MAUSAM, **56**, 3 (July 2005), 543-548

551.553.21 : 551.577.2

Mesoscale features of monsoon precipitation system as revealed by the objective analysis of rainfall from the use of high dense land rainfall observations

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(*Received 23 March 2004, Modified 18 November 2004*)

सार – इस शोध–पत्र में जून 2001 के सघन भू प्रेक्षणों और उपग्रह वर्षा अनुमानों का उपयोग करते हुए भारतीय मानसून क्षेत्र में 1°×1° अक्षांश/देशांतर के विभेदन पर दैनिक वर्षा के विश्लेषण के लिए एक सरल पद्धति का अनुप्रयोग किया गया है । इससे प्राप्त हुए परिणामों से पता चला है कि इस विश्लेषण में मानसून वर्षा प्रणाली के बृहत मान के साथ–साथ मेसोस्केल के लक्षणों को ग्रहण करने की क्षमता है। आशा है कि इन आँकड़ों की उपलब्धता सिनॉप्टिक मौसम वैज्ञानिकों और सांख्यिकीय मौसम पूर्वानुमान निदर्श समुदाय के लिए बहुत उपयोगी सिद्ध होगी।

ABSTRACT. A simple method for daily rainfall analysis at the resolution of 1° × 1° Lat./Long. over Indian monsoon region is applied from the use of dense land observations and satellite rainfall estimates for the month of June 2001. The results obtained show that the analysis is able to capture large scale as well as mesoscale features of monsoon precipitation system. The availability of this data is expected to be very useful for the synoptic meteorologists and numerical weather prediction modelling community.

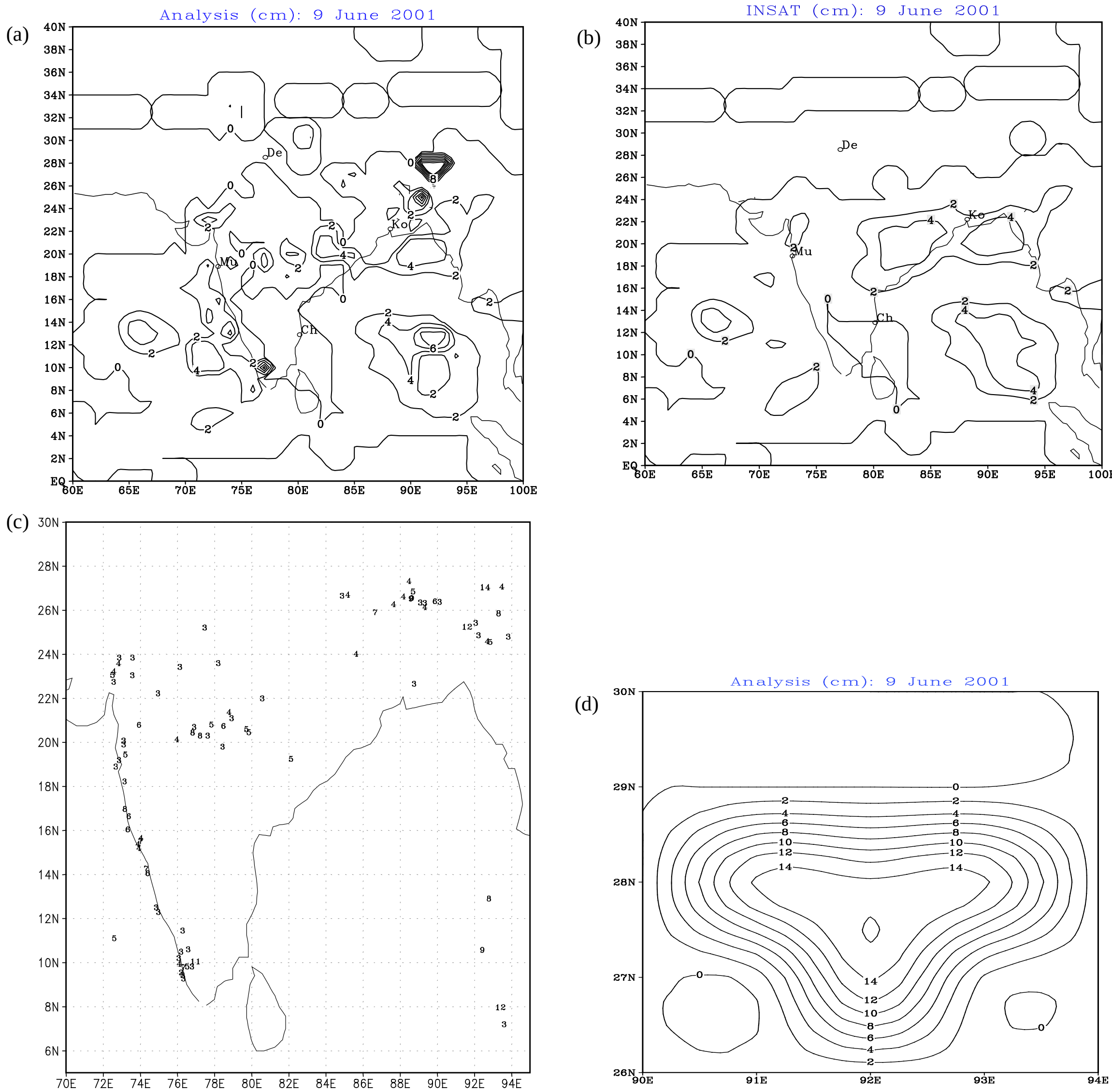
Key words – Objective analysis, Monsoon precipitation system, Mesoscale feature.

