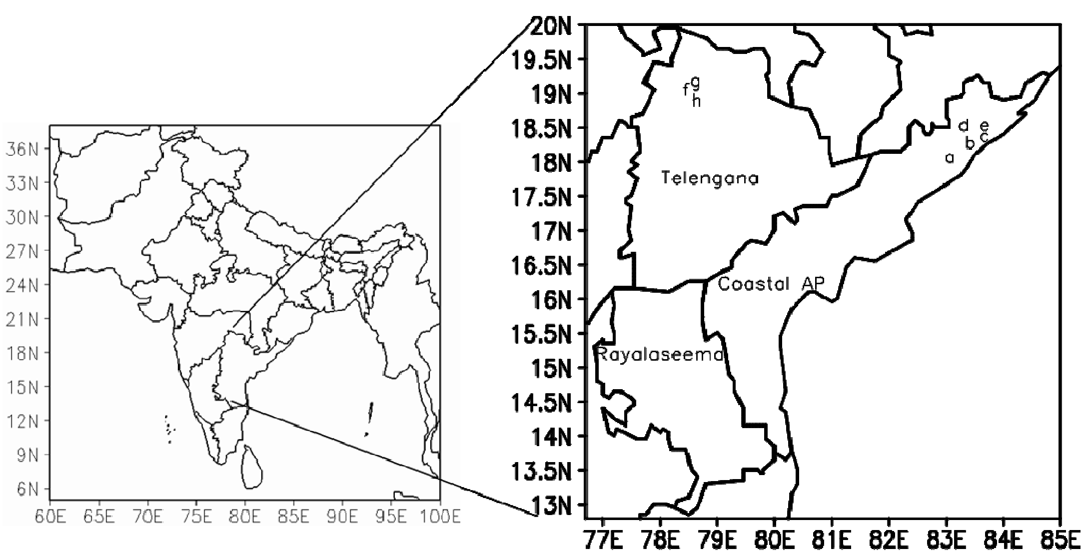

Fig. 1a. Study region with heavy rainfall episodes over different stations (Table 1) in Andhra Pradesh state of India.

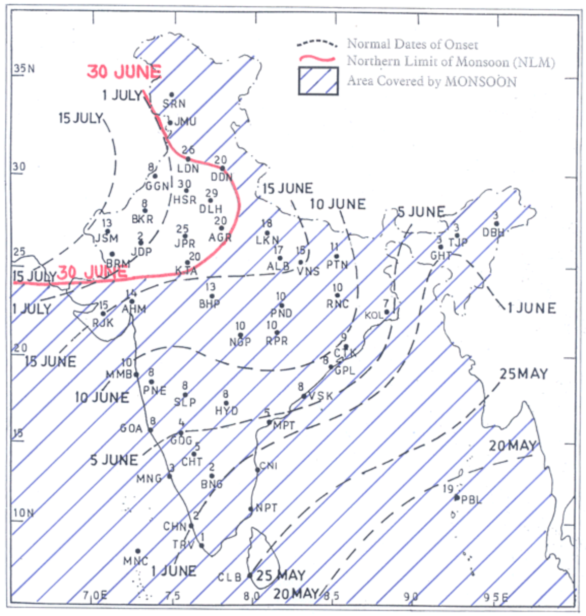

Fig. 1b. Onset dates and progress of Indian southwest monsoon from 26 May to 30 June (Source: India Meteorological Department).

