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Impact of special observations on the numerical simulation of a heavy rainfall event during ARMEX-Phase I

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सार – इस शोध पत्र में उच्च विभेदन मेसोस्केल निदर्श–एन.सी.ए.आर. एम.एम. 5 का उपयोग करते हुए 26–28 जून 2002 (आरमेक्स चरण – I) के दौरान भारत के पश्चिमी तट पर भारी वर्षा की घटना को अनुकरित किया है। क्विकस्कैट और एस. एस. एम./आई. सतही पवनों के साथ आरमेक्स चरण – I के विशेष प्रेक्षणों को शामिल करते हुए और आरमेक्स चरण – I के विशेष प्रेक्षणों को शामिल न करते हुए दो प्रयोग किए गए। 81, 27, 9 और 3 कि.मी. के विभेदनों के चार समूहों के प्रभाव क्षेत्रों के साथ एन.सी.ए.आर. एम.एम. 5 को 25 जून 2002 के 0000 यू. टी. सी. से 72 घंटे के लिए समाकलित किया गया। एन सी. इ. पी. विश्लेषण से 1–डिग्री के विभेदन पर आरम्भिक और परिसीमा की स्थितियाँ प्राप्त की गई हैं। परिमाणात्मक वर्षा के आकलनों और एम.एम. 5 आऊटपुट से पवन क्षेत्रों का विश्लेषण किया गया है। इन निदर्श परिणामों से मेसोस्केल संवहनी प्रणाली के निरूपण और इससे 27 और 28 जून 2002 को हुई भारी वर्षा का पता चलता है। इस निदर्श से एक दिन में लगभग 30 सें.मी. तक भारी वर्षा होने का पूर्वानमुान लगाया जा सकता है जबकि कुछेक स्थानों पर लिए गए प्रेक्षणों से एक दिन में 50 सें. मी. तक वर्षा का पूर्वानुमान लगाया जा सकता है आरमेक्स प्रेक्षणों के समावेशन और उपग्रह पवन आँकड़ों के साथ किए गए प्रयोगों से अधिकतम वर्षा के स्थान का और वर्षा बैंड के संचलन का पूर्वानुमान लगाने में सुधार हुआ प्रतीत होता है, किंतु इसमें भारी वर्षा की तीव्रता में थोड़ी कमी देखी गई है।

ABSTRACT. The heavy rainfall event over west coast of India during 26 - 28 June 2002 (ARMEX Phase - I) is simulated using a high-resolution mesoscale model-NCAR MM5. Two experiments were made with and without the inclusion of special observations of ARMEX – Phase I along with Quickscat and SSM/I surface winds. NCAR MM5, with four nested domains of 81, 27, 9 and 3 km resolutions, is integrated for 72 hr from 0000 UTC of 25 June 2002. The initial and boundary conditions are derived from NCEP analysis at 1 - degree resolution. Quantitative precipitation estimates and the wind fields from MM5 output are analysed. The model results indicate the formation of a mesoscale convective system and associated heavy rainfall on 27 and 28 June 2002. The model could predict heavy rainfall upto about 30 cm/day though some observations at isolated locations are up to 50 cm/day. Experiment with the inclusion of ARMEX observations and satellite wind data seem to improve the prediction of the location of the maxima and the movement of the rain band but with a slight decrease in the intensity of the heavy rainfall.

Key words – ARMEX, Mesoscale model – MM5, Quickscat, SSM/I, Winds, Heavy rainfall.

1. Introduction

The Indian sub-continent receives 70% of the annual rainfall during June-September, generally termed as summer (southwest) monsoon season. The occurrence of rainfall has important socio-economic implications as need for agriculture and other chores. The onset of the summer monsoon is associated with sudden increase of rainfall associated with decrease of temperatures and increase of humidity. After the onset phase, rainfall shows intra-seasonal fluctuations with alternating active and weak phases. Observations indicate that maximum amount of precipitation occurs over northeast India and along the west coast (Rao 1976). It is also observed that a few heavy rainfall events, sometimes exceeding 20 cm/day, occur along the west coast during this season. These intense rainfall events confine to small regions of few kilometers extent and are attributed to mesoscale convective systems. Due to paucity of sufficient observations, it is often difficult to track their genesis. Hypotheses are proposed about the occurrence of an off-shore trough along the west coast and the genesis of mesoscale convective systems associated with this off-shore trough. The Department of Science and Technology (Government of India) envisaged and initiated the conduct of Arabian Sea Monsoon Experiment (ARMEX) in different phases to understand the mechanisms associated with Arabian Sea warm pool during the pre-monsoon period and heavy precipitation events during the monsoon season. The Phase - I of ARMEX was conducted from 29 May to 15 August 2002 during which special observations were collected with the aim to understand heavy rainfall events along the west coast during the summer monsoon season. Das *et al*. (2003) simulated the heavy precipitation event of 26-28 June 2002 using NCAR MM5 with three nested domains at 90, 30 and 10 km resolutions. They reported simulation of maximum rainfall upto 30 cm/day when high resolution nudging was used.

TABLE 1

Details of NCAR MM5 with different options

Model type	Primitive equation, Non-hydrostatic			
Vertical resolution	23 sigma levels			
Horizontal resolution of domains	81 km	27 km	9 km	3 km
Domain of integration	5.385 - 28.86° N 64.07 - 85.929° E	10.195 - 25.183° N 67.47 - 77.43° E	14.623 - 22.817° N 70.062 - 75.57° E	18.398 - 21.943° N 71.168 - 74.381° E
Convection scheme	Grell	Grell	Explicit	Explicit
Explicit moisture scheme	Simple ice scheme (Dudhia)			
PBL scheme	Medium Range Forecast model scheme			
Radiation scheme	Dudhia scheme for short wave radiation Rapid radiative transfer model for long wave radiation			
Surface scheme	OSU/Eta land- surface model			
Sea Surface Temperature	Real SST			

In this study, an attempt is made to simulate one of the heavy rainfall events occurred during 26-28 June 2002 using a high-resolution mesoscale model. As synoptic analysis method provides only qualitative prediction, numerical models alone have the possibility to give quantitative estimation of the rainfall. However results from the numerical models are to be interpreted and established with in the limitations of models' capabilities. For the present study NCAR MM5 is used due to the flexibility available to choose the region of interest, grid domain, representation of different physical processes and easy portability. In order to simulate the heavy rainfall event associated with mesoscale systems, the horizontal resolution of the model should be chosen such that the model can resolve the structure of the system. In this case it is desirable to have the model resolution at few kilometers. As short-range weather prediction is an initial value problem, the predictability depends on the accuracy. of the initial state. Though the models can be designed to have any desired resolution, their application also depends on the availability of observations over the region of interest. ARMEX provided special observations at selected locations on the west coast of India, which were noted to be helpful to synoptic studies. In the present study, simulation of a heavy rainfall event is attempted using a high-resolution mesoscale model to study the impact of special observations during ARMEX- Phase I.