1. Introduction

For the purpose of verification of numerical model output one needs to get the rainfall observations at the model grid points. The daily gridded rainfall data has also various other utilities such as, for the physical initialization of numerical models (Krishnamurti *et al.* 1995), for calculation of fresh water flux for ocean modelling, studying precipitation system, precipitation climatology (Spencer, 1993), river management etc.

In absence of such data, satellite derived precipitation estimates are used in number of studies (Janowiak, 1992; McBride and Ebert, 2000; Roy Bhowmik and Prasad, 2001) for validation of rainfall forecast from Numerical Weather Prediction (NWP) models. But the accuracy of the satellite product is limited due to the indirect relationship of cloud top temperature and precipitation (Richard and Arkin, 1981). It is well established (Arkin *et al*., 1989; Janowiak, 1992; Ebert and Marshal, 1995; Roy Bhowmik and Sud, 2003) that satellite precipitation estimates fail to capture orographic rainfall, apart from certain other seasonal and geographical biases. Despite these shortcomings, this is the only source of rainfall information presently available over the Ocean and data sparse land region. In view of growing demand of gridded rainfall data, recent studies (Xie and Arkin, 1996; Mitra *et al*., 1997; 2003) emphasized for improved rainfall analysis dataset by combining rain gauge data and satellite estimates. Xie and Arkin (1996) discussed a methodology to obtain a rainfall data set from satellite estimates and rain gauge data on monthly time scale. Mitra *et al*. (1997, 2003) applied Cressman technique (1959) for objective analysis of rainfall over Indian monsoon region at the resolution of 1.5° × 1.5° Lat./Long. from the use of INSAT (Indian Geostationary Satellite) derived precipitation estimates at 2.5° × 2.5° Lat./Long. resolution and rain gauge data available in real time by global telecommunication system (GTS). They concluded that there is a scope for further improvement in the analysis by increasing land observations and grid resolution. In their studies, number of land stations (about 80 to 140 stations) used for contributing to 185 grid boxes for Indian land region is not adequate. For 150 km grid spacing each grid box covers an area of 22500 sq. km. Assuming that each rain gauge represents an area of 75 × 75 sq. km, it needs at least 4 number of observations for computation of reliable grid box average.