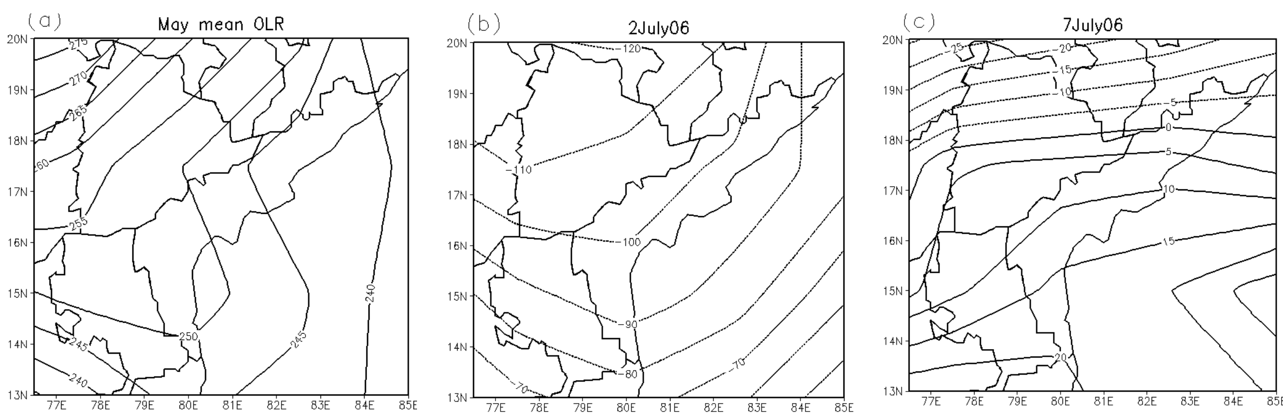

Fig. 2. (a) Mean monthly OLR distribution for May 2006; (b) & (c) Pentad anomaly of OLR during the study period over Andhra Pradesh.

are of paramount importance in the designing of water storage projects and agriculture point of view in Andhra Pradesh. So far there were no studies in this direction of identifying mesoscale systems and simulating heavy rainfall events during Onset phase. So an attempt is made to predict heavy rainfall events during Onset phase of monsoon over Andhra Pradesh.

Data and Synoptic evolution

The datasets used in this study are National Center for Environmental Prediction (NCEP) Final Analysis (FNL) model initialization fields (1°×1°) at 6 hr intervals, daily rain gauge data from the India Meteorological Department (IMD), TRMM-3B42RT merged precipitation data for the period 25 May to 5 July and NOAA pentad Outgoing Longwave Radiation (OLR) data starting from May to July 2006.

In this case study the date of Onset of monsoon over Kerala was 26 May 2006, which is six days earlier than its normal date. The northern limit of monsoon is shown in figure. 1b. Monsoon was very active during the first week of June. On first week of June a well marked low-pressure area was observed over North Bay of Bengal with associated upper-air cyclonic circulation extended up to mid-tropospheric levels; it further developed into a depression on 3 June and later it further strengthened into deep depression on 4 June. During this period isolated and extremely heavy rainfall (>250 mm) amounts were also noticed over Konkan & Goa (including Mumbai), Madhya Maharashtra and south Gujarat. But this area is not included in this study. Next, it is also observed that the period 29 June to 4 July leading to the catastrophic heavy rainfall events; monsoon was active over peninsular India. On this day an east-west shear zone in

