

Role of mesoscale low and urbanization on exceptionally heavy rainfall event of 26th July 2005 over Mumbai : Some observational evidences

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सार – विभिन्न शोधकर्ताओं द्वारा यह निष्कर्ष निकाला गया है कि कोंकण तट से परे मेसोस्केल निम्न/भ्रमिल के बनने और शहरी उष्ण द्वीप (यू. एच. आई.) प्रभाव के कारण मुख्यतः मुम्बई में 26 जुलाई 2005 को अत्यधिक भारी वर्षा हुई। तथापि, इन अध्ययनों से भारी वर्षा की घटना के दौरान और उससे पहले मेसोस्केल भ्रमिल और यू. एच. आई. के विद्यमान होने के प्रेक्षणों के कम प्रमाण मिले हैं। अतः कोंकण तट से परे मेसोस्केल निम्न के विद्यमान होने और मुम्बई में इस अत्यधिक भारी वर्षा की घटना पर शहरी उष्ण द्वीप (यू. एच. आई.) प्रभाव की संभावित भूमिका की जाँच करने के लिए अध्ययन शुरू किया गया है। इस कार्य के लिए मुम्बई हाई क्षेत्र के अतिरिक्त सिनॉप्टिक आँकड़े और मुम्बई क्षेत्र के अधिकतम और न्यूनतम दैनिक तापमानों का विश्लेषण किया गया है। इस विश्लेषण से 25–26 जुलाई 2005 के दौरान दहानू के पश्चिम में मेसोस्केल निम्न दाब क्षेत्र और समदाबीय निम्न क्षेत्र के बनने की पुष्टि हुई है। मुम्बई क्षेत्र में अधिकतम और न्यूनतम दैनिक तापमानों के विश्लेषण से 25–26 जुलाई 2005 के दौरान यू. एच. आई. प्रभाव की पुष्टि हुई है।

ABSTRACT. The 26th July 2005 exceptionally heavy rainfall event over Mumbai has been mainly attributed to a mesoscale low/vortex off Konkan coast and urban heat island (UHI) effect as demonstrated by various research groups. However, these studies are limited on observational evidence regarding the existence of the mesoscale vortex and UHI prior to and during this heavy rainfall event. Hence, a study has been undertaken to examine the existence of the mesoscale low off Konkan coast, which might have triggered this exceptionally heavy rainfall over Mumbai and the possible role of UHI effect over Mumbai on this heavy rainfall event. For this purpose the additional synoptic data from Mumbai high region and daily maximum and minimum temperatures over Mumbai region have been analysed. The analysis confirms the existence of a mesoscale low pressure area and isallobaric low to the west of Dahanu during 25th - 26th July 2005. The analysis of daily maximum and minimum temperatures over Mumbai region confirms the UHI effect during 25th -26th July, 2005.

