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Performance of NCMRWF Models in Predicting High Rainfall Spells During SW Monsoon Season - A Study for Some Cases in July 2004

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Abstract

It is well recognized fact that accurate prediction of southwest (SW) monsoon (Hereafter called as monsoon) rainfall by a numerical weather prediction (NWP) model is a very difficult task because the land-air-sea interactions involved in the rainfall processes are very complex. In spite of these problems, attempts are made for last few years to forecast the monsoon rainfall on different spatio-temporal scales using very sophisticated models. In India, four models (T80, T170, MM5 and Eta) are run at the National Center for Medium Range Weather Forecasting (NCMRWF) for predicting rainfall and some other important weather parameters. In order to understand the present status of these models in predicting the spells of high rainfall, a study is carried out to assess their performance during active monsoon situation. For this purpose, the rainfall amount predicted by the models in the vicinity of the stations is compared with the observed rainfall at the stations. The stations which experienced minimum 5 cm/day are considered. Inter-comparison of model forecast is also carried out. The period of study is from 1- 4 August 2004.

The results show that, in general, all the models predicted good rainfall activity along the west coast of India, which is consistent with the observations. However, the amount of rainfall was under-predicted. Overall performance of Eta model was better as compared to other models. However, certain heavy rainfall spells occurred over some other regions were not captured by any of the models. The reasons for difference between observed and model forecast rainfall are brought out in this report in the light of the initial fields of the models as well as regional aspects of monsoon rainfall.

1. Introduction

The quantum of rainfall received during the monsoon season (June-September) is of vital importance for India, as the most of the agricultural production as well as the power generation chiefly depend upon monsoon rainfall. Therefore, vast amount of research work has been carried out over the years for understanding various facets of monsoon and attempting to predict monsoon rainfall on different spatio-temporal scales (Rao, 1976, Fein and Stephens, 1987). All India monsoon rainfall mainly comprises the rainfall of the short duration spells over different parts of the country. These spells are associated with certain semi-permanent synoptic or the mesoscale systems.

Monsoon is a gigantic tropical phenomenon involving complex land-air-sea interactions of different scales over the data sparse region. Therefore, the prediction of monsoon rainfall by any technique on any time or space scale is quite intriguing. In last couple of decades, several sophisticated numerical weather prediction (NWP) models have been developed with complex physical processes and advanced data assimilation schemes. In India, National Center for Medium Range Weather Forecasting (NCMRWF) at Noida, provides daily weather forecast based on the NWP models for the benefit of the farmers and other user community. The short range (1-3 days) prediction of the high rainfall spells of monsoon is of utmost importance for issuing the warning about catastrophic floods, disruption of transport over the regions and to take necessary measures to reduce the damage to life and property. As the accuracy of the amount of rainfall forecast is very important, a study is carried out to assess the performance of different NWP models run at NCMRWF in predicting events of high rainfall during monsoon.

The high rainfall spells ($\geq$ 5 cm/day) were reported at some stations during an active monsoon situation of August 2004. They are studied with respect to the corresponding NWP models forecast.

2. Synoptic situation

During August 1-3, 2004, monsoon was active over large parts of India and many stations experienced high rainfall spells. This period is considered for the study. The broad features of the synoptic systems present over the region (Figure 1) are briefly described below.

The monsoon trough at sea level passed through Rajasthan, Madhya Pradesh, Bay of Bengal off north Andhra-Orissa coasts and thence to Andaman sea. The off-shore troughs at sea level were noticed over the Arabian Sea from Maharashtra to Kerala coast during 31 July to 2 August and from south Gujarat to Karnataka coast during 3-4 August 2004. One low pressure area (LPA) had formed over the central India during 31 July to 2 August 2004. Several upper air cyclonic circulations (UPCYCIR) of varying durations were present over Madhya Pradesh, Gujarat and Rajasthan, northwest Bay of Bengal off Orissa-West Bengal, Andhra-Orissa coasts, Jharkhand, Punjab and the adjoining area. A western disturbance (WD) as an upper air system was noticed on 31 July 2004 over north Pakistan, Jammu and Kashmir. It moved away northeastwards on 1 August 2004. The synoptic chart of India Meteorological Department (IMD), Pune for 2 August 2004 at 03 UTC (0830 LST) is shown in Figure 2. The mean sea level pressure (MSLP) distribution over the region is depicted with the isobars at 2 hPa interval. The monsoon trough and the off shore trough are seen in the figure and the locations of the lowest closed isobars of 996 hPa are noticed over Pakistan, East Rajasthan and adjoining region. The details of the synoptic situations and the day-to-day weather during 1-3 August 2004 are available in IMD reports.

3. NWP models

Four NWP models run at NCMRWF are considered for the present study. Out of these, T80 and T170 are the global spectral models. They are adopted from National Center for Environmental Prediction (NCEP), USA. Other two models viz. MM5 and Eta are the mesoscale models. The MM5 model is a fifth generation model developed at Penn State University and National Center for Atmospheric Research (NCAR), USA (Grell et al., 1994). The Eta model uses a step mountain co-ordinate (eta) system (Janjic, 1994). Both the mesoscale models are run with the initial boundary conditions from T80 model. Important specifications of the models are given in Table 1. Other details of the models are available on NCMRWF website: http://www.ncmrwf.gov.in .