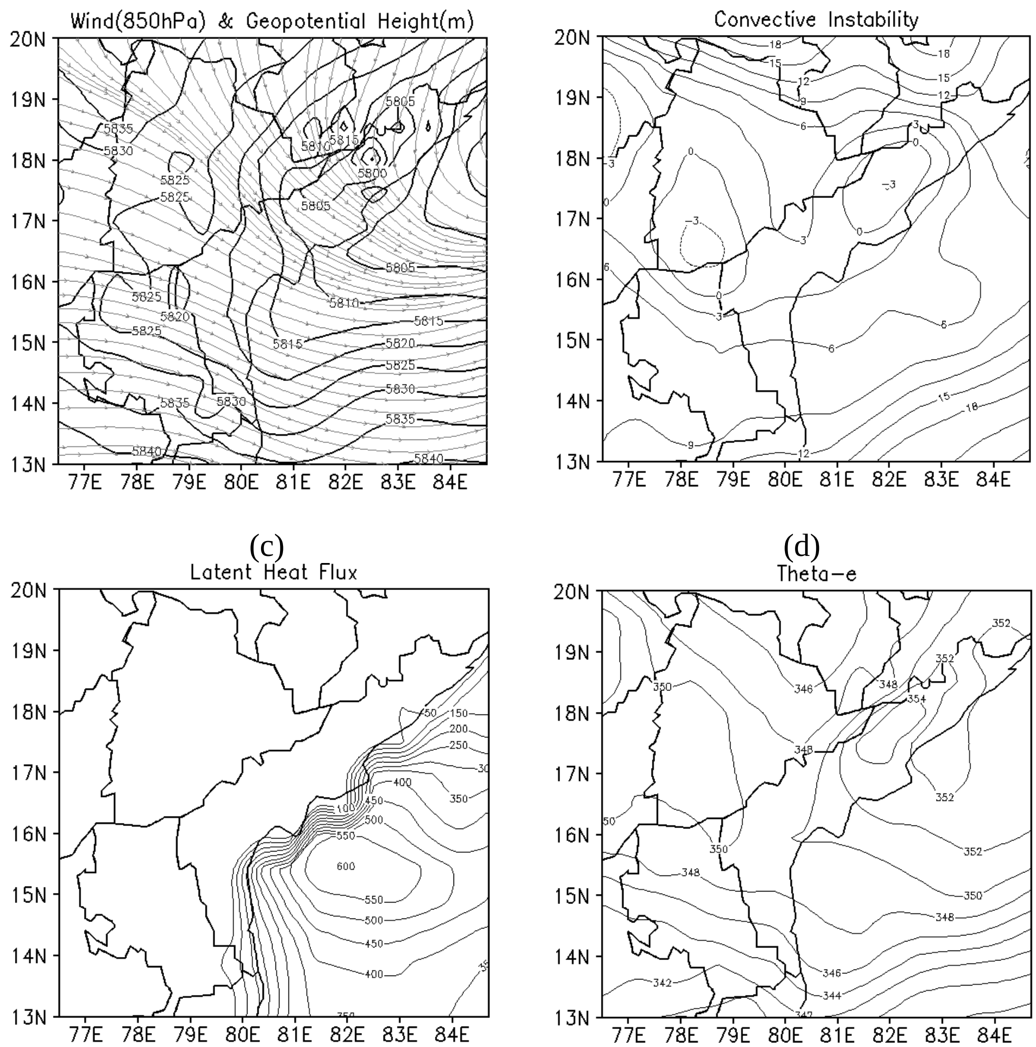

Fig. 3. Output from CNTRL at 0000 UTC 29 June 2006. (a) 500 hPa of geopotential height (m), with streamlines at 850hPa; (b) Convective instability (interval 3K); (c) surface latent heat flux (interval 50 W/m^2); (d). 1000 hPa equivalent potential temperature (interval 2K).

the middle troposphere run roughly along 18°N across India with an embedded cyclonic circulation over Telangana. A low-pressure area formed over northwest Bay of Bengal off Gangetic West Bengal and Orissa coast on 29 June; later it became depression on 2 July and laid over northwest Bay and adjoining west central Bay and neighbourhood and further intensified into a deep depression by evening. On the same day it crossed Orissa coast with an associated upper-air circulation extended upto 7.6 km above sea level. Later it weakened into a depression and moved west northwesterly direction and lay over southwest Madhya Pradesh on 5 July. Southwest monsoon has thus vigorous over coastal AP and Telangana on 29 June to 4 July. This resulted in widespread heavy rainfall episodes due to mesoscale system over the study region. The widespread and intense heavy rainfall episodes are presented in table 1 at different dates under the influence of mesoscale systems and these events are simulated with MM5.