In the present study about 573 daily rain gauge observations received from synoptic and DRMS (District-wise Rainfall Monitoring Scheme) network of India Meteorological Department (IMD) are utilized as observed data set. In order to cover the data gaps over the sea areas, this rainfall data set is supplemented by INSAT



Figs. 1(a-d). (a) Rainfall analysis (cm) of 9 June, (b) same as (a) except for the satellite estimates, (c) corresponding land rainfall observations (cm) and (d) Orographic rainfall (cm) of 9 June over Assam hills during the formation of a monsoon low pressure system over the north Bay of Bengal

derived precipitation estimates. These satellite data are obtained on the grid resolution of 1° × 1° Lat./Long. following the algorithm described by Arkin *et al*. (1989). The data sets for this study cover the area between Lat. 0° to 40° N and Long. 60° to 100° E, which includes 415 grid boxes over the Indian land areas.

The objective of this study is to demonstrate the potential of this analyzed data to capture monsoon precipitation system and its structural characteristics. The study is based on daily rainfall data for the month of June 2001. Daily rainfall represents 24 hours accumulated rainfall ending at 0300 UTC of a day.

2. Methodology

In any objective analysis technique the main idea is that estimation at any point is considered as a weighted average of the mean values of irregular sites. If $Z_{i,m}$ are the observations from i = 1,…., n measurement sites, then following Zakia Sen (1997), the estimated value Z_m at the grid point m can be written as :

$$Z_m = \left[\frac{\sum_{i=1}^{n} W\left(r_{i,m}\right) \quad Z_{i,m}}{\sum_{i=1}^{n} W\left(r_{i,m}\right)} \right]$$

Where the weighting function $W(r_{i,m})$ is defined as (Thiebaux and Pedder, 1987) :

$$W(r_{i,m}) = \left(\frac{R^2 - r^2_{i,m}}{R^2 + r^2_{i,m}}\right)^2, \quad \text{for} \quad 0 < r_{i,m} < R$$

$$= 0 \,, \quad \text{for} \quad r_{i,m} \geq R$$

$$= 1 \,, \quad \text{for} \quad r_{i,m} = 0$$

R is called the radius of influence and $r_{i,m}$ is the distance between i th site and the estimation point m. For the present study R is considered as 200 km.

As adequate land observations are available over the country (573 observations for 415 grid boxes of size 1° × 1° Lat./Long.), for the grid boxes over the Indian land, satellite estimates are not included for computation.

3. Results and discussion

Monsoon low pressure system is the main rain producing system of summer monsoon over Indian region which forms over the northwest Bay of Bengal and moves northwest wards across the country giving rise to heavy to very heavy falls during its passage. Western Ghats of India is another region where heavy orographic rainfall occasionally occurs during the active phase of monsoon due to the strong lower tropospheric westerlies. Intense orographic rainfall is also realized often over the hill areas of Assam because of orographic lifting. Although the daily rainfall analysis is done for 30 days of June 2001, in this paper episode of a monsoon low pressure system whose life span was more than a week, is selected for discussion.

The low pressure area formed over the northwest Bay of Bengal and neighborhood on 9 June, became well marked over the same area on 11 June. It concentrated into a depression on 12 June and lay centered near Lat. 20° N / Long 87° E. Moving northwesterly direction it crossed Orissa coast in the afternoon of 12 June. It moved further inland and situated over northwest part of Orissa in the morning of 13 June. It weakened into a well marked low pressure area on 14 June and lay over Chattisgarh and neighborhood. Subsequently as a low pressure area system persisted over east Madhya Pradesh and neighborhood on 15 June and over northwest Madhya Pradesh and adjoining Rajasthan on 16 June with the associated upper air cyclonic circulation extending upto mid-tropospheric levels.