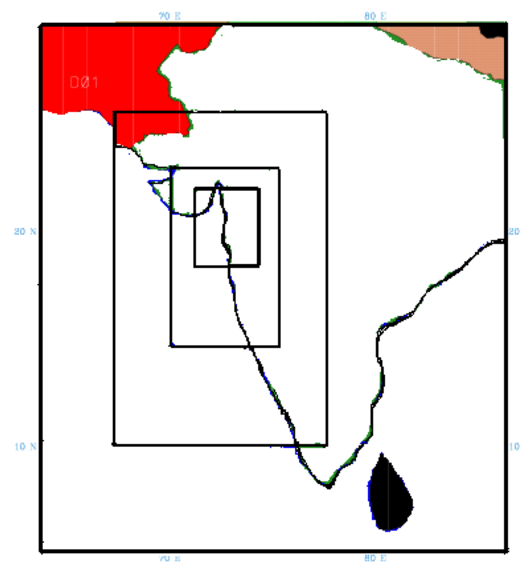
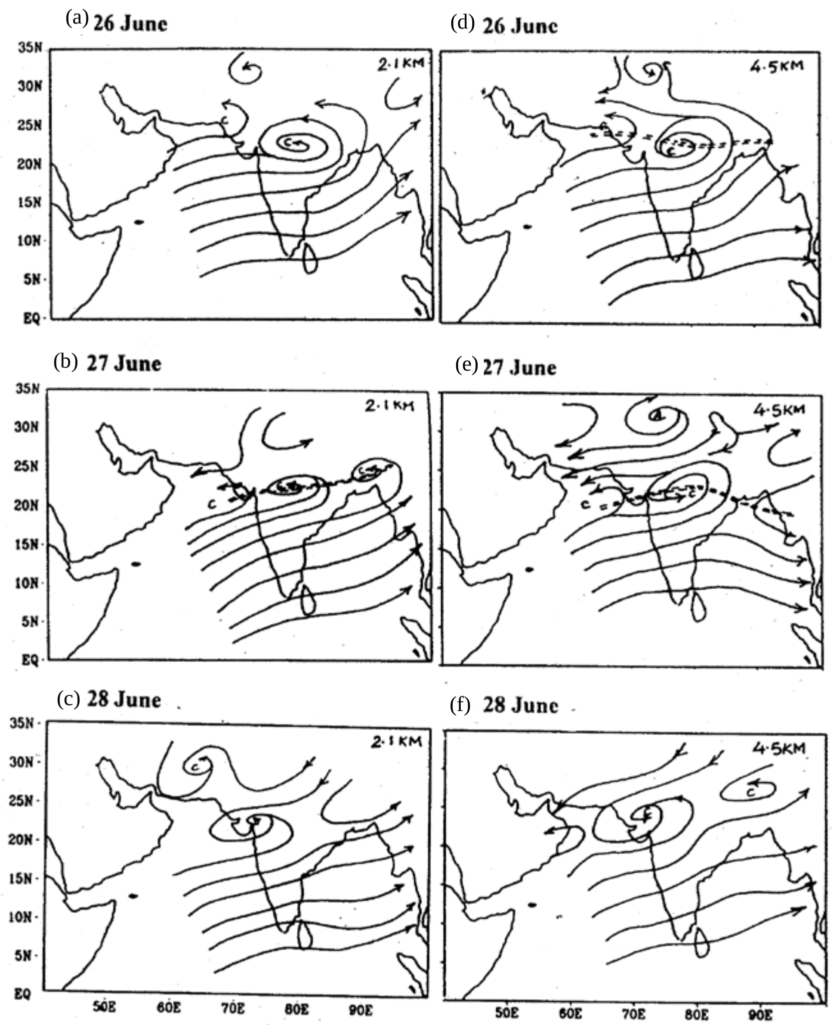


Fig. 1. Model regions of the four nested domains

2. Data and methodology

The fifth generation mesoscale model first designed at Penn State University (USA) and later modified at National Centre for Atmospheric Research (USA), now popularly referred as NCAR MM5 (hereafter in this paper referred to as MM5), is well documented [Anthes and Warner 1978, Grell *et al.*, (1994)]. MM5 is a non-hydrostatic, primitive equation model with grid point formulation in sigma coordinates and with options for different schemes of convection, planetary boundary layer, radiation and soil characteristics. The model has capability to have multiple nesting and four-dimensional data assimilation. MM5 is designed to have four nested domains with the horizontal resolutions 81, 27, 9 and 3 km as shown in Fig. 1 covering the Indian subcontinent and neighbourhood. The 9 km and 3 km domains are chosen to capture the region of heavy rainfall event occurred during 26-28 June 2002 over Maharashtra and Gujarat. The details of MM5 as used in the present study are given in Table 1. MM5 is integrated for 72 hours starting from 0000 UTC of 25 June 2002. The initial and boundary conditions are taken from NCEP FNL global analysis available at 1-degree resolution. Boundary conditions are provided every 6 hr as available from NCEP. Time varying Sea Surface Temperatures (SST) data are also provided from NCEP FNL. USGS topography data available at resolutions of 30 min



Figs. 2(a-f). Wind flow from observations at 2.1 and 4.5 km on 26, 27 and 28 June 2002. (Mohanty *et al.,* 2002)

(~ 56 km), 10 min (~19 km), 5 min (~ 9 km) and 2 min (~ 4 km) are used to interpolate the model topography for the four domains with the resolutions at 81, 27, 9 and 3 km respectively.