Model description

The state-of-the-art to simulate the rainfall events during Onset phase in this study is version 3 of the fifth generation of the Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model, MM5 (Grell *et al*., 1994). This non-hydrostatic, terrain-following sigma coordinate mesoscale model has been used with some success in simulating extreme precipitation events in many parts of the Northern Hemisphere (Colle and Mass, 2000; Romero *et al*., 2000; Yeh and Chen, 2002; Das *et al*., 2003; Bohra *et al*., 2006; Singleton and Reason, 2006; Mohanty *et al*., 2002; Routray *et al*., 2005). There is, however, a little evidence in the literature that MM5 has been widely applied to Southern Hemisphere extreme weather events; it is of interest to study how well MM5 can represent an extreme weather event in this different setting. The last version

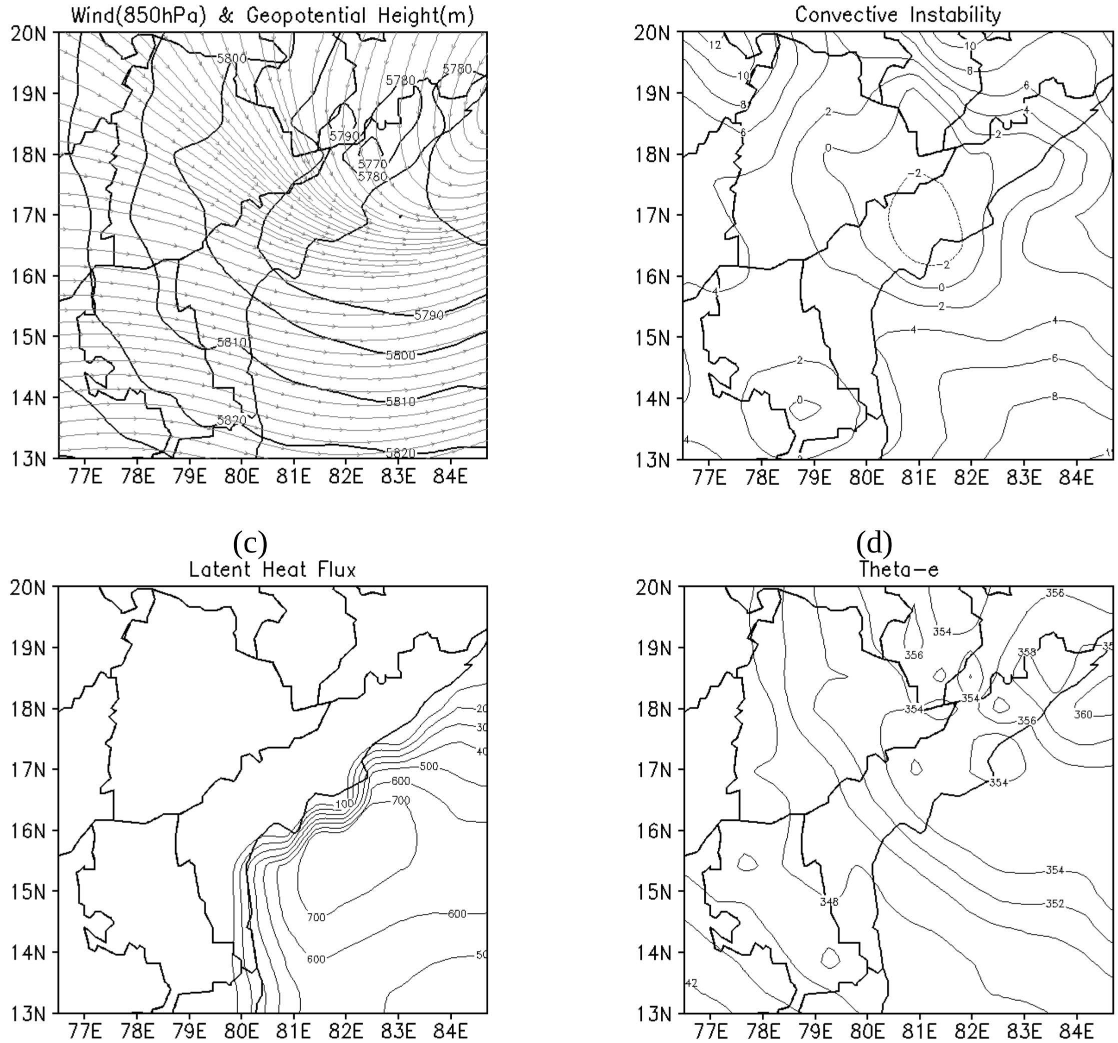

Fig. 4. Same as figure 3 except 0000 UTC 3rd July 2006.

included grid nesting options (one and two-way), parallel processing versions (shared and distributed memory) and four-dimensional data assimilation. One of the differences when compared to other atmospheric models is the number of physical options in the code available through simple changes in the configuration files. The code of MM5 is extensive possessing more than 200 subroutines and more than 50,000 code lines (Grell *et al*., 1994). It was written with the objective of being portable among the most several computational platforms.