4. Methodology

The cumulative rainfall reported by the stations for 24 hours at 03 UTC is compared with the corresponding rainfall predicted by the NWP models for 24 hours in the vicinity of the stations. The stations reported rainfall is collected from All India

Weather summary, Weekly weather reports and website (http://www.imd.ernet.in) of IMD. The station locations with abbreviated names are shown in Figure 1. The models predicted rainfall amount is picked up from NCMRWF prediction charts valid for 24 / 48 hours. The T80 and MM5 models rainfall predictions were valid at 00 UTC whereas for T170 and Eta, the predictions were valid at 03 UTC. Therefore, while comparing the model predicted rainfall with the station reported rainfall, there may be some difference for T80 and MM5 models because of three hours lag.

5. Results

Table 2 shows the stations reported rainfall and the corresponding rainfall predicted by all four models for 2 August 2004. The predicted rainfall amount from 0.1 to 0.7 cm is denoted as 0.5 cm implying that some rainfall was predicted by the model near the station location. Figures 3 (a) and 3 (b) show T170 model predicted rainfall chart over the region and the reported rainfall at the stations on 2 August 2004 respectively. Isolines of 0.1 cm rainfall are not shown in Figure 3 (a), but they are taken into account. The Tables and the charts for other models and days are not shown in the report for brevity. Figures 4-6 show the histograms of the rainfall reported at the stations and the corresponding models (T170, MM5 and Eta) predicted rainfall during 1-3 August 2004 respectively.

5.1 Characteristics of the rainfall reported at the stations

Total 29 stations spread over different parts of India reported high rainfall spells during the period. Six stations viz. Bhira, Dahanu, Mumbai, Mahabaleshwar, Agumbe and Koida reported high rainfall on all three days, seven stations viz. Honawar, Veraval, Porbandar, Ajmer, Long Island, Pune and Chandigarh for two days and remaining 16 stations for one day. Out of 48 such cases, half of the cases were with the reported rainfall of 10.0 cm/day or more. During the period of study, Mahabaleshwar (46.0 cm) reported the highest rainfall on August 3, 2004.

5.2 Models predicted *vis-à-vis* stations reported rainfall

The salient features of the rainfall forecast with respect to each of the NWP models considered here are briefly described below.

(a) T80 model : T80 model has predicted widespread rainfall over the country. The predicted rainfall was in the range from about 0.5 cm to 4.5 cm/day. Along the west coast of India model showed good rainfall activity. However, it was much under predicted as compared to the reported rainfall. In general, high rainfall amounts are not predicted by the model. At some locations, the model predicted the rainfall of order of 1.0-2.0 cm/day, but the station in the region reported much less or no rainfall.

(b) T170 model : T170 model predicted rainfall at many places like T80 model but with more amount, the maximum being in the range of 4.0 - 8.0 cm/day. However, for some stations like Karwar, Honawar and Agumbe model predicted either less or the same rainfall as compared to T80 model. Model predicted 2.0-4.0 cm/day rainfall for Bhira and Mahabaleshwar while the stations reported 21.0 to 46.0 cm/day rainfall. For Mumbai, model predicted rainfall was comparable to the reported rainfall when it was on the lower side (5.0-8.0cm/day) on 1 and 3 August 2004. On 2 august 2004 when Mumbai reported 15 cm rainfall, the model predicted it about 4.0-8.0 cm. At Guna and Gannavaram model predicted better rainfall than other models and was reasonable on 1 and 3 August 2004. Surat recorded 25.0 cm rainfall on 3 August and the model predicted 5.0 cm rainfall at that place, which was more than the rainfall of other models. Over Jammu and Kashmir model predicted more than 2.0-4.0 cm/day rainfall on all three days, but except on 3 August 2004 (1.0 cm), practically no rainfall was reported at Srinagar, a station in this region for 2 August 2004 as seen from Figures 3 (a) and 3 (b). In general, very high rainfall spells are not predicted by the model as the case of T80.

(c) MM5 model : MM5 model predicted isolated high rainfall amount up to 8.0-16.0 cm/day. Rainfall predicted by MM5 model was much less as compared to the reported rainfall at some stations on 1 August. However, on 2 and 3 August, the rainfall reported by some of the

stations was more as compared to 1 August and MM5 model also predicted increased rainfall activity. In some cases, model predicted reasonable rainfall as compared to the station reports e.g. at Bansawara on 1 August, Pune on 2 August and Satara, Panjim, Port Blair and Long Islands on 3 August 2004. At some of the stations where very high rainfall was reported, the model underpredicted it in the range 0-2.0 cm/day. On the other hand, at some locations the model predicted good amount of rainfall whereas the stations in the region didn't report such rainfall e .g. over west Madhya Pradesh on 1 August and Jammu and Kashmir area during 1-3 August 2004. This suggests that model has shown the tendency to generate heavy rainfall spells at some locations where the observations didn't support such an activity.