Two numerical simulation experiments have been performed without and with the inclusion of ARMEX special observations and satellite winds and are referred to as El and E2 respectively. For the experiment E2, all the available special observations collected during ARMEX period were used. These data include surface winds from Quickscat and SSM/I, Radio-sonde/Rawin observations from 16 stations, which include land stations and two ships as given in Table 2. All the available data from these sources at 0000 UTC of 25 June 2002 are combined with the NCEP FNL analysis to obtain the initial conditions for MM5. The experiments El and E2 differ only with respect to the inclusion of special observations and satellite winds in the preparation of initial conditions.

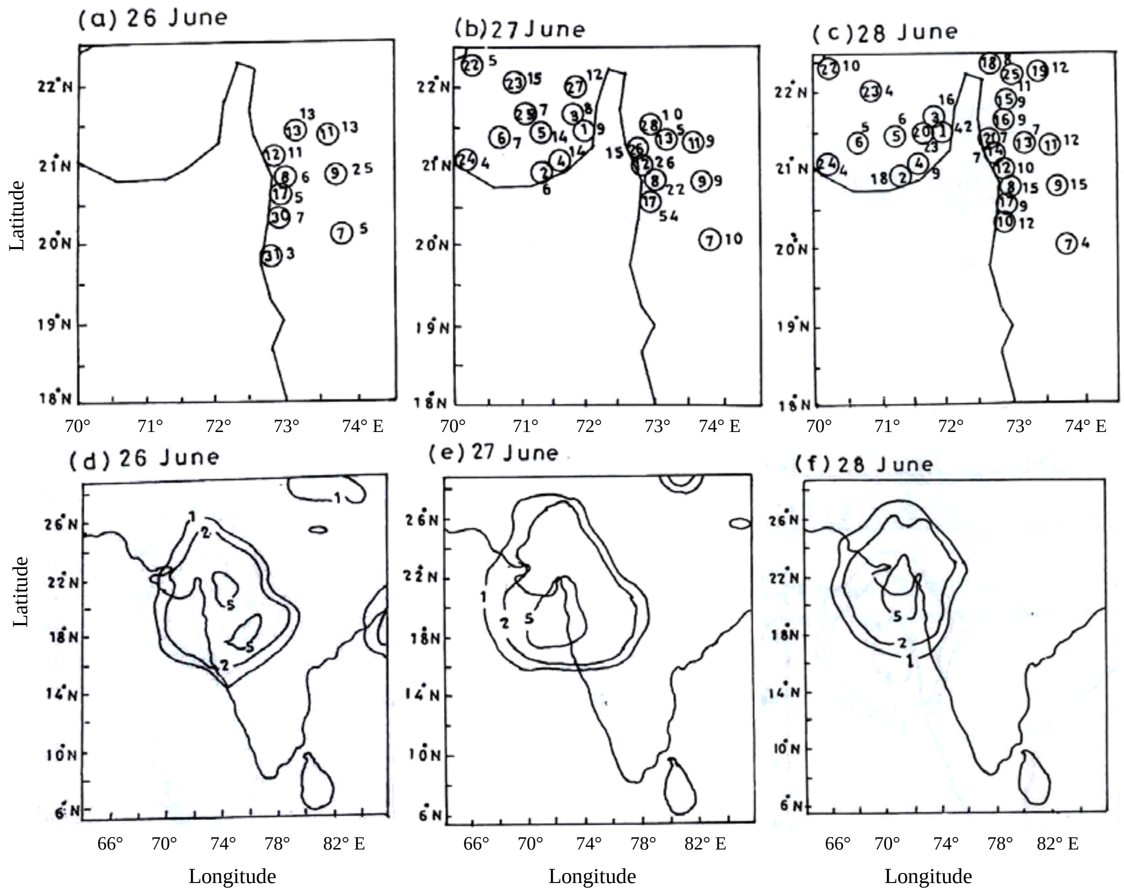
TABLE 2

Names of the stations and available special observations

Radiosonde	Ahmedabad, Mumbai, Goa, Mangalore, Aminidevi Island, Cochin
Rawins	Ahmedabad, Mumbai, Goa, Mangalore, Aminidevi Island
Pilot	Bhuj- Rudramata, Surat, Veraval
Ship	Sagar Kanya, Hansa Goa

3. Results

Two numerical experiments (El and E2) were conducted using MM5 with and without inclusion of special observational data to study the impact of ARMEX special observations on the simulation of heavy rainfall event. As mentioned earlier, MM5 has been integrated for 72 hr starting from 0000 UTC of 25 June 2002. The



Figs. 3(a-f). Rainfall observations. Top panel shows data from stations along the west coast and bottom panel shows rainfall distribution from TRMM satellite

results obtained at 24, 48 and 72 hr are analysed and compared with the observations.