In the present study the horizontal resolution of 60 km and 20 km was initially used on a double nested of 46×46 and 49×46 grid points centered at 17.5°N and 82.5°E, which covers Andhra Pradesh state very well to identify heavy rainfall events during the Onset phase of monsoon season. In the vertical 23 σ levels were used with increased resolution in the lowest kilometer in order to adequately resolve the boundary layer. Topography was taken from the USGS 5-min resolution data set and interpolated onto the model grid using an overlapping parabolic interpolation method.

Initial and boundary conditions (atmospheric variables, soil moisture and temperature) were interpolated from the NCEP FNL data at 21 standard pressure levels under 100 hPa onto the MM5 grid. Boundary layer processes were parameterized using the MRF scheme (Hong and Pan, 1996), while surface, land, temperature and moisture were calculated using the five layer soil model (Dudhia, 1996), which considers soil properties up to 2m below the surface**.** Cloud radiation interaction is allowed between explicit cloud and clear air. Moist convection was parameterized using Grell (1993). The explicit microphysics parameterization, which uses predictive equations for cloud water, rainwater, snow and ice has been performed using the simple ice scheme of Dudhia (1996).

Control simulation (CNTRL experiment)

Indian summer monsoon normally bursts in the first week of June over extreme south India and covers in northwesterly direction whole of India by 15 July in different pulses; above advance process is recognised by