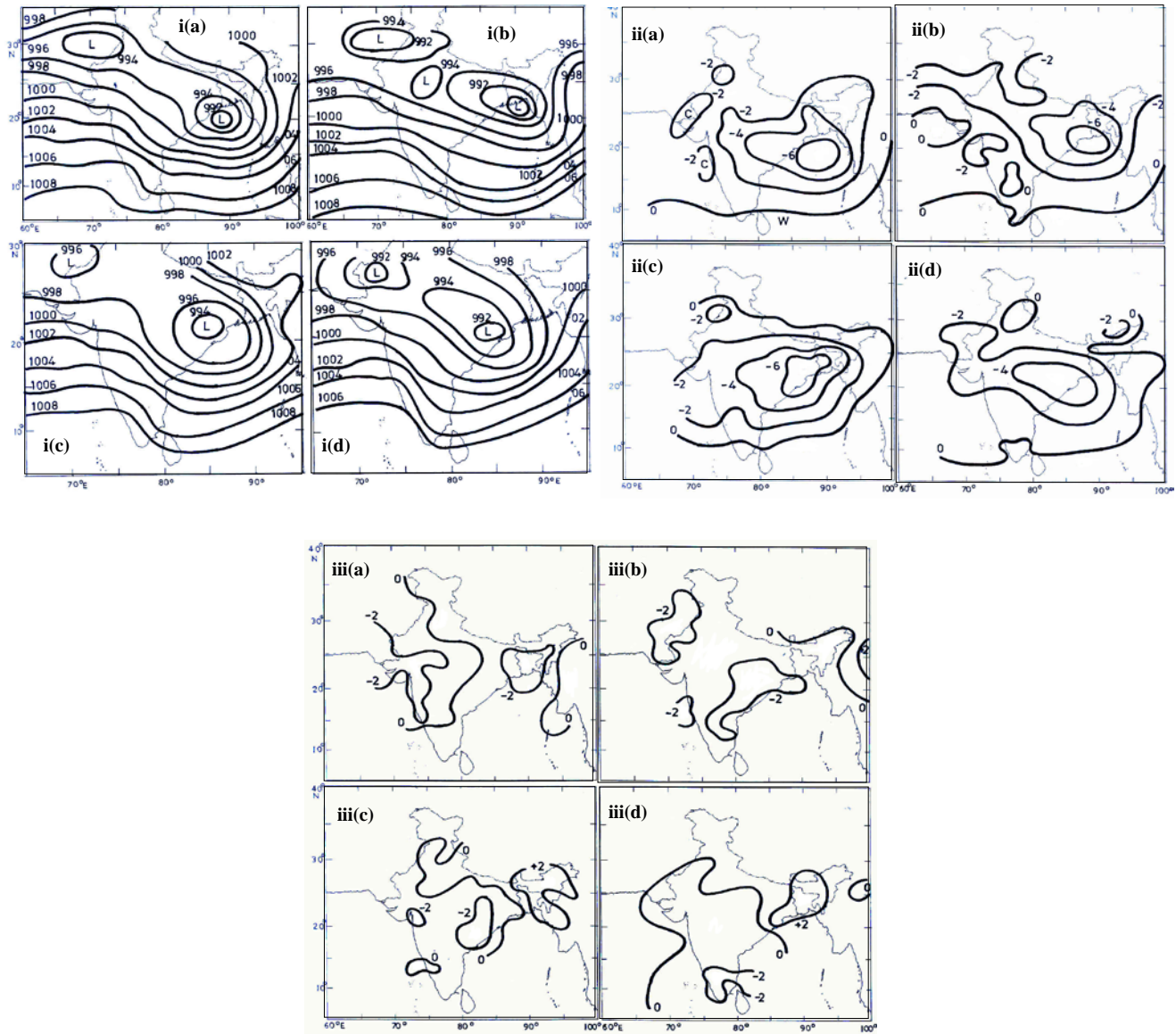
Key words – Heavy rainfall, Mesoscale low, Urban heat island.

1. Introduction

On 26th July 2005, an unexpected heavy precipitation event occurred over the Mumbai urban region and adjacent areas. The 24 hours cumulative rainfall ending at 0300 UTC of 27th July at Santacruz airport was 944.0 mm. A number of stations in Mumbai and Thane districts reported more than 600 mm of rainfall during the 24 hours period from 0300 UTC of 26th July to 0300 UTC of 27th July. Vihar Lake in Thane district received the highest rainfall of 1049.0 mm during this period. The 600 mm contour line extended to a distance of 40–50 km with NE–SW orientation. The rainfall intensity exceeded 50 mm per hour during the period 0900 to 1600 UTC of 26th July with maximum of 190 mm during 1000 to 1100 UTC (Shyamala and Bhadram, 2006). The normal life was completely disrupted across the state with Mumbai being

the most severely hit. The event caused nearly 500 deaths and is classified as a billion US Dollars natural disaster (NCDC, 2007).