Figs. 1 (a&b) shows the rainfall distribution based on the analysis and satellite estimates respectively of 9 June

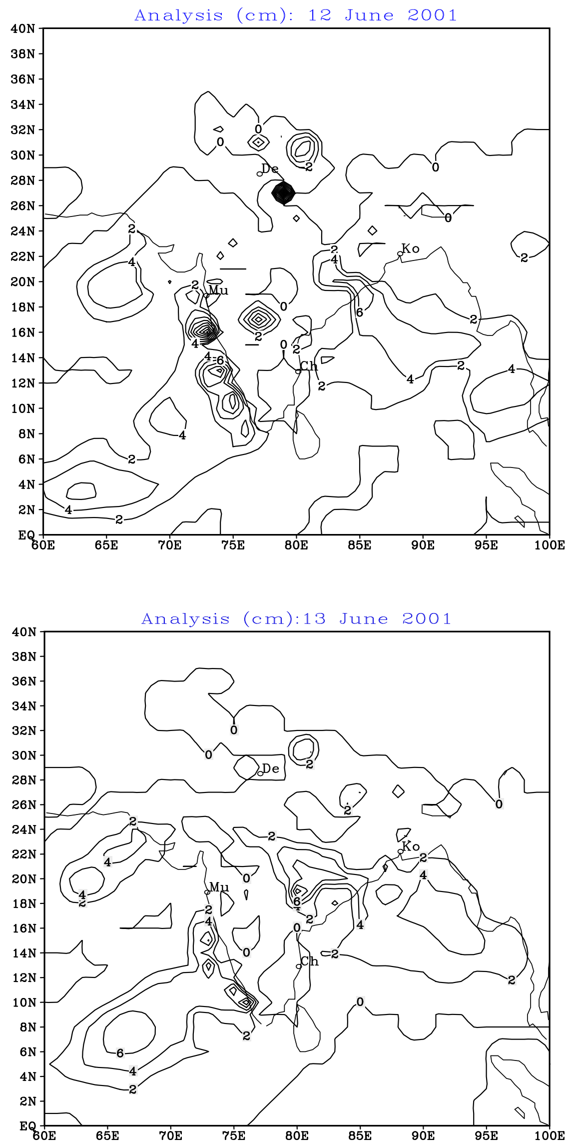


Fig. 2. Rainfall analysis of 12 and 13 June 2001 during the movement of monsoon low pressure system across the country

2001 when the monsoon low pressure area was forming over the northwest Bay of Bengal. Isohyets are plotted at a regular interval of 2 cm. The analysis shows rainfall (2-6 cm) belts over the northwest Bay of Bengal, Orissa, west coast of India (Kerala, Karnataka and south Konkan coasts) and over the Andaman Sea. Another small-scale heavy rainfall pocket is also seen over the Khasi hill areas in Assam. In the satellite estimates [Fig. 1(b)] rainfall activities along the west coast of India and over Assam hills are absent. Satellite estimates have less spatial variability and are generally very smooth. The corresponding plot of land rainfall observations is shown