3.1. *Description of the synoptic event*

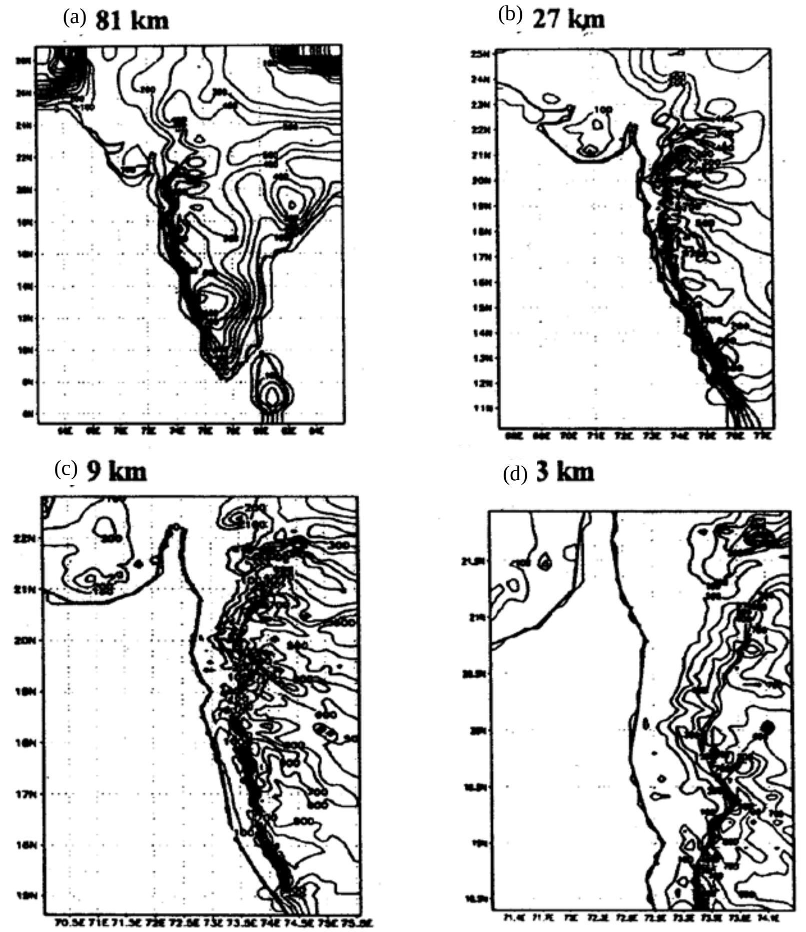
A brief description of the atmospheric circulation during the period 25 - 28 June 2002 as reported by Mohanty *et al*., (2002) is presented as follows. On 25 June, at 0000 UTC, a low pressure area lies over Madhya Pradesh and adjoining region which was a remnant of the low pressure system formed over the head Bay of Bengal and moved northwestwards Figs. 2(a-f). The rainfall reported from different stations along the west coast on 26, 27 and 28 June 2002 as reported by Mohanty *et al*., (2002) are given in Figs. 3(a-f) along with TMI observations. A list of the names of the stations for which rainfall observations are reported is given in Table 3. It is to be noted that TMI gives a smooth distribution of rainfall with a maximum of 5 cm on 26, 27 and 28 June 2002, which indicate that TMI is area averaged precipitation and cannot capture the heavy rainfall. At 0000 UTC of 26 June, the low pressure moved westwards and lies over southwest Madhya Pradesh. Correspondingly the north-south pressure gradient along the west coast

TABLE 3

Rainfall observation stations (Figure 3)

S. No.	Station Name	S. No.	Station Name	S. No.	Station Name
1	Bhavnagar	12	Navasari	22	Jamnagar
2	Jafarbad	13	Mandavi	23	Wankanaer
3	Ballabhapur	14	Ankaleswar	24	Porbandhar
4	Mahuva	15	Anand	25	Vadodara
5	Amreli	16	Jambusar	26	Surat
6	Junagadh	17	Valsad	27	Dhanduka
7	Nasik	18	Kheda	28	Bharuch
8	Chikhana	19	Godhra	29	Jasdan
9	Ahwa	20	Palitana	30	Daman
10	Daman	21	Dabhoi	31	Dahanu
11	Sonagadh				

increased to 9 hPa between Dahanu and Trivandrum from 6 hPa on 25 June 2002. Due to these two synoptic features, moderate to heavy rainfall was reported along the west coast of India with a maximum of 7 cm at Surat. At 0000 UTC on 27 June 2002 the low pressure over central India moved westwards and lies over west Madhya



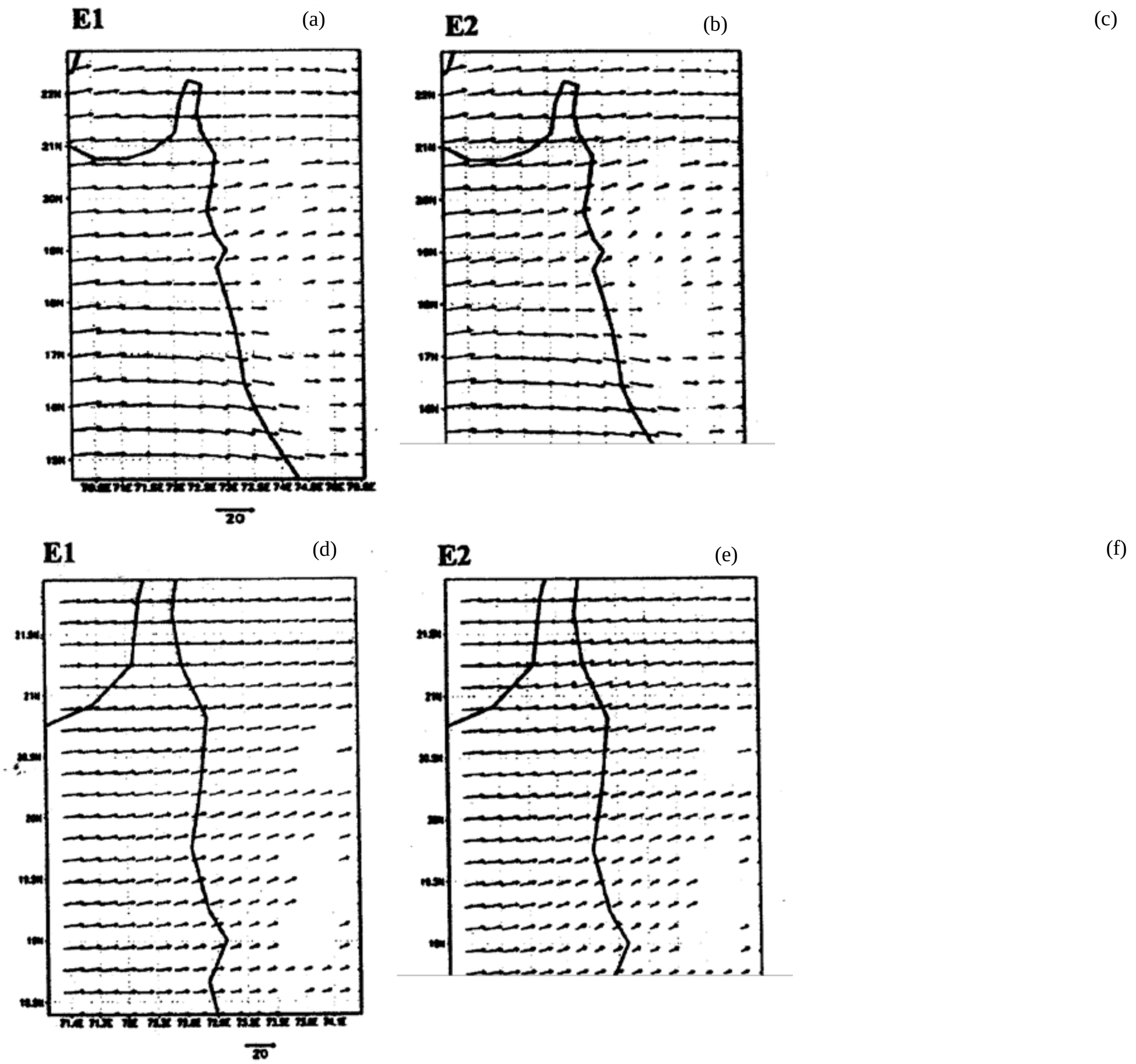
Figs. 4(a-d). Model topography for the four domains at resolutions of (a) 81 km (b) 27 km (c) 9 km and (d) 3 km. Contours are drawn at interval of 100 m