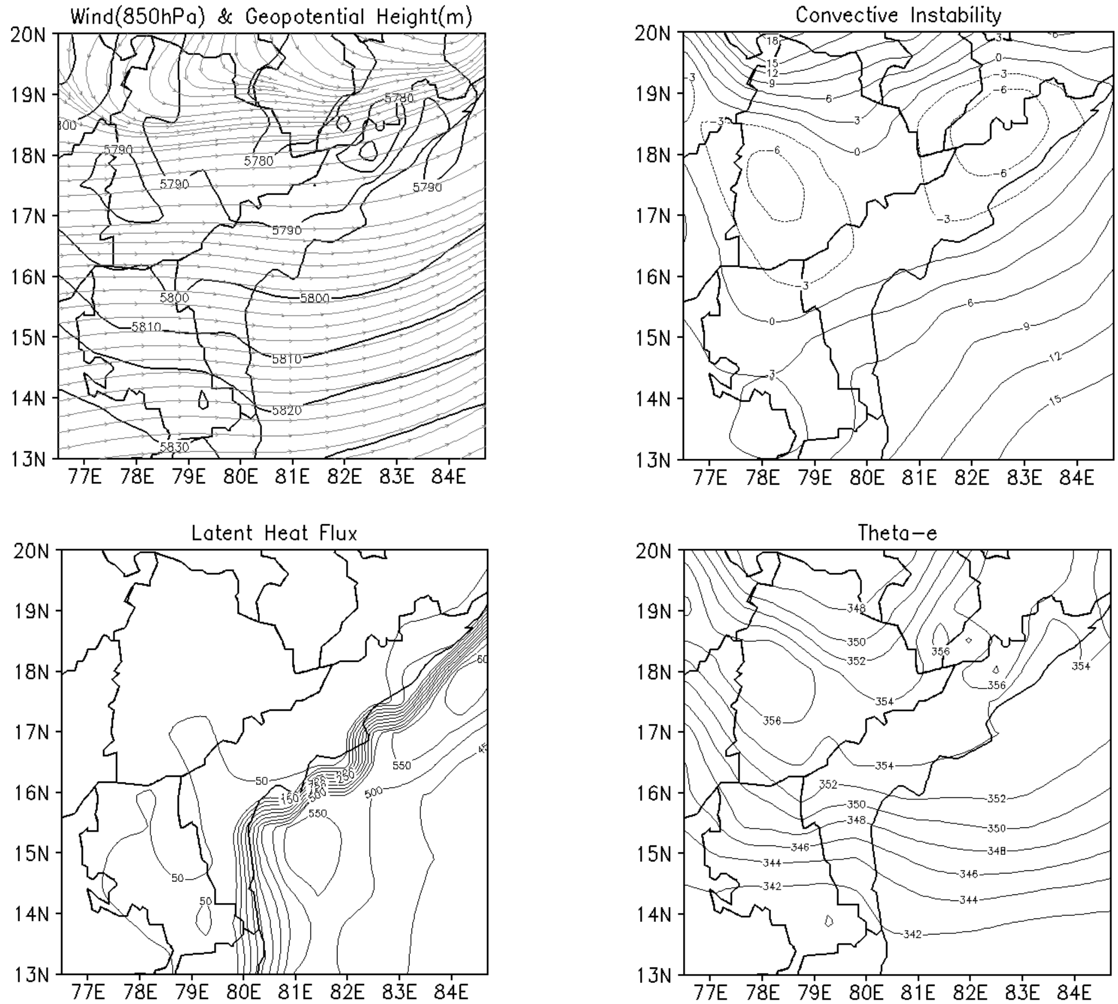

Fig. 5. Same as figure 3 except 0000 UTC 4th July 2006.

gradual OLR anomalies changes due to mesoscale systems. In this case study the mean monthly OLR values vary from 220-280W/m² in May over Andhra Pradesh with a center over northwest India. As OLR is a proxy to rain, during this advance of monsoon period there are several changes in the OLR values from May to Onset phases of summer monsoon due to the presence of mesoscale systems like Onset vortex, offshore vortex and moving troughs and thunderstorm activity etc. We have examined departures of pentad OLR values from six pentads mean of May 2006 across the study region to see different phases of (Fig. 2a) Onset of monsoon and to identify heavy rainfall events if any. It is interesting to note that heavy precipitation events were identified during first (28 June - 2 July) and second pentads (3-7 July) of July 2006. Due to mesoscale systems abnormally negative OLR anomalies (70 to 120 W/m²) persisted in some areas of north coastal AP and north Telengana (Fig. 2b&c) regions. This sudden enhanced environmental mesoscale activity inspires the authors to simulate heavy rainfall events over some parts of Andhra Pradesh namely north coastal AP and north Telengana during the Onset phase of monsoon 2006.

The model derived wind field and geopotential height at different levels are analyzed (Fig. 3a, 4a and 5a). The cyclonic circulation is clearly identified over the study region at 850 hPa. In addition comparison of time series of surface pressure and air temperature from the IMD weather stations in the coastal AP with output from CNTRL (not shown) indicates that the model timing of the largest changes in pressure and temperature as well as their tendencies are consistent with the observed. Over the ocean, CNTRL shows a zonal band of precipitation in Bay of Bengal, co-located with the cloud observed in the corresponding INSAT satellite image (not shown).

Mesoscale aspects

The days 29 June, 3 and 4 July 2006 were chosen from the study period since these were the heaviest rainfall (lowest OLR) events occurred in both the observations

