Impact of mesoscale–synoptic scale interactions on the Mumbai historical rain event during 26–27 July 2005

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The exceptionally heavy rainfall event during 26–27 July 2005 over Mumbai and Thane districts has been analysed in this article to identify the meteorological conditions that possibly caused the phenomenally heavy rainfall. Using satellite and radar inputs combined with synoptic and thermodynamic analysis, it is found that formation of mesoscale convective systems over Mumbai, comprising super thunderstorm cells and their interaction with the synoptic scale low-pressure area from the Bay of Bengal led to the concentrated very high intensity rainfall.

Keywords: Mesoscale convective systems, super thunderstorm cells, synoptic scale systems, synoptic scale–mesoscale interactions.

VERY heavy rainfall events frequently occur in Mumbai and Thane districts during monsoon season. However, the phenomenally heavy rainfall during 26–27 July 2005 was historical as a number of stations in Mumbai and Thane districts reported more than 600 mm of rainfall during the 24 h period from 0830 h IST of 26 July to 0830 h IST of 27 July. According to India Meteorological Department (IMD) convention, rainfall amount for the 24 h period ending at 0830 h IST of the date is denoted as rainfall of that day. Accordingly, the rainfall that occurred during 0830 h of 26 to 0830 h of 27 July is given as rainfall of 27 July. We study here the meteorological aspects of the rainfall that occurred in Mumbai during 26–27 July 2005.

Vihar Lake in Thane district received the highest rainfall of 1049.0 mm during 26–27 July. Figure 1 is the isohyetal map of Mumbai and Thane districts showing rainfall distribution during 26–27 July 2005. It may be seen from Figure 1 that the very heavy rainfall event was not a localized one, as the 600 mm contour line extended to a distance of 40–50 km with NE–SW orientation. Some of the other significant rainfall amounts are: Santacruz 944.2 mm, Bhandup 815.0 mm, Bhivandi 748.0 mm, Thane 736.4 mm, Tulsi Lake 601.0 mm and Dharavi 493.0 mm. Very heavy rain started from 1430 h IST of 26 July and continued till 2130 h IST. Table 1 gives the temporal distribution of rainfall at Santacruz on 26 July.

Figure 2 is the hourly rainfall plot of the above rainfall distribution. The rainfall intensity exceeded 5 cm per hour during the period 1430 to 2130 h of 26 July with maximum of 19 cm during 1530 to 1630 h IST. This historical offloading of high intensity rainfall in just a 7 h period from 1430 to 2130 h brought Mumbai to a complete standstill for more than 24 h, resulting in huge loss of lives and property. The economic and social impact of this calamity has been widely discussed and made public by various media and is therefore not included here. Here we have attempted to study this unusual event from different meteorological aspects: synoptic, thermodynamic, satellite and radar, and identify the possible causes for the same.

Previous studies and scope of the present investigation

Srinivasan[1] observed that active monsoon conditions over north Konkan were usually associated with a trough

Table 1. Temporal distribution of rainfall (RR) at Santacruz during 26–27 July 2005

Date	Hours IST	RR (mm)	Remarks
26 July	0830–1130	0.9	
	1130–1430	18.4	
	1430–1530	100.2	Very high intensity RR
	1530–1630	190.3	Very high intensity RR
	1630–1730	90.3	Very high intensity RR
	1730–1830	100.4	Very high intensity RR
	1830–1930	95.0	Very high intensity RR
	1930–2030	72.2	Very high intensity RR
	2030–2130	60.2	Very high intensity RR
	2130–2230	22.5	
	2230–2330	18.4	
	2330–0030 (27)	40.0	
27 July	0030–0130	42.5	
	0130–0230	33.7	
	0230–0530	11.0	
	0530–0830	48.2	
Total	24 h RR	944.2	