(d) Eta model : Eta model has predicted 12 instances each with minimum rainfall 4.0 cm/day and 8.0 cm/day during the period of study. Bhira received more than 10.0 cm/day rainfall on all three days considered here. Eta model also predicted minimum 8.0 cm/day on all these days. The rainfall 4.0-8.0 cm predicted on some occasions was consistent with the reported rainfall e.g. at Pune, Baroda, Ahmedabad, Porbandar and Honawar. For Mumbai, the rainfall was over predicted on 1 August i.e. 8.0-16.0 cm as compared to the reported rainfall of 5 cm. In general, the model prediction was more uniform with good amount of rainfall at many stations as compared to other models. Rajagopal and Iyengar (2005) studied some cases of monsoon 2002 and showed that Eta model predicted rainfall along the west coast of India was quite close to the observations. The results presented in this report conform with this study.

5.3 High rainfall spells not predicted by the models

It is noticed that seventeen spells (about 30 %) of the high rainfall amount in 24 hours received at Dehradun (7.0 cm), Chandigarh (12.0 and 24.0 cm), Ambala (34.0 cm), Veraval (14.0 and 13.0 cm), Porbandar (8.0 and 9.0 cm), Ajmer (9.0 cm), Surat (25.0 cm), Kakinada (12.0 cm), Koida (8.0, 6.0 and 24.0 cm), Mount Abu (24.0 cm), Long Islands (6.0 cm) and Maya Bandar (9.0 cm) were not predicted by any model commensurate with the observations (Figures 4-6).

6. Discussion of the results

6.1 Station locations and the local conditions for high rainfall

The stations considered here are located in different regions. Bhira, Mumbai, Dahanu, Panjim, Honawar and Karwar are on the windward side while Pune and Satara are on the leeward side of western ghats. Mahabaleswar (altitude 1382 m) and Agumbe (altitude 645 m) are situated on the western ghats. Mount Abu (altitude 1195 m) in Rajasthan is a hill station. Bansawara is in East Rajastan while Gannavaram, Kakinada and Koida are in the eastern peninsula. Guna is in central India and Gaya is in the eastern region. Surat, Ahmedabad, Baroda, Veraval, Porbandar and Ajmer are in the western India between 20° to 27°N. Dehradun, Chandigarh and Ambala are near 30°N. Port Blair, L ong Islands and Maya Bandar are islands in the Bay of Bengal.

The main weather systems of the region responsible for high rainfall during monsoon are described in section 2. The rainfall along the west coast of India was mainly due to the activity of the off-shore trough, UPCYCIR and the topographic influence of western ghats. Similarly, the rainfall spells at the stations in Gujarat and Rajasthan could be mainly due to the UPCYCIR over this region. The enhanced rainfall activity at Mt. Abu (24.0 cm on 2 August 2004) could be attributed to the topography and the UPCYCIR. At Kakinada and Koida the rainfall must have been due to the activity of the LPA and the monsoon trough. The high rainfall at some north Indian stations like Chandigarh, Dehradun and Ambala could be due to the passage of the WD and the prevailing UPCYCIR over the region.

6.2 Comparison of initial fields

In order to see how the mean sea level pressure (MSLP) patterns are represented in NCMRWF- T80 model initial data as compared to IMD analysis (Regional Specialised Meteorological Center (RSMC), New Delhi), the two analyses for 2 August 2004 (00 UTC) are shown in Figures 7 (a) and 7 (b) respectively. It is seen that the lowest MSLP in IMD analysis was 996 hPa over northwest Bay and adjoining region as well as over northwest India whereas for T80 model initial analysis it was about 1000 hPa at these locations. The synoptic chart of IMD, Pune (Figure 2) and these two charts bring out marked differences in three analyses in resolving the meteorological systems and assessing their depth/strength in terms of

pressure gradients and the lowest pressure. Initial systems are weak in NCMRWF analysis as compared to IMD (RSMC) analysis. Closed isobars over head Bay and adjoining region seen in IMD (RSMC) and NCMRWF are not noticed in IMD synoptic analysis. On the other hand, a closed LPA with 996 hPa depicted in the synoptic analysis over north Indian region is not seen in other two analyses. The synoptic MSLP analysis is the subjective one performed by the experienced meteorologist while other two analysis fields are carried out by different objective analysis schemes adopted at NCMRWF and IMD (RSMC). Thus, the inter-comparison of the three initial MSLP analyses carried out at three centers show that they differ significantly from each other and it is not known which one is the closest to real state of the atmosphere. The mesoscale models (MM5 and Eta) use the analysis of T80 model as initial conditions. The difference was also noticed in upper air flow patterns of NCMRWF and IMD analyses in representing the circulations features in the initial fields (Not shown). NWP being the initial value problem, it is clear that if the initial analysis of the model doesn't represent the strength, size, gradients etc. of the important weather systems responsible for high rainfall events, the changes in the model specifications will not bring the desired effect in the accuracy of the rainfall prediction in the quantitative terms.

7. Conclusions

Almost all the models predicted good rainfall activity along the west coast of India. This was consistent with the observations, although the amount was under predicted. The global models predicted wide spread rainfall over the country with less amount. Mesoscale models predicted high rainfall spells to a reasonable amount as compared to the reported rainfall at some stations. Overall performance of Eta model was better as compared to other models for predicting rainfall along the west coast of India and over some other places. Nearly, one third of the cases of high rainfall spells were not predicted by any of the models. Most of such locations are north of 20^{o} N or the eastern peninsula or in the Bay of Bengal. All the models over-predicted the rainfall at certain places. In general, no particular NWP model has performed satisfactorily in predicting the high amount of rainfall in different parts of the India at the same time.