Jenamani *et al.* (2006), Lal *et al.* (2006) and Shyamala and Bhadram (2006) have analysed different observational characteristics of the rainfall event and the possible causes using conventional surface rainfall and upper air data. Their studies mainly focused on rainfall analysis at mesoscale, synoptic features, thermal and moisture analyses, characteristics of air masses responsible for the event, convective instability analysis and the possible role of orography in causing the event. They have also analysed the satellite and Radar imageries to find out the role of mesoscale convective cloud clusters. All these studies indicate that formation of mesoscale convective systems over Mumbai, comprising super



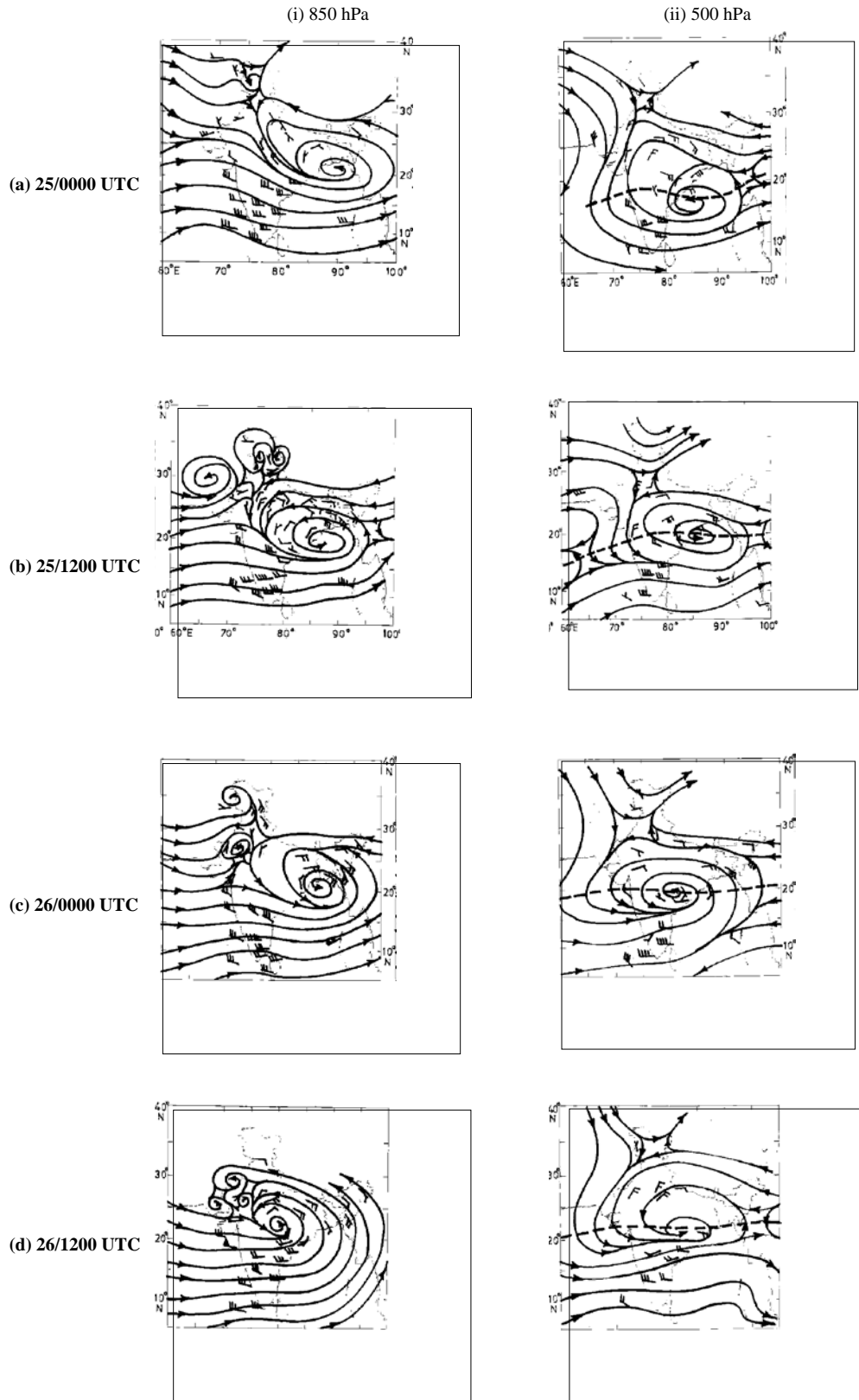
Figs. 1[i(a-d)-iii(a-d)]. (i) Mean sea level pressure (ii) 24 hrs pressure change and (iii) pressure departure from normal over Indian region (a) 0300 UTC of 25th July 2005, (b) 1200 UTC of 25th July 2005, (c) 0300 UTC of 26th July 2005 and (d) 1200 UTC of 26th July 2005