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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 the west coast. It may be noted that the above conditions were identified on the basis of synoptic charts, which were the only observational tools available then. Apte[2] developed a forecasting diagram for heavy rainfall over Mumbai based on the aforesaid conditions. Shyamala and Mukherjee[3] had observed that in addition to these conditions, 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. Prasad and Agarwal[4] noted that the east–west trough line along 19–21°N along with the above-mentioned synoptic conditions resulted in heavy rainfall over Mumbai. Shyamala and Shinde[5] had concluded that cyclonic circulations in the lower and middle troposphere were also effective rain-producing systems for the different areas in India, even when monsoon lows or depressions were not present. It was, however, observed that the above listed synoptic situations did not always result in heavy rains over Konkan. Shyamala and Iyer[6] studied the very heavy and exceptionally heavy rain situation over Mumbai and Konkan using a ternary approach, i.e. satellite, synoptic and statistical. The main conclusions of the study were: (i) the exceptionally heavy rain event of 12–13 July 2000 over Mumbai was associated with the development of mesoscale intense convective vortex off Mumbai in a synoptic scenario of well-marked low pressure area over the Bay of Bengal and that (ii) the probability of occurrence of rainfall exceeding 20 cm in Mumbai in any year is as high as 50%. Joseph[7] stressed the role of low-level jet at 850 hPa and development of mesoscale convective system as possible causes for heavy rains of July 2005 in Mumbai. Mohanty[8] observed that convection is the main forcing for tropical rain. Recently, Jenamani *et al.*[9] have studied observational/forecasting aspects of the meteorological event that caused a record rainfall in Mumbai on 26 July 2005. In the present study, an attempt has been made to analyse how the synoptic meteorological features interacted with the mesoscale convective phenomenon, leading to heavy rainfall over Mumbai during 26–27 July 2005.

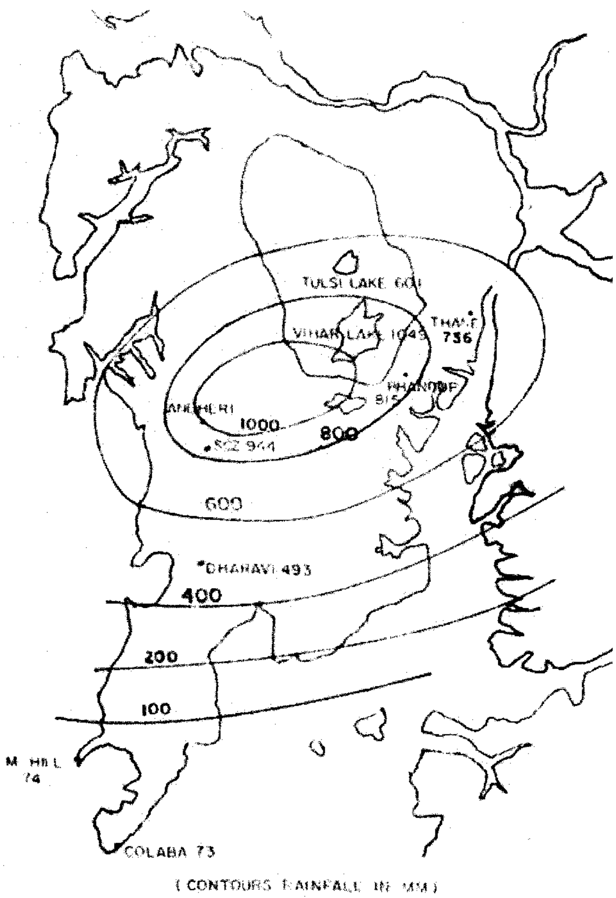

Figure 1. Isohyetal map 26–27 July 2005.

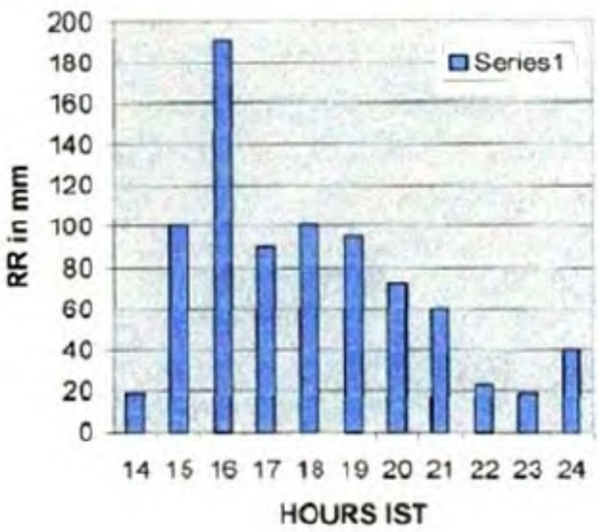

Figure 2. Hourly rainfall at Santacruz on 26 July 2005.