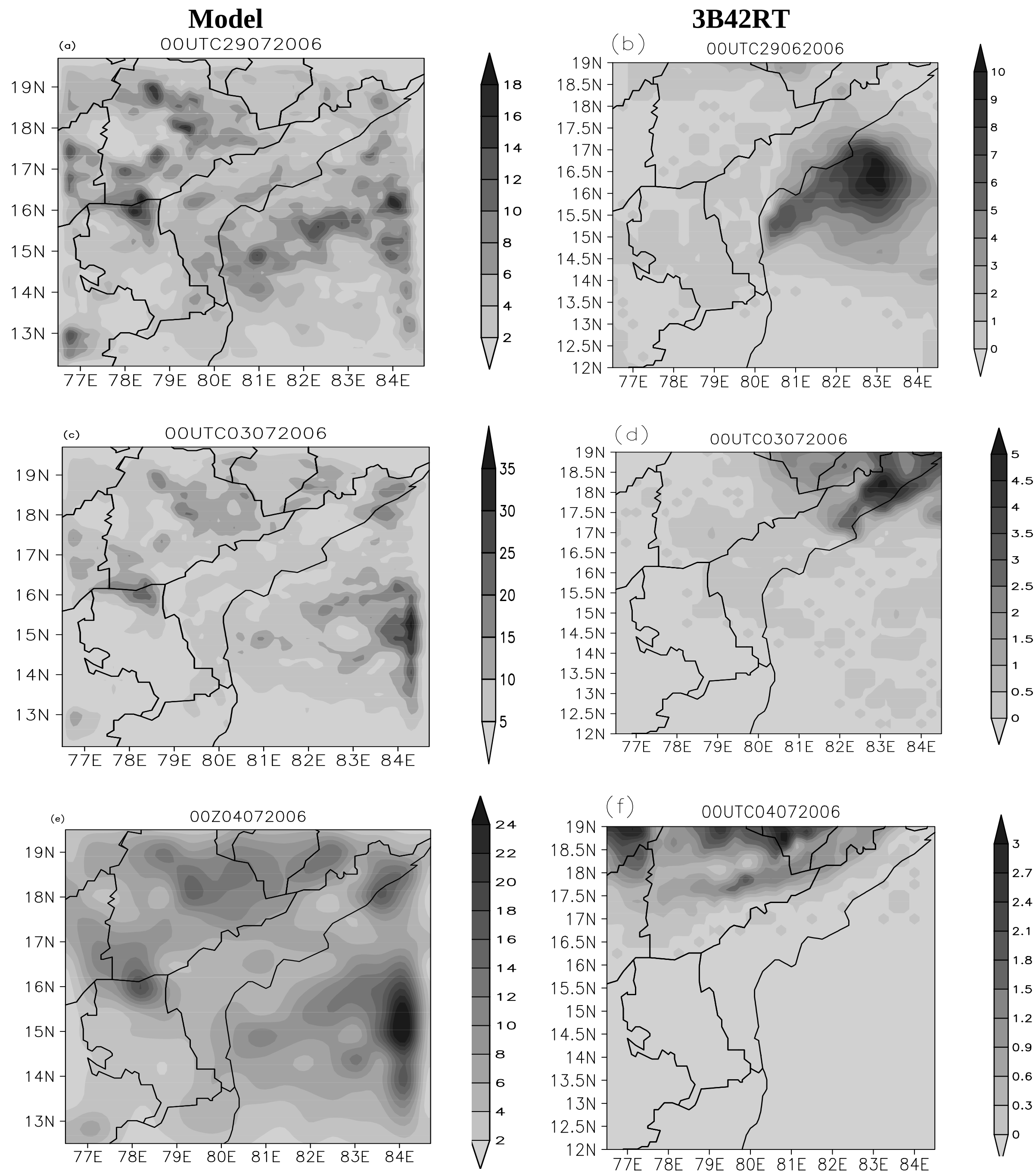

Fig. 6. Comparison the CNTRL simulation rainfall with 3B42RT rainfall product (cm)

(about 190 mm) and CNTRL. One of the most striking aspects of the large-scale flow in CNTRL at this time (Fig. 3a, 4a and 5a) was the formation of a meso-beta scale low-pressure system over northwest Bay of Bengal near Lat 20.5°N/Long 85.5°E and stronger low-level pressure gradients over the coastal ocean. The movement of the meso-low towards the coast was approximately in phase with the propagation of the heaviest precipitation over north coastal AP and north Telengana. This sequence of events suggests that the meso-low most likely formed as a result of destabilization of the atmosphere due to the advection of cold air aloft and then moved towards and off the coast and intensified due to latent heat release in the atmospheric column over the heavy precipitation. An examination of the temperature evolution in the mid levels of the atmosphere during this time (not shown) supports the hypothesis that latent heat release influenced the movement of the meso-low as a warm core air mass moved approximately in phase with the system.