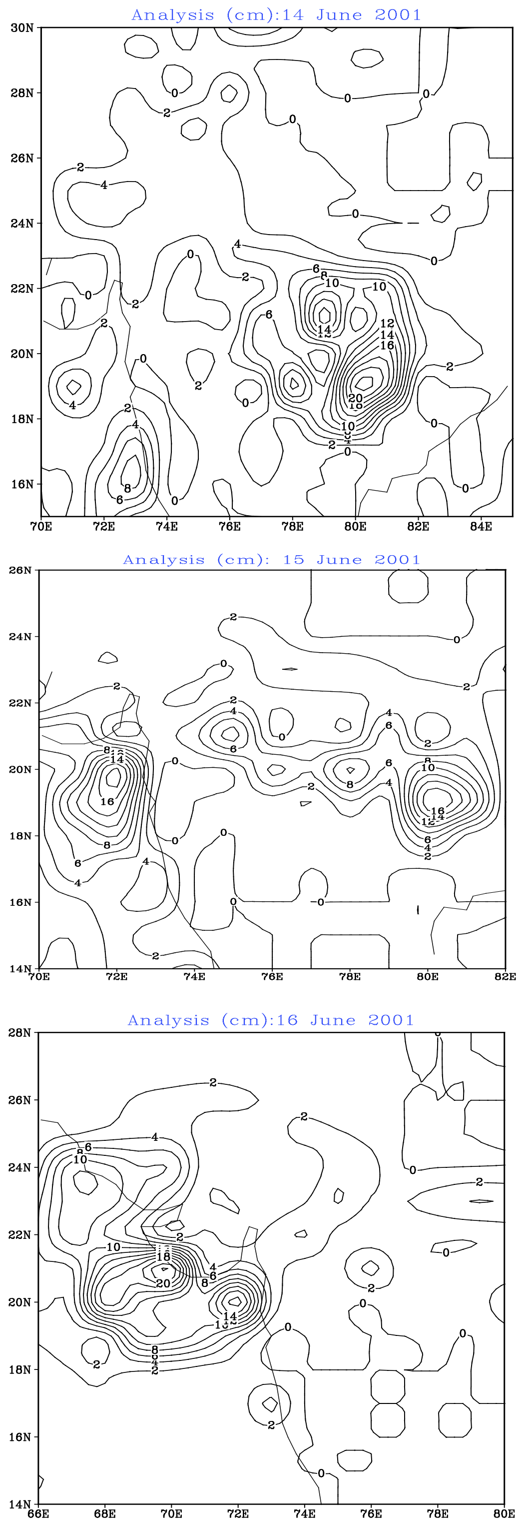


Fig. 3. Structural characteristics of rainfall (cm) distribution in association with monsoon low pressure system based on analysis for 14 June, 15 June and 16 June respectively

in Fig. 1(c). In order to avoid overlapping of rainfall between two neighboring stations, rainfalls less than 3 cm are not considered for plotting. [Higher amount of rainfall like 33 cm near Lat. 26°/Long. 89° is due to overlapping of two stations of rainfall amount 3 cm each] The plot of land rainfall is found to be in well agreement with the rainfall analysis [Fig. 1(a)]. The orographic rainfall over the Khasi hill in Assam is shown separately in Fig. 1(d). It is interesting to note that the analysis could bring out this mesoscale structure of orographic heavy rainfall (with peak amount 14 cm).

Fig. 2 presents the daily rainfall analysis of 12 and 13 June during northwest movement of the monsoon low pressure system. The active rainfall belt extended from the northwest Bay of Bengal to westwards over the land areas. The rainfall activity over the west coast of India increased considerably.

On 14 June a robust organization of convections ahead of the low pressure system is noticed. In order to examine the structural characteristics of this precipitation system, the analysis field (Fig. 3) is shown in a smaller domain covering the influenced area of this system. The analysis field of 14 June exhibits organization of mesoscale convections with two prominent rainfall maxima situated west and southwest of the system. The primary maxima with heaviest intensity of 22 cm is located near Lat. 19° N and Long. 80° E. The secondary maxima with intensity of 16 cm rainfall is seen near Lat. 21° N and Long. 79° E. Over the area between Lat. 18° to 22° N and Long. 77° to 80° E three other meso scale rainfall (4 to 10 cm) cells are seen. The depression was centered near Lat. 21° N and Long. 85° E on 13 June at 1200 UTC. Along the west coast of India intense orographic rainfall zone with peak intensity of 8 cm is noticed centered near Lat. 16° N and Long. 73° E. The corresponding satellite estimates shows a maximum value of 6 cm covering wider areas with center near Lat. 18° N and Long. 79° E (Fig. 4).