Data and source

The surface and upper air meteorological observations from different observing stations of IMD form the main dataset for the study. Satellite cloud imageries and satellite digital data from KALPANA-1 and the observations of IMD Mumbai radar have been considered for studying the cloud conditions that existed during the event. The hourly cloud imageries of Meteosat 5 satellite received at Dundee are used for studying the temporal evolution of cloud systems. The rainfall measurements by IMD and other agencies have been used for studying the aerial distribution of rainfall.

Table 2. Rainfall (cm) in different districts of Konkan during July 2005

Date	Thane	Mumbai	Raigad	Ratnagiri	Sindhudurg
21	Kalyan 15 Bhivandi 10 Thane 9 Dahanu 9	Colaba 10 Santacruz 10	Mhasala 17 Murudjanjira 17 Uran 17 Matheran 12	Chiplun 15 Dapoli 13 Khed 12 Rajapur 11	Devgad 10 Sawantwadi 8
22	Thane 9	Colaba 9 Santacruz 4	Alibaug 19 Shrivardhan 19 Mhasala 17 Murud 13	Guhagad 19 Rajapur 19 Ratnagiri 14 Chiplun 13 Mandangad 13 Rajapur 19	Devgad 20 Kudal 8 Malvan 8
23	Murbad 15 Bhivandi 9 Shahpur 9	Colaba 1 Santacruz 1	Matheran 8 Khalapur 6 Poladpur 6	Chiplun 13 Lanja 7 Rajapur 11 Dapoli 9	Kudal 7 Malvan 7 Sawantwadi 7 Vengurla 7
24	Murbad 7	Santacruz 1	Poladpur 21 Mangaon 14 Shriwardhan 12 Mahad 8 Mangaon 14	Dapoli 22 Rajapur 16 Ratnagiri 12 Lanja 9 Khed 14 Mandangad 15	Vengurla 17 Devgad 16 Kudal 15 Sawantwadi 12 Malvan 10
25	Murbad 16 Shahpur 8 Bhivandi 7 Wada 7 Kalyan 7	Colaba 1	Roha 48 Mangaon 24 Pen 23 Mhasala 23 Mahad 20	Mandangad 37 Khed 32 Chiplun 28 Dapoli 19 Harnai 15 Rajapur 16	Sawantwadi 21 Vengurla 18 Kudal 13 Devgad 13 Malvan 10
26	Murbad 13 Kalyan 11 Bhivandi 8 Wada 7	Santacruz 1	Poladpur 59 Mangaon 36 Matheran 33 Roha 13 Pen 12 Mhasala 11	Khed 26 Lanja 23 Mandangad 19 Rajapur 10 Ratnagiri 9	Kudal 13 Sawantwadi 11 Kankavli 11 Devgad 10
27	Vihar 105 Bhivandi 75 Thane 74 Kalyan 62 Murbad 18 Shahpur 14 Bhivandi 75	Colaba 7 Santacruz 94	Karjat 69 Panvel 47 Khalapur 30 Poladpur 17 Mahad 15 Uran 11	Rajapur 21 Lanja 11 Mandangad 10	Kudal 15

Methodology

The study has been done in four parts: (i) Synoptic analysis, (ii) Thermodynamic analysis, (iii) Radar analysis, and (iv) Satellite analysis.

It may be seen from Table 2 that heavy to very heavy rainfall occurred in the districts of Konkan from 21 July with the formation of a low pressure area over the Bay of Bengal and continued till 27 July.

Table 3 gives the rainfall at Colaba and Santacruz from 21 to 28 July 2005. Mumbai received heavy rainfall on 21 and 22 July at the time of formation of the low pressure area over Bay of Bengal. Rainfall was moderate during 23–25 July and exceptionally heavy only during 26–27 July.

Table 3. Rainfall distribution: Colaba and Santacruz 21–28 July 2005

Date	Colaba RR (mm)	Santacruz RR (mm)
21	103.9	90.5
22	90.5	38.5
23	8.2	13.4
24	0.6	14.7
25	8.0	0.8
26	0.8	11.9
27	73.4	944.2
28	31.3	19.0

Examining the synoptic situations that prevailed over India during 21–27 July 2005, it is seen that: (i) An upper air cyclonic circulation lay over north and adjoining central Bay of Bengal extending between 5.8 and 7.6 km above sea level on 22 July 2005. Under its influence, a low pressure area formed over Orissa–West Bengal coasts and adjoining areas on 23 July. The system persisted on 24 and 25 July and became a well-marked low pressure area (WML). It moved inland and lay over Orissa and adjoining Jharkhand on 26 July and over east Madhya Pradesh and adjoining Vidarbha on 27 July. Subsequently, it moved northwest and was located over north Gujarat and its neighbourhood on 28 July. (ii) An offshore trough running from Konkan to Kerala coast was seen on 21 and 22 July. The trough extended from Karnataka to Kerala coast on 23 and 24 July. It extended from Konkan to Karnataka coast on 25–27 July. (iii) The monsoon trough shifted southwards at the beginning of the week and was located in the near normal position with the eastern end southward till 27 July.