Pradesh while the north-south pressure gradient along the west coast is reported to be 8 hPa. Correspondingly heavy to very heavy precipitation was reported from Maharashtra and Gujarat with maxima of 61 cm, 54 cm and 49 cm at Pardi, Valsad and Lonavala respectively. The observations indicate that rainfall was isolated along the west coast on 26 June, while the rainfall increased and also extended northwest over to south Gujarat. The synoptic situation at 0000 UTC of 28 June shows low pressure over southeast Rajasthan and Gujarat, the pressure gradient continues to be steep over Gujarat, Konkan coasts but reduced over Karnataka and Kerala coasts. Correspondingly rainfall was confined to Gujarat with a maximum of 43 cm at Bhavnagar. This description shows that a low pressure system moving from head Bay of Bengal contributed for increase of north-south pressure gradient along west coast of India. This increase of the pressure gradient along the west coast contributed to intense rainfall during 26 - 28 June with very heavy rainfall on 27 June. The rainfall belt moved northwestwards from 26 to 27 June and then shifted westwards from 27 to 28 June.

3.2. *Model results*

In the present study MM5 is designed to have four nested domains with horizontal resolutions of 81, 27, 9 and 3 km. All the four domains are two-way interactive during the model integration. The model topography for the four domains is shown in Figs. 4(a-d). It is to be noted that model topography shows finer orography features with increasing resolution.

The initial values for the four domains have been interpolated from NCEP FNL data at 1-degree resolution. For the experiment E2, special observation data from the 16 stations (Table 2) and satellite winds are combined with NCEP FNL to create initial conditions. The wind field at 925 hPa for the 9 km and 3 km domains at 0000 UTC of 25 June 2002 for experiments El and E2 and the wind difference (El - E2) are shown in Figs. 5(a-f). It is to be noted that the inclusion of ARMEX special observations and satellite winds contribute for a slight weakening of the cyclonic circulation along the west coast southeast Gujarat and north Maharashtra. The wind field

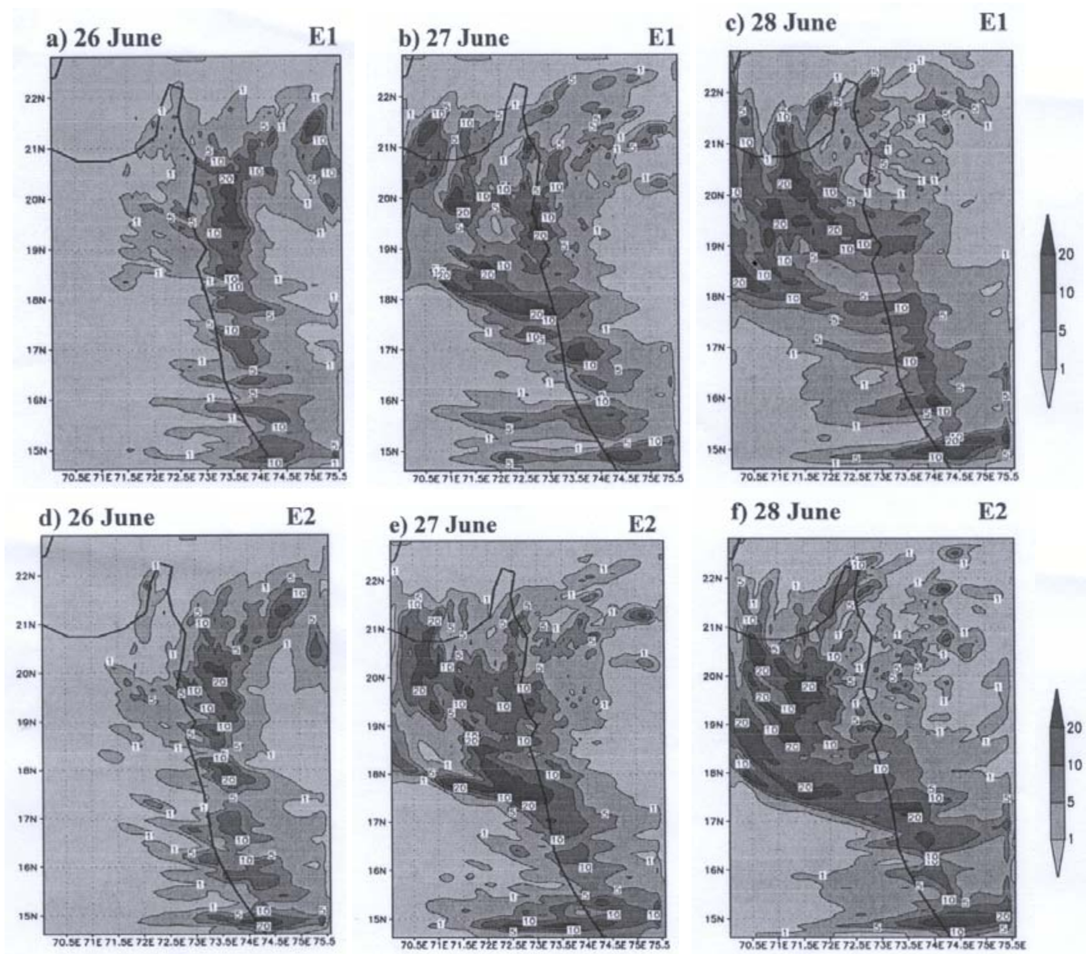


Figs. 5(a-f). Initial wind field at 925 hPa at 0000 UTC of 25 June 2002 for the experiments El and E2. Top panel correspond to 9 km domain and bottom panel correspond to 3 km