thunderstorm cells and their interaction with the synoptic scale low-pressure area from the Bay of Bengal have led to the concentrated very high intensity rainfall. Vaidya and Kulkarni (2007) independently confirmed a similar conclusion and found that a cloud burst phenomenon was the main reason for the heavy rain. They also concluded that the event could be reasonably simulated using a high resolution mesoscale model with a proper choice of boundary conditions and domain size (to capture the synoptic and mesoscale feedbacks). Joseph (2006) stressed the role of low-level jet at 850 hPa and development of mesoscale convective system as possible

causes. However, all these studies could not prove the hypothesis of existence of mesoscale vortex with observational data.

Most forecasting models also could not bring out the existence of mesoscale low/vortex (Bohra *et al.*, 2006, Lal *et al.*, 2006, Chang *et al.*, 2009 and Lei *et al.*, 2008)

Niyogi *et al.* (2006) have shown that urban land surface leads to UHI effect that can influence local storm structure causing enhanced convection and increased precipitation. Lei *et al.* (2008) has stressed the role of



Figs. 2[i&ii (a-d)]. Stream line analyses over Indian region at (i) 850 hPa and (ii) 500 hPa level during (a) 25/0000 UTC, (b) 25/1200 UTC, (c) 26/0000 UTC and (d) 26/1200 UTC

urban landscape and hence UHI on 26th July 2005 heavy rainfall event over Mumbai. However, the existence of UHI prior to and during this heavy rainfall event has not been verified with observational data. Considering all the above, a study has been undertaken to examine the existence of the mesoscale low off Konkan coast, which might have triggered this exceptionally heavy rainfall over Mumbai. The study also aims to examine the existence of UHI effect over Mumbai prior to and during this heavy rainfall event. The data and methodology followed for this purpose are presented in Section 2. The results of the study are analysed and discussed in Section 3.

2. Data and methodology

Considering the objective as mentioned in the previous section, the additional three hourly synoptic data recorded over the meteorological observatories in Mumbai high region maintained by Oil and Natural Gas Corporation (ONGC) Limited, Government of India during the period, 25th-26th July 2005 were collected apart from the conventional three hourly synoptic data of India Meteorological Department (IMD) observatory network. The data from these observatories are available in three hourly intervals during 0300 and 1200 UTC of 25th and 26th July 2005. These additional data have been plotted along with the conventional synoptic data of IMD, and isobaric analysis has been carried out for every three hourly observations. The isobaric analyses have also been performed based upon these observations. There is no other data available over the sea region to examine the existence of the mesoscale low off Konkan coast.

To verify the existence of the UHI near Mumbai during 25th - 26th July 2005, the surface maximum and minimum temperatures over the region have been collected from IMD and analysed. The maximum and minimum temperatures of two IMD stations, *viz.*, Colaba and Santacruz have been taken into consideration.

3. Results and discussion

The synoptic features associated with the exceptionally heavy rainfall over Mumbai on 26th July 2005 are analysed and discussed in Section 3.1. The mesoscale features associated with this rainfall is presented and discussed in Section 3.2. The role of UHI effect on this rainfall is analysed and presented in Section 3.3.

3.1. Synoptic features

The isobaric analyses along with the 24 hour pressure changes and pressure departures over Indian

region at 0300 and 1200 UTC of 25th and 26th July 2005 are shown in Figs. 1[(a-d)-iii(a-d)]. The stream line analysis over Indian region based on 0000 and 1200 UTC observations of 25th and 26th July 2005 are shown in Figs. 2[i&ii(a-d)]. The main synoptic features on 25th and 26th July (Figs. 1-2), were as follows.