Figure 3 *a–c* is the surface weather chart of 25/0830, 26/0830 and 27/0830 IST, while Figure 4 *a–c* depicts the upper air flow at 700 hPa (3.1 km asl) on 25/1730, 26/0830 and 26/1730 IST.

The main synoptic features on 25 and 26 July, observed from Figures 3 and 4 are: (i) Well-marked low pressure area over north Bay of Bengal off Orissa coast on 25 July; over Orissa and adjoining Jharkhand on 26 July and over east Madhya Pradesh and adjoining Vidarbha on 27 July. (ii) Trough off the West coast extending from Konkan coast to Karnataka coast. (iii) Strong lower tropospheric winds of 25–30 knots on 25 July and 30–35 knots on 26 July over north Maharashtra coast.

It may be seen from the above analysis that there was no significant change in the surface and upper air conditions from 25 to 26 July. However, the rainfall characteristics changed from 'no heavy' to 'record heavy' situation in Mumbai from 25 to 26 July.

Thermodynamic analysis

The upper air temperature and humidity structure of the atmosphere over Mumbai (Santacruz) on 26 July 2005 is shown in Figure 5. During the monsoon season it is generally seen that the air is nearly saturated up to at least 300 hPa and the dry adiabat and isohygric run close to each other, as was seen on 25 July. However, on 26/0530 IST, the atmosphere between 800 and 550 hPa levels was relatively dry as seen from Figure 5. It may be mentioned that dew point value of –53.0°C reported at 500 hPa has not been taken into account in Figure 5 according to IMD procedures of scrutiny of data. This middle level dryness in the atmosphere with strong vertical wind shear resulted in high conditional instability. These conditions are conducive for the development of very severe local thunderstorms called as super cells[10]. Super thunderstorm cells did develop on the afternoon of July 26. However, the thermodynamic diagrams (tephigrams) of 25 and 27 July did not indicate any such middle level dryness and conditional instability, which are essential for the development of super thunderstorm cells.