at 3 km domain clearly shows northeast wind anomaly over north and northwest anomaly over south indicating the impact of special observations over specific regions. Time varying boundary conditions are same for both the experiments. MM5 is integrated for 72 hr starting from 0000 UTC of 25 June 2002 and selected fields of rainfall and wind are analysed and discussed. An assessment of MM5 to simulate the heavy rainfall event and the impact of ARMEX special observations is studied.

3.2.1. *Model derived rainfall*

Though the model output for four domains is available the results are presented only for the domains of 9 and 3 km. The rainfall accumulated for 24 hr at 0000 UTC of 26, 27 and 28 June for both the experiments El and E2 for 9 km and 3 km domains are presented in Figs. 6(a-f) & 7(a-f). For El, 9 km domain, the rainfall distribution on 26 [Fig. 6(a)] shows that moderate to heavy rainfall is confined to a narrow north-south band along the west coast with moderate precipitation over southeast Maharashtra. On 27 June, the rainfall bands move northwestwards over to south Gujarat. Rainfall is isolated over a small region of south Maharashtra where as south Gujarat receives heavy rainfall. The distribution on 28 June shows that the rainfall belt shifts eastward over to southeast Gujarat. Correspondingly for E2 [Fig. 6(d)], 9 km domain, the distribution on 26 June is similar to El with north-south band along the west coast. On 27 June, the rainfall bands moved northwestwards with heavy rain occurring over southwest Gujarat. This differs from El where rainfall was present over southeast Gujarat. The region of heavy rainfall differs from El where the rainfall belt moved further east. These results indicate the



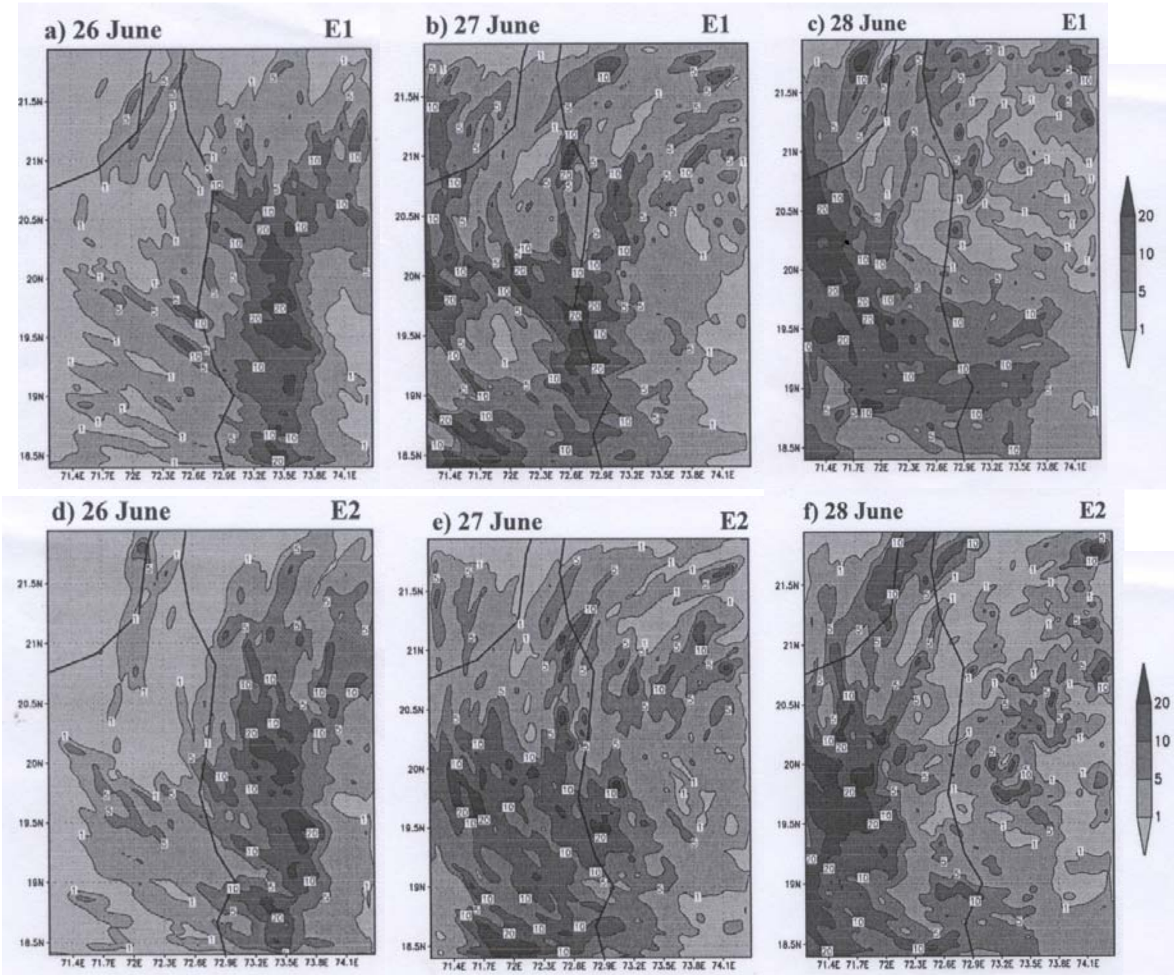
Figs. 6(a-f). Model derived rainfall distribution for the 9 km domain. Top panel correspond to experiment El and bottom panel correspond to the experiment E2 (with inclusion of ARMEX special observations and satellite winds)

presence of a mesoscale convective system along the west coast on 26 June, which intensified and moved northwestwards giving heavy rainfall over south Gujarat on 27 June and then weakened on 28 June agreeing with the observations.