A well-marked low pressure area lay over North Bay of Bengal off Orissa coast on 25th July; over Orissa and adjoining Jharkhand and Chhattisgarh on 26th July and over east Madhya Pradesh and adjoining Vidarbha on 27th July. Strong mean sea level pressure gradient of about 8 hPa prevailed between Dahanu and Trivandram with relatively higher gradient over Konkan – south Gujarat coast. Strong lower tropospheric winds of 25–30 knots on 25th July and 30–35 knots on 26th July prevailed over north Maharashtra coast. The southward shifting of the western end of monsoon trough was observed from 25th to 26th July. The orographic interaction of Western Ghats with basic monsoon flow is also evident as strong westerly winds prevailed over the region. Though all these conditions were favourable for heavy to very heavy rainfall over Mumbai (Srinivasan, 1972; Shyamala & Mukherjee, 1985; Prasad and Agarwal, 1996; Shyamala & Bhadrani, 2006; Joseph, 2006 and Jenamani *et al.*, 2006) these conditions are not sufficient enough for a forecaster to issue the warning for exceptionally heavy rainfall over Mumbai. Srinivasan (1972) have shown that active monsoon conditions over north Konkan are usually associated with a trough off the west coast of India, formation of lows/depressions over north Bay of Bengal, presence of mid tropospheric cyclonic circulation (MTC) off north Maharashtra–south Gujarat coasts between 700 and 500 hPa and strong pressure gradient along west coast. Prasad and Agarwal (1996) have noted that the east–west trough line along 19 - 21° N along with the above mentioned synoptic conditions results in heavy rainfall over Mumbai. Shyamala and Mukherjee (1985) have observed that formation of low-level circulation (LLC) at 850 hPa over the Arabian Sea and adjoining north Maharashtra–south Gujarat coasts was necessary for heavy rainfall over north Konkan at the time of formation of monsoon depressions over the Bay of Bengal.

3.2. Mesoscale features

Considering the observations recorded over Mumbai high regions by ONGC along with the conventional data of IMD, the isobaric analysis has been performed over Mumbai region and neighbourhood. The three hourly isobaric analyses are shown in Figs. 3(a-g). According to the analysis, there was a mesoscale low over the Arabian Sea with its centre located to the west of Dahanu during 0300 UTC of 25th July 2005 to 0900 UTC of 26th July 2005. Further, the pressure gradient from the centre of this

(a) 25/0300 UTC

(b) 25/0600 UTC

(c) 25/0900 UTC

(d) 25/1200 UTC

Figs. 3(a-d). Three hourly synoptic observations of MSLP, 24 hours pressure change and vector wind plotted according to WMO code over Mumbai region and adjoining sea area along with the isobaric analysis (hPa) at (a) 0300, (b) 0600, (c) 0900 and (d) 1200 UTC of 25th July 2005