The heavy rainfall belts gradually shifted westward during 15 and 16 June. On 16 June rainfall activity was confined over north Konkan and adjoining areas of Gujarat region and Arabian Sea. In the analysis of 15 June (Fig. 3) the rainfall maxima of order 16 cm and 8 cm are observed at Lat. 19° N / Long. 80° E and Lat. 20° N / Long. 78° E respectively. Two other meso scale rainfall (6 to 8 cm) cells are observed east of Long. 74° E between Lat. 20° and 22° N. Along the west coast of India very intense orographic rainfall zone with peak intensity of 18 cm is located with center near Lat. 20° N and Long. 73° E. The satellite estimates show east west oriented rainfall maximum of order 4 to 6 cm covering the domain between Lat. 18° N to 22° N and Long. 70° E to 80° E. On

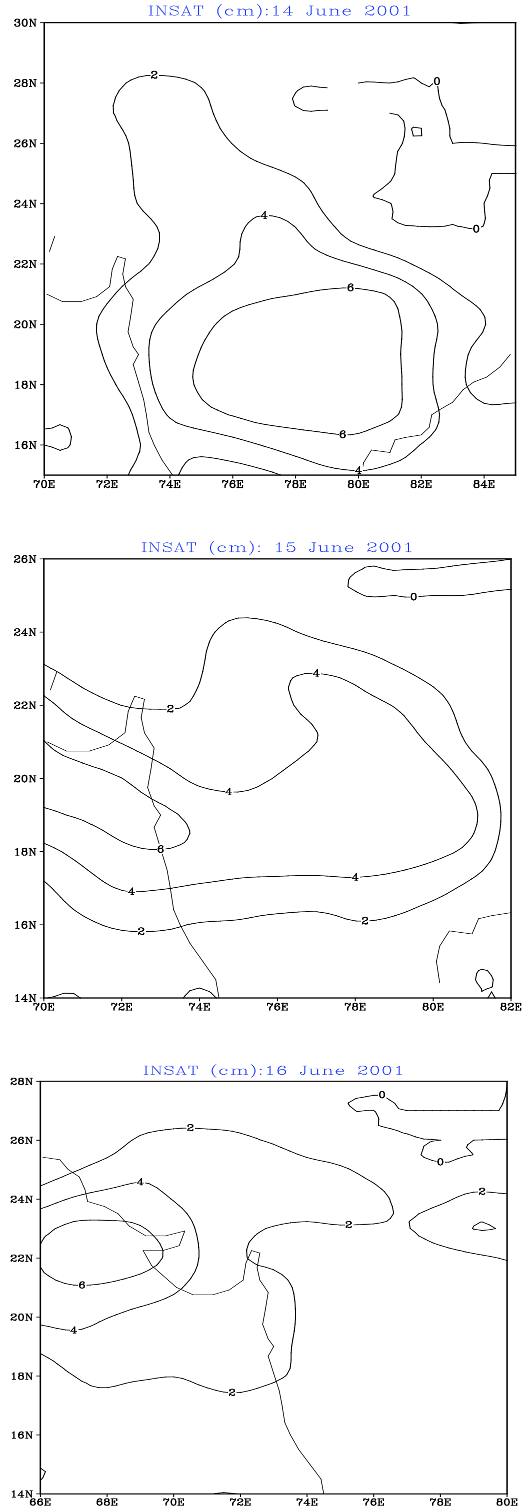


Fig. 4. Same as Fig. 3 except for the satellite estimates (cm)