Results from 3 km domain are described Figs. 7(a-f) as follows. The mesoscale pattern of the rainfall is noted more clearly than 9 km domain. In E1, heavy rainfall was confined to a narrow region between 19° - 20.5° N; 73.5° E where the rainfall was more than 10 cm. The pattern on 27 June indicates the movement of the rain belt westwards, with isolated regions of heavy precipitation noted over north Maharashtra and south Gujarat. On 28 June, the rain belt was over the Arabian Sea extending towards south Gujarat. Heavy rainfall was noted over southeast Gujarat agreeing with the observations. It is also observed that the rainfall maxima of more than 20 cm/day are simulated at selected locations on 27 and 28 June in E1. Correspondingly for E2, the rainfall pattern is similar to E1 on 26 June, but differs on 27 and 28 June. On 27 June, the rainfall region moved westwards over the Arabian Sea and the rainfall was less over south Gujarat than E1. On 28 June, heavy rainfall was confined to eastern Gujarat and extending to small regions over south and southeast Gujarat. Heavy rain, upto 20 cm/day, is located over southeast Gujarat. The location of the heavy rainfall is better simulated in E2 agreeing with the observations than of E1 where as the intensity of rainfall is better predicted in E1.

3.2.2. *Model wind*

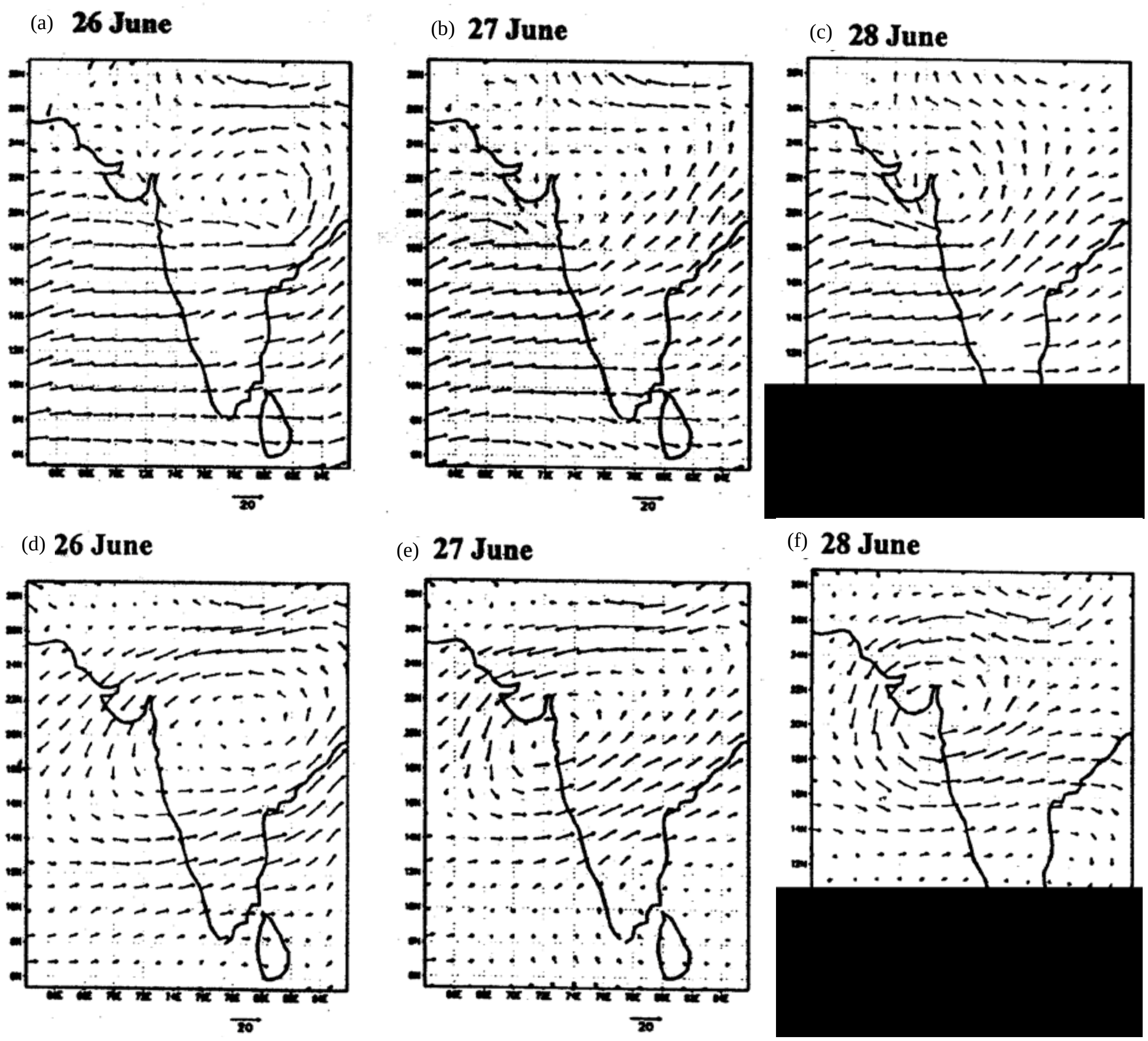
The model derived wind fields at different levels for both experiments E1 and E2 are analysed. But the discussion here is restricted to important features and corresponding Figures are only presented. Figs. 8(a-f) shows the model wind field for 81 km domain at 925 hPa and 500 hPa for E1. It is noted that cyclonic circulation prevails over central India extending upto 500 hPa on 26 June. This system moved westwards over to Maharashtra with the cyclonic circulation extending up to 500 hPa. This moved further westward over to south Gujarat on



Figs. 7(a-f). Model derived rainfall distribution for the 3 km domain. Top panel correspond to experiment El and bottom panel correspond to the experiment E2 (with inclusion of ARMEX special observations and satellite winds)