The comparison of three initial MSLP analyses performed at three centers show different pressure patterns in resolving the weather systems for the same synoptic situation. Therefore, it is not known which are exact fields for the model

initial analysis. This is one of the reasons for improper prediction by the models. Secondly, the regions of India are non-homogeneous with respect to land-ocean contrast, terrain distribution and the prevailing weather systems. Therefore, it is very difficult to assess what specifications of the model are required for a particular region to bring out combined effect of the local factors to predict high amount of rainfall comparable to the observations.

The study suggests that in order to cater the urgent need for the reasonably good prediction of high rainfall spells by NWP models, the development of empirical relationship between model predicted and the stations reported rainfall under specific weather conditions would be desirable, till one unified model is developed taking into account the complexities of monsoon over different regions of the country.

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Table 1: ***Model specifications***

Model	Specifications			
	Horizontal resolution (km)	Vertical levels	Topography	Convection parameterisation scheme
T80	150	18	Mean	Deep : Kuo (modified) Shallow : Tiedtke
T170	75	28	Mean	Deep : Kuo (modified) Shallow : Tiedtke
MM5	30	23	USGS	Grell : Arakawa – Schubert (simplified)
Eta	48	38	Silhouette	Betts-Miller-Janjic

Table 2: *Stations reported and corresponding models predicted rainfall (cm) on 2 August 2004 in the vicinity of the stations.*

No.	Stations	Reported rainfall	Model predicted rainfall			
			T80	T170	MM5	Eta
1	Dahanu	20.0	2.5	8.0	2.0	8.0
2	Mumbai	15.0	3.0	4.0-8.0	4.0-8.0	8.0-16.0
3	Bhira	26.0	3.5	4.0	8.0	8.0
4	Mahabaleshwar	21.0	3.0	4.0	8.0-16.0	4.0
5	Agumbe	7.0	2.0	1.0	1.0	4.0
6	Koida	6.0	1.0	1.0	0.0	0.5
7	Pune	6.0	2.5	2.0-4.0	4.0-8.0	6.0
8	Veraval	13.0	1.5	2.0	2.0-4.0	4.0
9	Porbandar	9.0	1.5	2.0	1.0	4.0
10	Ahmedabad	7.0	1.0	0.5	0.0	4.0
11	Baroda	5.0	1.5	2.0	0.0	4.0
12	Ajmer	5.0	0.5	1.5	1.0	1.0-2.0
13	Mt. Abu	24.0	0.5	1.0	2.0	2.0
14	Dehradun	7.0	0.5	1.0	0.5	0.5
15	Chandigarh	12.0	0.5	0.5	0.0	0.5

Figure 1. Regions and the stations considered in the study. (●) indicates station location. Abbreviations of the stations used in the figure :

AGB – Agumbe, AHM – Ahmedabad, AJM – Ajmer, AMB – Ambala, BSR – Banswar, BRD – Baroda, BRA – Bhira, CHN – Chandigarah, DHN – Dahanu, DDN – Dehradun, GNV – Gannavaram, GYA – Gaya, GNA – Guna, HNV – Honawar, KND – Kakinada, KWR - Karwar, KDA - Koida, LGL - Long Islands, MWR - Mahabaleshwar, MYB - Maya Bandar, MAB - Mount Abu, MUM – Mumbai, PJM - Panjim, PRE - Porbandar, PBL - Port Blair, PNE - Pune, STA - Satara, SRN - Srinagar, SRT - Surat, VVL - Veraval.