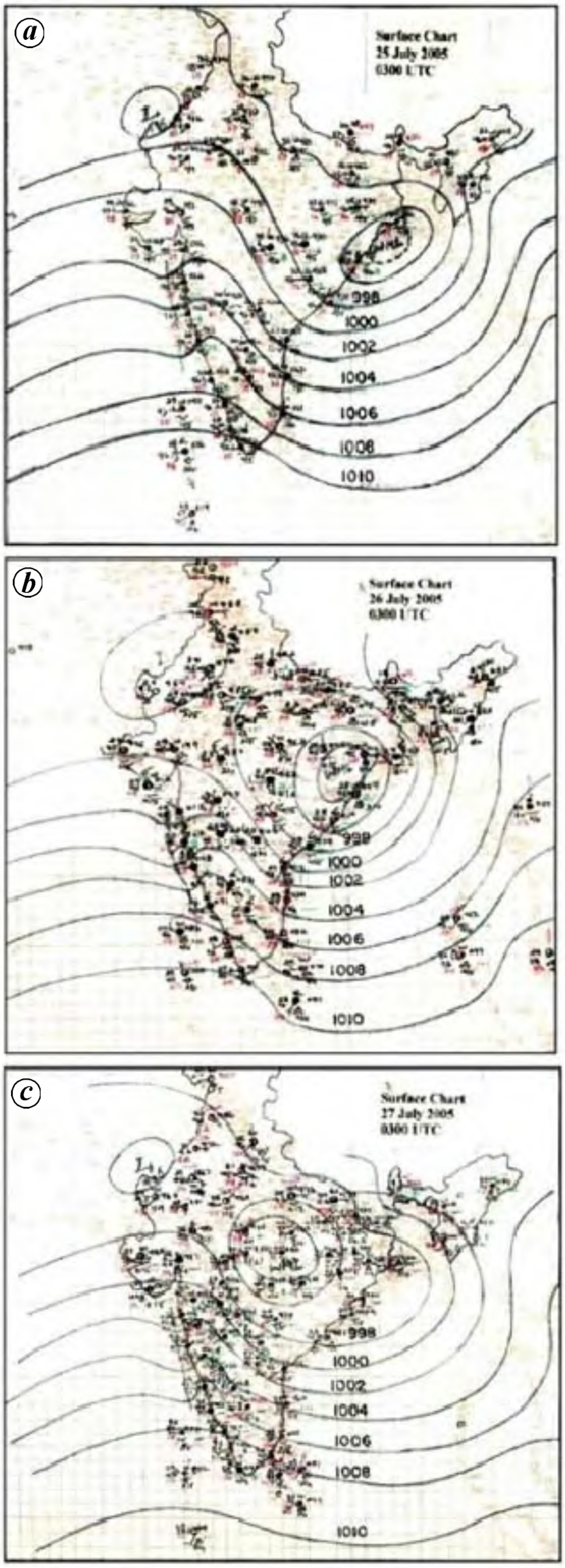

Figure 3. Surface weather charts of (***a***) 25/0830, (***b***) 26/0830 and (***c***) 27/0830 IST.

Radar analysis

At 26/0830 h IST the radar picture of IMD Mumbai radar showed overhead echo extending up to 100–150 km around the station with cloud top heights reaching 5–6 km. At 26/1130 IST convective echo band was observed in NE–SW direction extending up to a distance of 100 km, the cloud tops reaching about 6 km. At 26/1430 IST the convective radar echoes had covered the entire area around the station up to a distance of 100 km to the east and about 60 km to the west with bright strong cells, heights reaching 15 km to the north. High intensity, very heavy rainfall started over Santacruz and its neighbourhood with the development of super cells resulting in 10 cm rain during 1430–1530 h and 19 cm during 1530–1630 h IST as shown in Figure 2. Overhead convective echoes with cloud heights reaching 10 km continued till 2130 h IST of 26 July, and Santacruz continued to receive heavy rainfall of lesser intensity compared to that during 1430–1630 h IST.

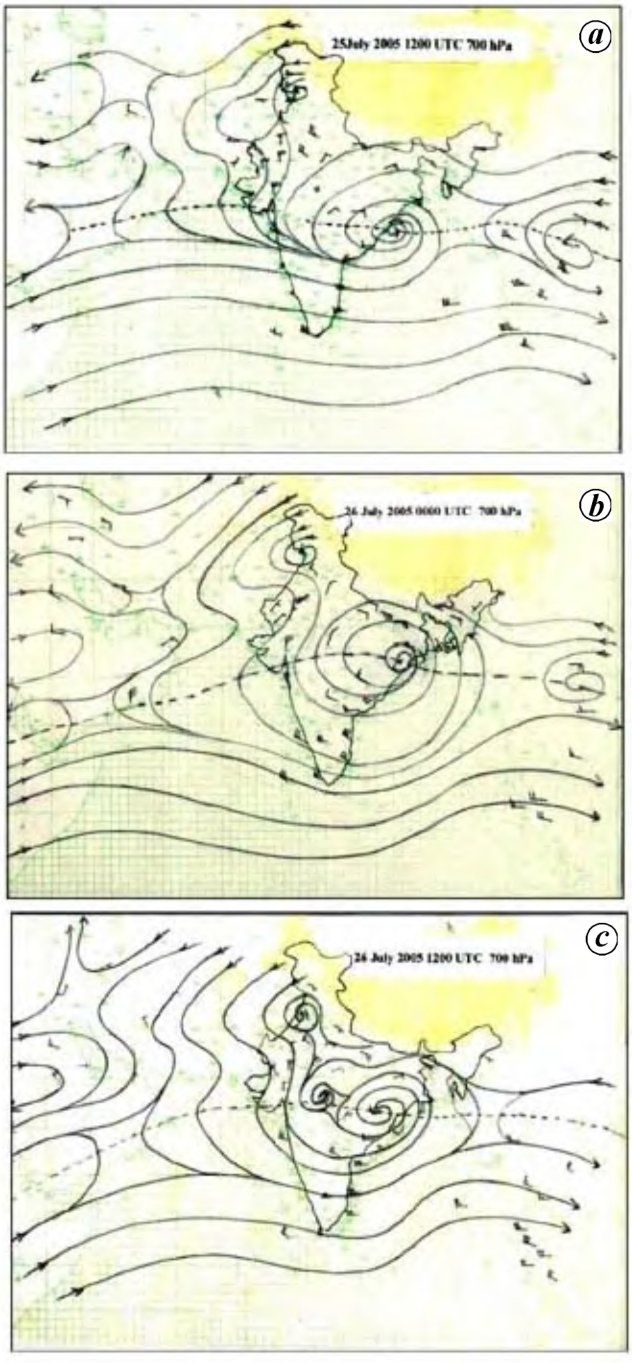

Figure 4. Upper air flow at 700 hPa on (***a***) 25/1730, (***b***) 26/0830 and (***c***) 26/1730 IST.