28 June, with the cyclonic circulation upto 500 hPa. The results from E2 (not presented) are similar to El.

The model wind field for the 3 km domain at 925 hPa is presented in Figs. 9(a-f). The wind field of El shows northerly flow on 26 June over Maharashtra and northwesterly flow over Gujarat indicating a trough around 20° N; 73.5° E. This convergent flow along the west coast seems to have contributed for the rainfall noted earlier. E2 shows the formation of a small cyclonic circulation around 19.8° N; 73° E. This differs from El, where the formation of the trough was more eastward. The flow is more convergent indicating the formation of a mesoscale system. On 27 June, results of El indicate clear formation of a trough along 73.2° E around 18.5° N. In E2, a closed cyclonic circulation is distinctly noted at 19.5° N; 73.3° E and with northerly flow over the Arabian Sea off the west coast extending up to 19° N as compared to 19.6° N in El. Slightly stronger northnorthwesterly winds are predicted over south Gujarat in E2 as compared to pure northerly flow in El. This indicates convergence over southeast Gujarat resulting in increased rainfall on this day. The closed cyclonic circulation of E2 may be a better representation to yield the observed heavy precipitation. On 28 June, El shows northerly flow over Gujarat becoming northwesterly over Arabian Sea moving on to west coast to indicate the presence of a trough along 20° N, 73° E. Correspondingly E2 shows northnorth-easterly winds over southeast Gujarat becoming northwesterly over Arabian Sea indicating a trough along 20.2° N; 72.9° E. Experiment E2, with inclusion of special observations, clearly shows the formation of a trough on 26 June, intensifying into a mesoscale convective system on 27 June and then weakening to an intense trough on 28 June. This simulation of the formation of a mesoscale convective system could be possible only with high resolution of 3 km domain, where as the same could not be simulated with 81, 27 and only faintly with 9 km. The movement of the cyclonic circulation towards north could also be clearly simulated.



Figs. 8(a-f). Model derived wind field for the domain with 81 km for the experiment El. Top panel correspond to 925 hPa level and bottom panel correspond to 500 hPa level

4. Summary and conclusions

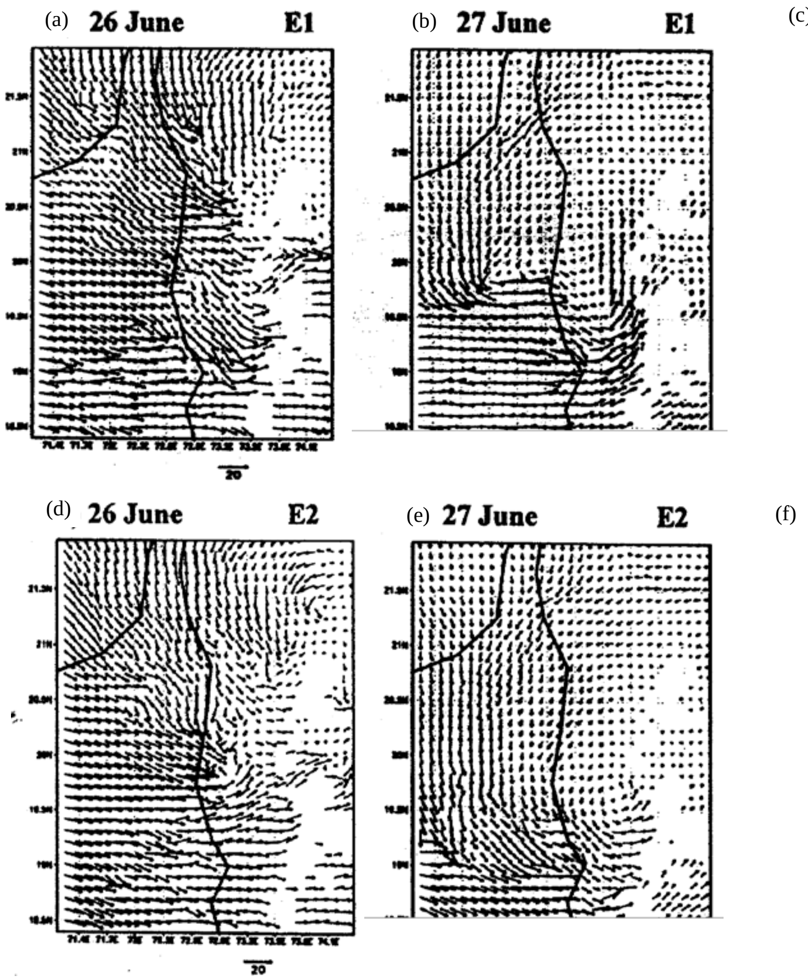
NCAR MM5 is used to simulate a heavy precipitation event during ARMEX Phase-I with resolutions at 81, 27, 9 and 3 km. Model integration was done for 72 hr from 0000 UTC of 25 June 2002. The results are summarised as follows:

(*i*) MM5, with 81 km resolution, could simulate the westward movement of a low pressure system over central India on 25 June 2002. The broad circulation features at 925 hPa and 500 hPa agree with the observations.

(*ii*) MM5, with 9 and 3 km resolutions, could simulate with moderate rainfall along the west coast on 26 June 2002 and the occurrence of heavy rainfall on 27 and 28 June. The northward and northwestward shift of the rain belt is also simulated.

(*iii*) MM5, with 3 km resolution, could simulate a trough on 26 June intensifying on 27 June and weakening on 28 June agreeing with the observations.

(*iv*) Experiment with data inclusion of ARMEX special observations and satellite winds show improved features in the wind circulation. The location of the maxima of rainfall is better simulated in E2 where as the intensity of the rainfall is better in El. This may be due to the differences in the initial conditions, which show weakening of the cyclonic circulation over southeast Gujarat and north Maharashtra from the inclusion of special ARMEX observations and satellite winds.



Figs. 9(a-f). Model derived wind field (m/sec) at 925 hPa for the domain with 3 km. Top panel correspond to El and bottom panel correspond to E2 (with inclusion of ARMEX special observations and satellite winds)

The above conclusions clearly indicate that MM5 has the potential to predict mesoscale convection systems and support the results of Das *et al*., (2003). The present study indicates the capability of NCAR MM5 to simulate the heavy precipitation event without nudging. However, more experiments are to be conducted before arriving at definite conclusion. Though MM5 could predict heavy rainfall at certain locations the maximum value is confined to less than 30 cm/day over land as expected due to constraints of model resolution.

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