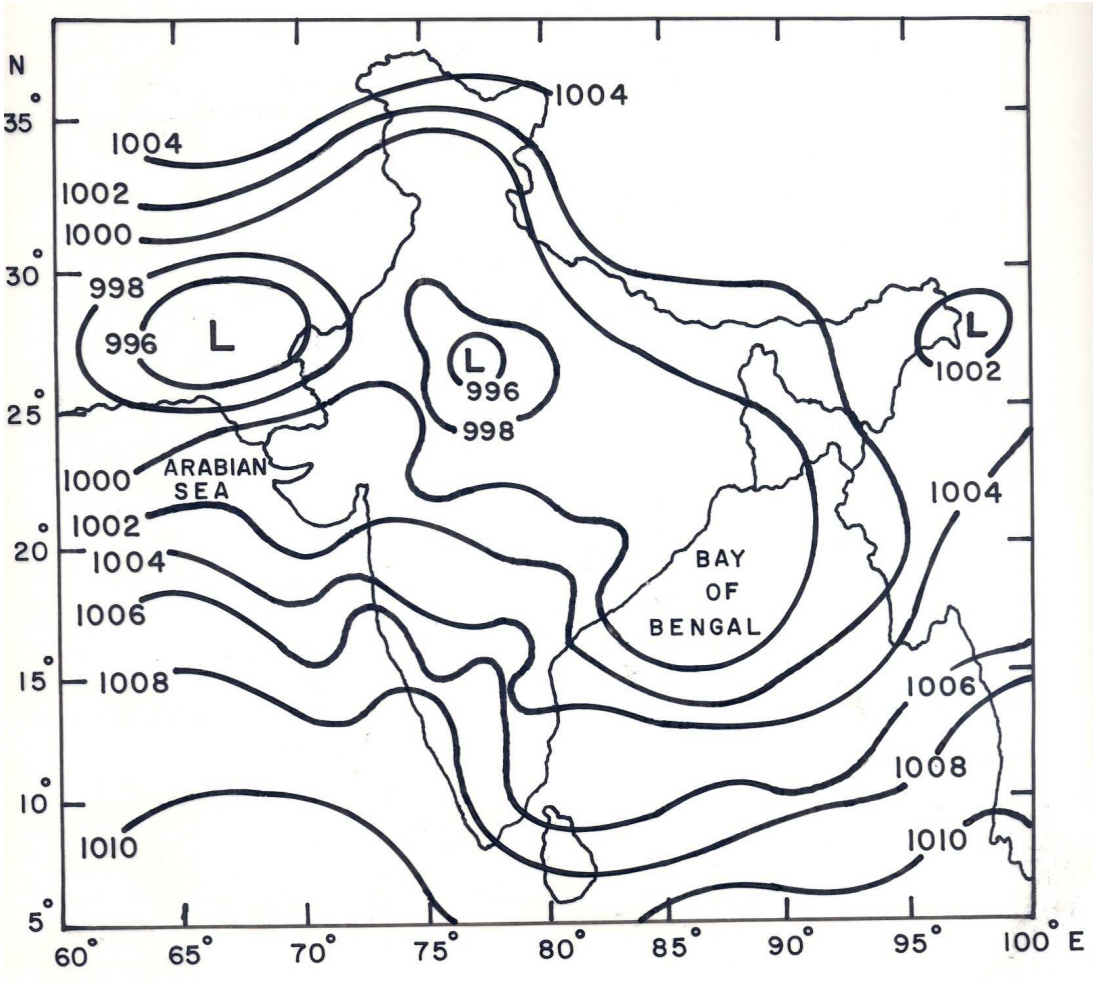

Figure 2. IMD Synoptic chart for 2 August 2004 (3 UTC) - MSLP at 2 hPa interval

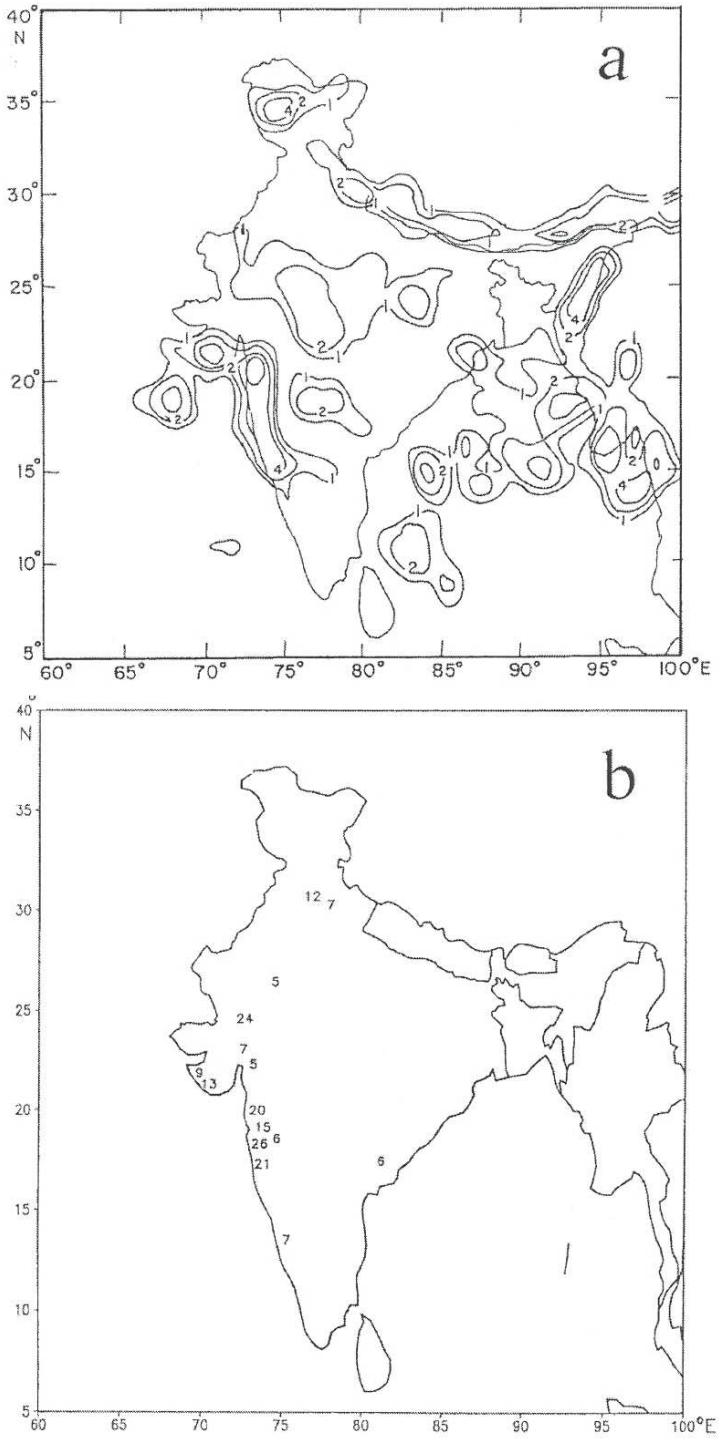

Figure 3. (a) Rainfall (cm) predicted by T170 model for 24 hours valid on 2 August 2004 at 03 UTC. Contour intervals at 1, 2, 4, 8…cm (b) Rainfall (cm) reported at the stations on 2 August 2004 at 03 UTC (IMD)