An area of convectively unstable stratification (the difference in equivalent potential temperature (θ_e) between 1000 hPa and 500 hPa) existed over the coastal ocean east of 82.5°E and this just penetrated onto the land near coastal AP (Fig. 3b, 4b and 5b.). This instability arose from warm moist air extending down the east coast towards coastal AP with a tongue of high θ_e air present between 82° E and 84° E (Fig. 3d, 4d and 5d.). Thus, an extreme environmental rainfall event was the result of warm moist air being advected onto the coastal AP. There were also large surface latent heat fluxes (450-600 W/m²) from the ocean over the low-pressure region (Fig. 3c, 4c and 5c.), indicating that the warm Sea Surface Temperatures (SSTs) contributed to the low-level moisture supply to the rainfall. Simulated rainfall using MM5 is discussed as follows:

The CNTRL experiment shows that the simulated environmental rainfall over the north coastal AP (Komarada, Patapatnam, Veeraghattam, Palakonda and Palasa) and north Telengana (Asifabad, Sirpur and Adilabad) are ranged from 110-150 mm (Fig. 6a, 6c and 6e) on 3 and 4 July. The localized distribution of rainfall during the study period in 20 km is relatively better represented when compared to 60 km resolution simulations. This study is similar to Routray *et al*. (2005), assimilate heavy rainfall events with the same resolution and nudging using ARMEX observational data along the west coast of India. The CNTRL simulated rainfall is further compared with observational (Fig. 1a) 24 hr precipitation valid at 29 June, 3 and 4 July 2006 episodes separately. Although the relative paucity of rainfall stations prevents a detailed comparison, Fig. 6a, 6c and 6e gives an indication of the model performance for precipitation. The rainfall recorded at north coastal AP was 100-190 mm where as the CNTRL simulated showed a maximum of 70-150 mm. However, it was found that the timing of the most intense precipitation in CNTRL compared well with that observed and the results of simulated rainfall are presented in table 1. Present simulated study clearly demonstrates that the precipitation maximum episodes amount upto 80% of observational value over the study region.

However, many other aspects of the large-scale flow were adequately resolved in CNTRL; it suggests that its main deficiency is in correctly simulating the area of the extreme precipitation. Further, experiments will be undertaken with different parameterizations schemes for boundary layer processes and sub-grid scale convection, but the choice described in model description produces the results that best compare with the other schemes. Thus there is an improvement of 20% in precipitation due to the influence of environmental mesoscale systems for heavy rainfall episodes.

Finally, the CNTRL experiment based on the initial conditions of 00 UTC, from 25th May 2006 onwards was performed (Fig. 6a, 6c and 6e) to illustrate the heavy rainfall events if any. The CNTRL results are compared (Table 1) with both the IMD rain gauge observations and TRMM merged precipitation product 3B42RT (Fig. 1a and Fig. 6b, 6d and 6f) for the same episodes over Andhra Pradesh. It is noticed that the 3B42RT data set was underestimated as compared to the observed rainfall.

DISCUSSION AND CONCLUSIONS

Departures of mean monthly pentad OLR for May from the pentad in the advanced period (June and July) give some clue to identify negative OLR anomalies, which imply cloudiness and convection persisted in the area of heavy rainfall events due to mesoscale systems during Onset phase of monsoon over some parts of Andhra Pradesh.

In the present case study, strong low-level convergence of moist air in the presence of convectively unstable stratification was responsible for the environmental heavy rainfall observed over study region on 29th June, 3rd and 4th July 2006. In this CNTRL simulation of MM5 analysis convective instability, latent heat flux and equivalent potential temperature showed maximum quantities at the places of heavy rainfall episodes.

In addition, the above results may be further improved by nudging with additional dense network of surface, upper-air and satellite data. Further, the implementation of sophisticated assimilation technique like three dimensional variational assimilation system would produce even more realistic initial conditions for mesoscale model integrations in future.

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