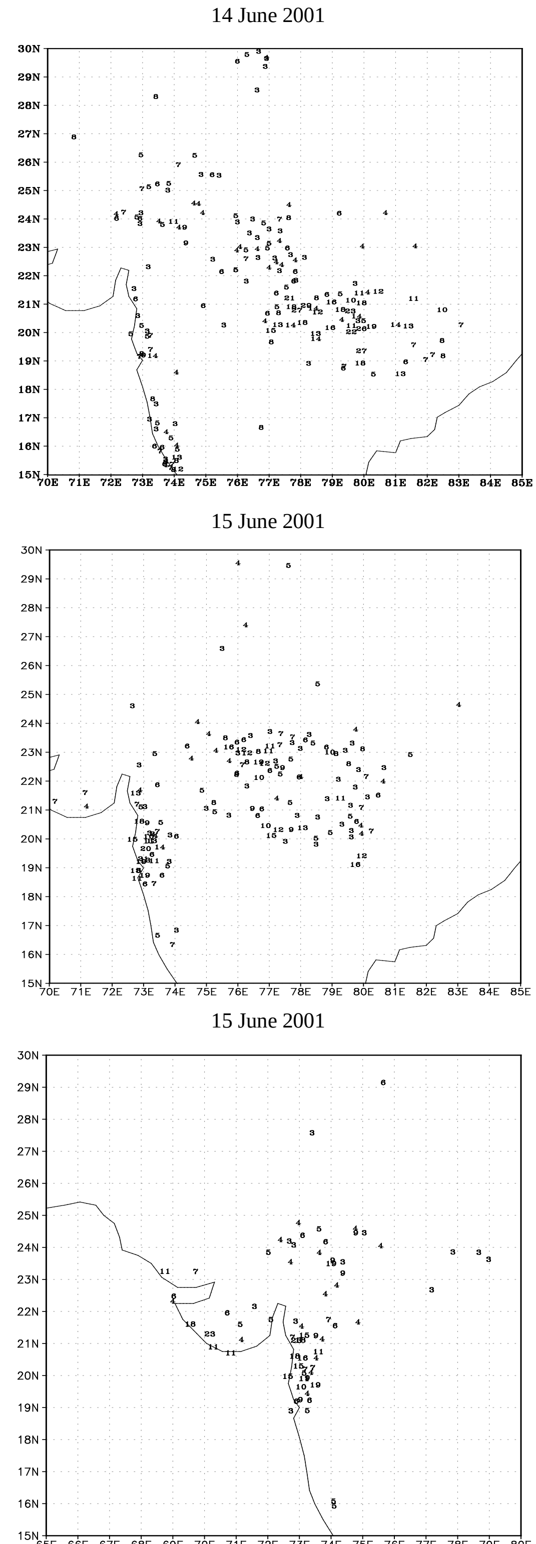


Fig. 5. Same as Fig. 3 except for land rainfall observations (cm)

16 June the intense rainfall belts rapidly moved westward. Two rainfall maxima of order 22 cm around Lat. 21° N /Long. 70° E and 18 cm around Lat. 20° N / Long. 72° E are observed. The corresponding satellite estimates (Fig. 4) shows a rainfall maxima of order 6 cm neat Lat. 22° N / Long. 69° E. The corresponding plots of land rainfall observations are shown in Fig. 5. [The higher rainfall amount of 44 cm near Lat. 24.5° / Long. 75.5° is due to overlapping of two stations]. The rainfall analysis (Fig. 3) is found to be in well matching with the corresponding land rainfall plots.

One of the important aspects of monsoon depression is the asymmetric distribution of rainfall around its center (Chaudhury and Gaikwad, 1983; Venkatraman *et al*., 1974; Rajamani and Rao, 1981). Most studies have showed that a primary zone of heavy rainfall occurs in the south-west sector about 200-500 km away from the center, while a secondary zone of comparatively less rainfall is located about 800 km west of the depression center. The area around first 100 km of the depression center is generally free from intense rainfall activity. These features are well captured in the daily analysis, particularly on 14 June when the system was more organized. The corresponding satellite estimates have lower values, less spatial variability and are generally very smooth. The orographic monsoon rainfalls which are absent in the satellite estimates are distinctly captured with realistic peak intensity and location in the rainfall analysis.

4. Conclusion

The present study demonstrates the potential of improved daily rainfall analysis for monitoring and analysis of monsoon precipitation system. The study shows that the daily rainfall analysis is able to capture large scale as well as mesoscale features of monsoon precipitation system. The study has confirmed the asymmetric mesoscale structure of precipitation associated with monsoon depression. Availability of this analysis rainfall data is expected to be very useful to NWP community for model initialization and model validation.

Acknowledgments

The authors are also thankful to Shri S. R. Kalsi, ADGM (S), India Meteorological Department for his encouragement and keen interest in this study. First author of the paper likes to thank Dr. M. Rajeevan, Director (LRF), IMD, Pune for providing station rainfall data.

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