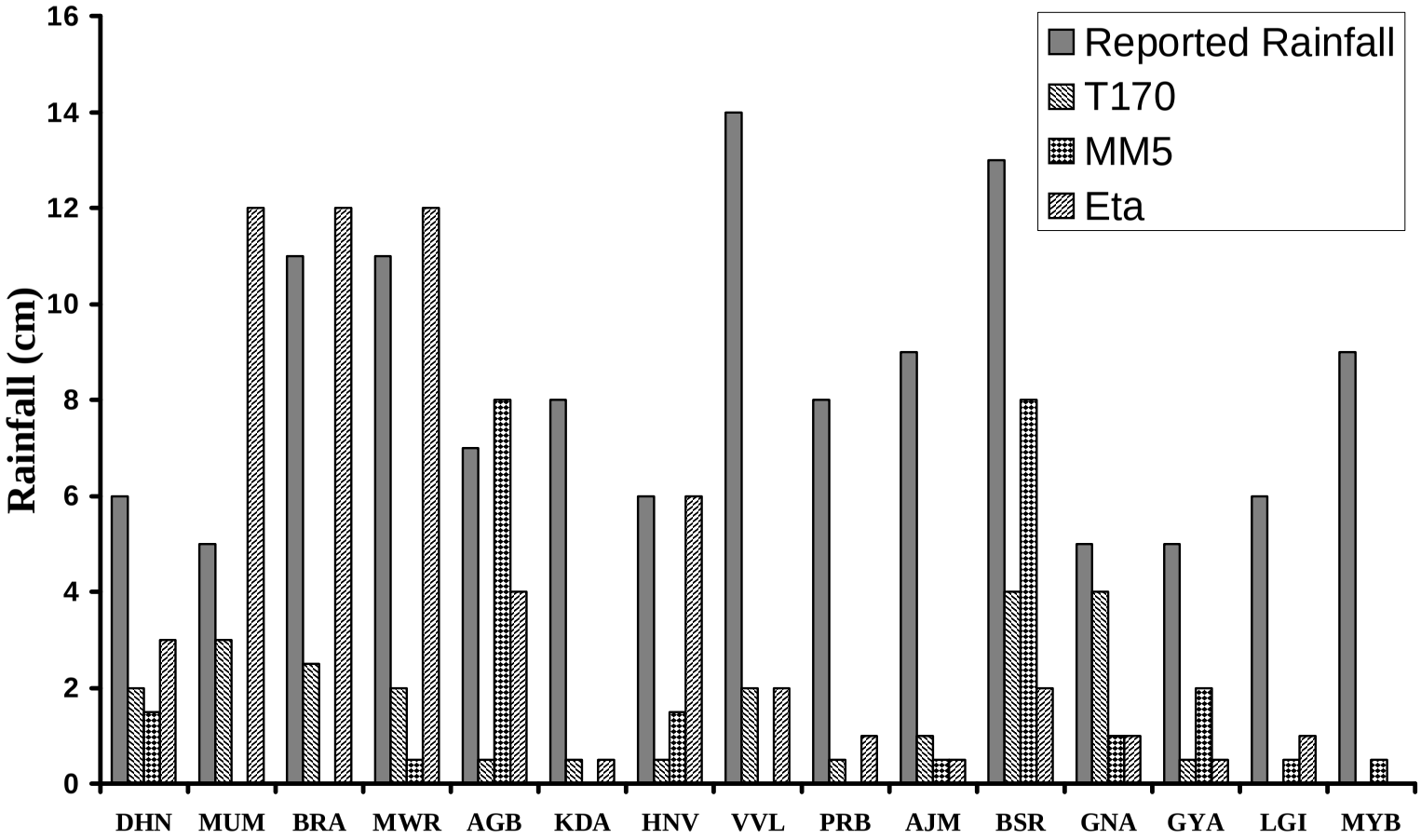

Figure 4: Histogram for the rainfall reported by the stations and that predicted by different models for 01 August 2004.