(e) 26/0300 UTC

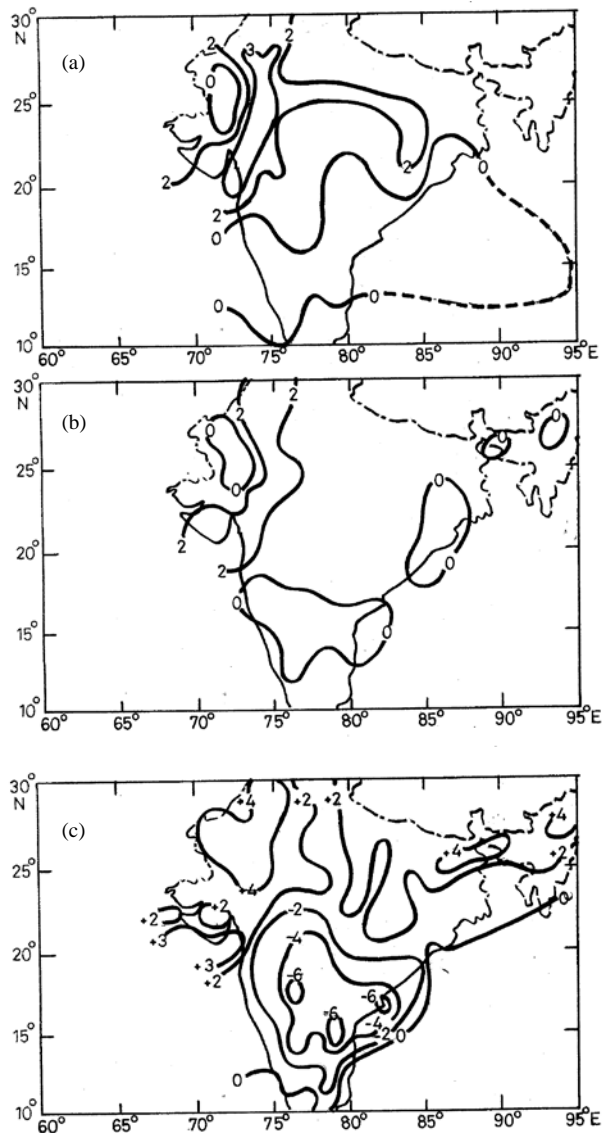
(f) 26/0600 UTC

(g) 26/0900 UTC

Figs. 3(e-g). Three hourly synoptic observations of MSLP, 24 hours pressure change and vector wind plotted according to WMO code over Mumbai region and adjoining sea area along with the isobaric analysis (in hPa) at (e) 0300, (f) 0600 and (g) 0900 UTC of 26th July 2005

low towards the southwest was maximum around 0600 UTC of 26th July 2005 about 3 hours prior to the commencement of intense rainfall at 0900 UTC. The closed isobar of 1000 hPa could be observed off the coast

till 0900 UTC of 25th July 2005. The mean sea level pressure fell thereafter and the closed low was associated with 998 hPa during 1200 UTC of 25th to 0900 UTC of 26th.



Figs. 4 (a-c). (a&b) Minimum temperature departure from normal (°C) as observed at 0300 UTC of 25th and 26th July, 2005 and (c) Maximum temperature departure from normal (°C) over Indian region recorded at 1200 UTC of 25th July, 2005

Considering, the 24 hour pressure changes, the additional data from ONGC observatories over Mumbai High region confirmed the occurrence of mesoscale isallobaric low over the Arabian Sea off north Konkan coast prior to and during the occurrence of heavy rainfall.

3.3. UHI effect

Analysis of maximum and minimum temperatures during the period indicates localised heating with 2-3° C above normal temperatures on 25th and 26th over Mumbai

region [Figs. 4(a-c)]. Simulating the 26th July 2005 heavy rain event in Mumbai using a mesoscale model (RAMS) coupled with an explicit urban energy balance scheme, Lei *et al.* (2008) have demonstrated that coupling the explicit urban model shows a consistently enhanced performance. The urban landscape causes an UHI and hence may cause mesoscale convergence zone. This convergence zone appears to be a major reason for the moisture transport and heavy rain. According to International panel on climate change (IPCC) report (IPCC Report, 2001), global warming is expected to accelerate the hydrological cycle and lead to precipitation extremes in some areas. Goswami *et al.* (2006) analysed the rainfall pattern over the Indian monsoon region and concluded that the heavy rain events are significantly increasing.

4. Conclusions

The following broad conclusions are drawn from the above results and discussion:

(i) The analysis of additional data available from Mumbai high region confirms the existence of a mesoscale low pressure area and isallobaric low to the west of Dahanu during 25th-26th July 2005. It may be the main reason in addition to the favourable synoptic and large scale features as discussed by Shyamala and Bhadram (2006) and Jenamani *et al.* (2006) for this exceptionally heavy rainfall event.

(ii) The analysis of daily maximum and minimum temperatures over Mumbai region confirms the existence of UHI effect and hence endorses the findings of a Lei *et al.* (2008) regarding the impact of urbanization on occurrence of this heavy rainfall event.

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