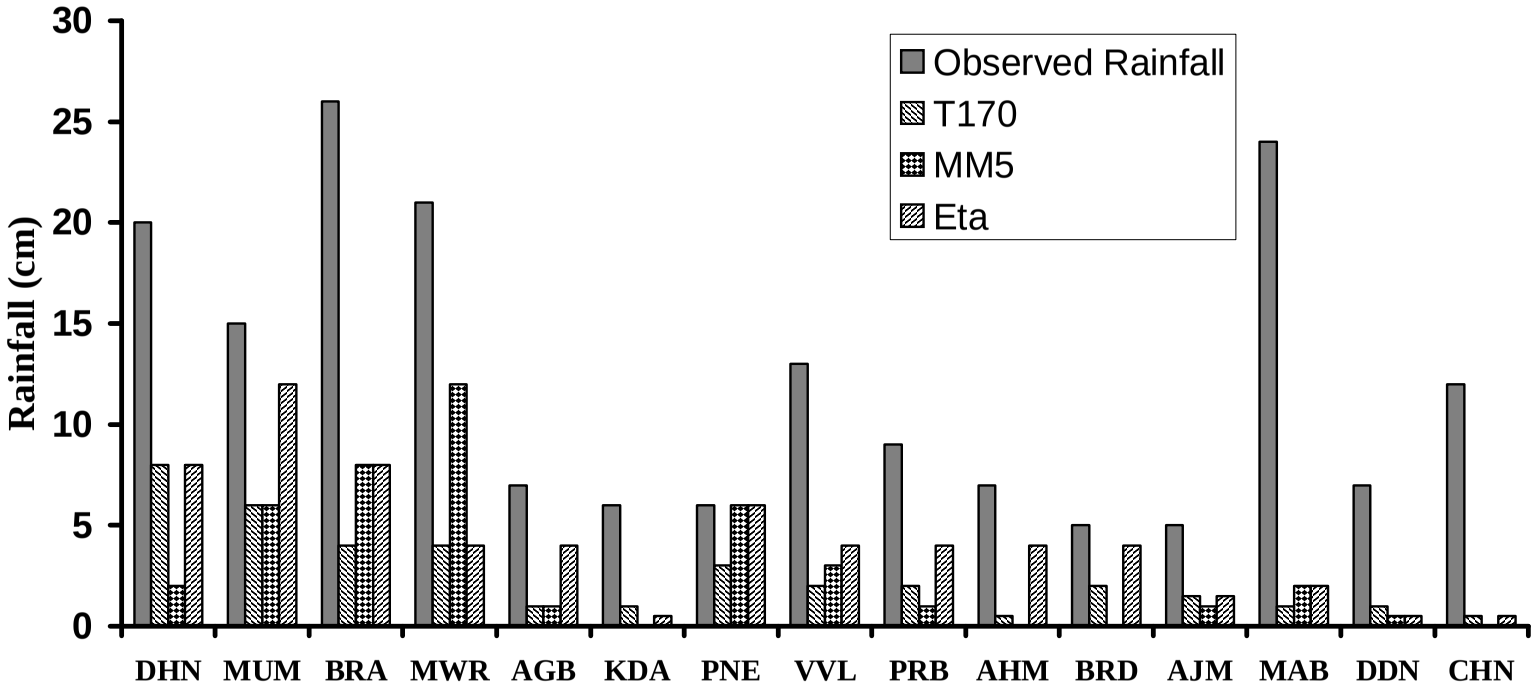

Figure 5: Same as figure 4, but for 02 August 2004.

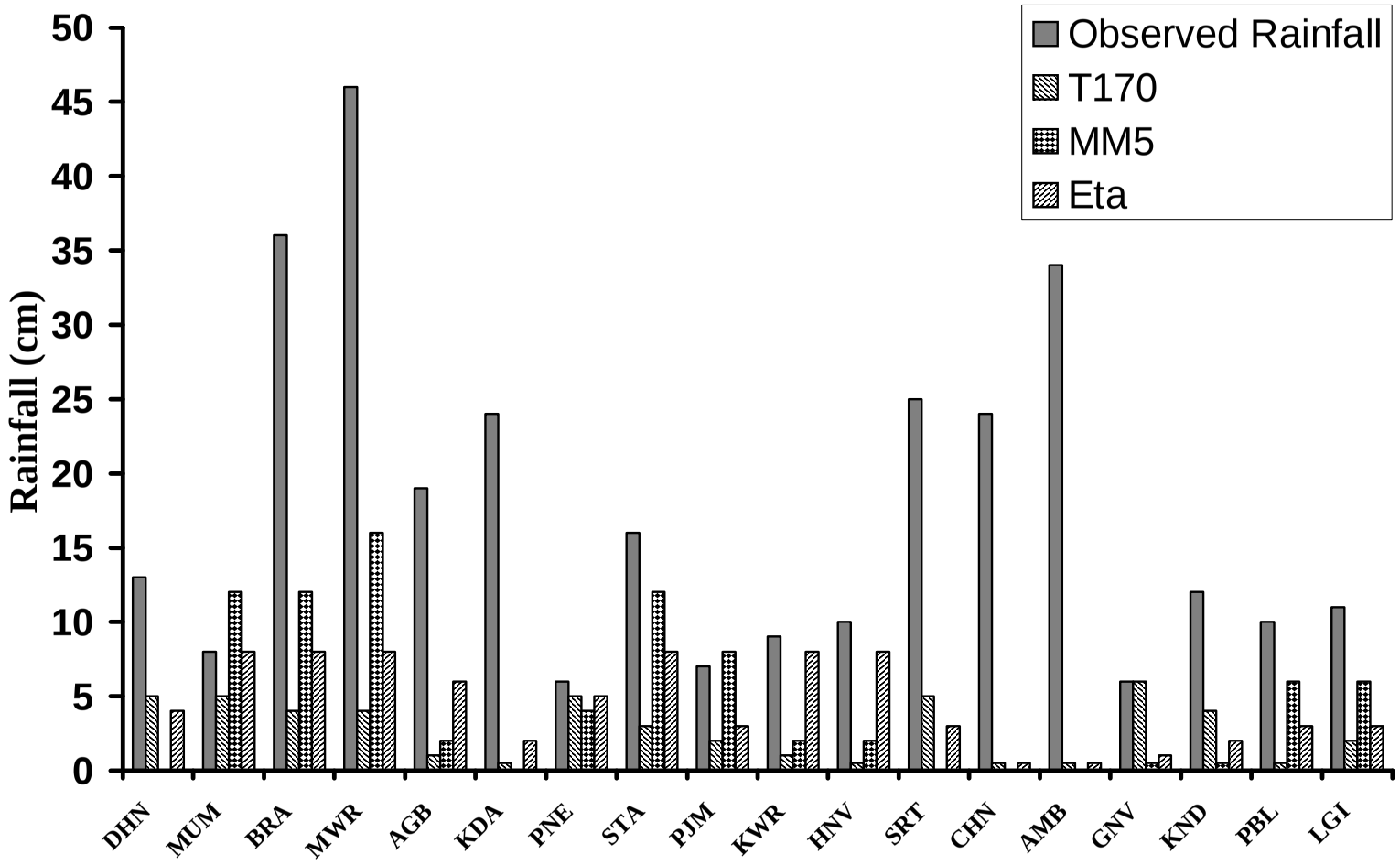

Figure 6: Same as figure 4, but for 03 August 2004.

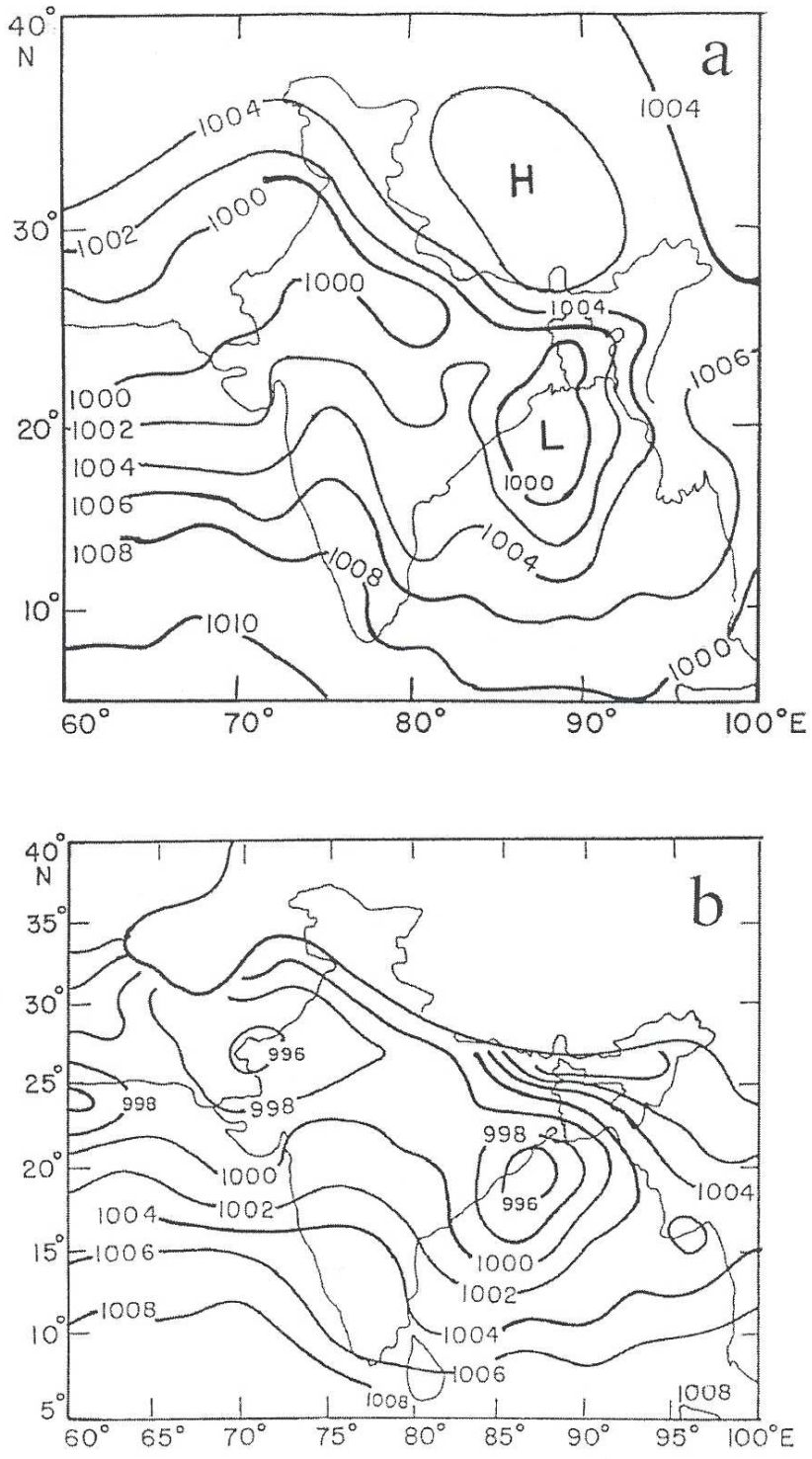

Figure 7. MSLP (hPa) analyses on 2 August 2004 (00 UTC) (a) NCMRWF – initial analysis for T80 model (b) IMD (RSMC), New Delhi