Satellite analysis

As the synoptic and upper air conditions were the same on 25–27 July, hourly and three-hourly satellite data from Dundee METEOSAT5 and KALPANA-1 satellite were examined from 25/0530 to 28/0530 hrs IST for the development of any significant features. (i) A north-south band of convective clouds was seen off Konkan–Karnataka coast at 26/0630 IST. (ii) Three distinct cloud clusters/ vortices were seen over Orissa, Central India and Mumbai at 26/1430 IST (Figure 6). The cloud cluster over Orissa was due to the well-marked low pressure area, while those over Central India and Mumbai appeared to be of mesoscale convective type. Accentuation of the Arabian Sea current and formation of convective cloud band from the Arabian Sea towards the low pressure area can also be seen in Figure 6. (iii) On examining the digital outgoing long-wave radiation (OLR) values during the period 26/0830–26/1730 IST over one degree grid area around 19.5N/73.5E (near Mumbai), it is observed that the OLR value of 185.92 W/sq. m at 0830 IST decreased to 139.84 W/sq. m at 1430 IST, indicating the development of a very severe super cell/convective system around Mumbai giving rise to exceptional very high intensity rainfall. The scale of these mesoscale super cells was around 40–50 km. (iv) The three vortices as mentioned under (ii) persisted till

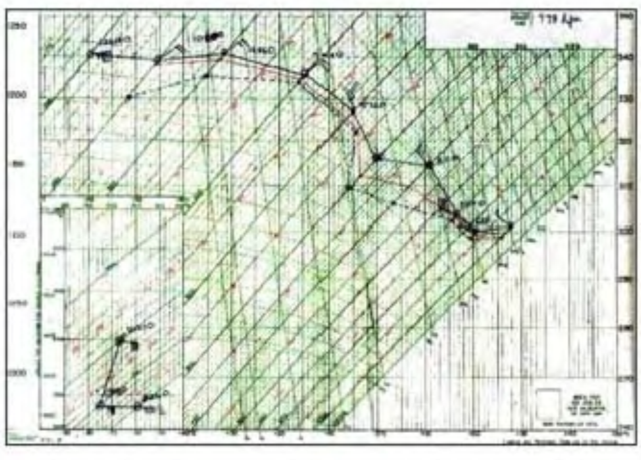

Figure 5. Upper air temperature and humidity structure of the atmosphere over Mumbai on 26 July 2005.

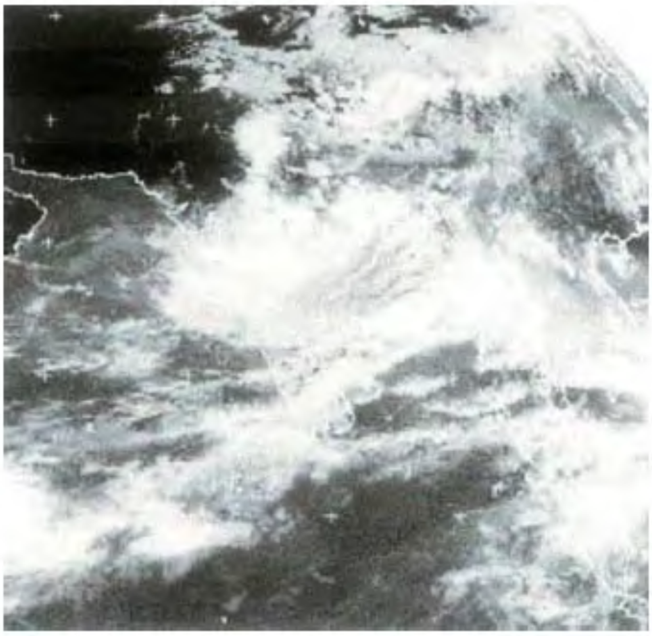

Figure 6. METEOSAT 5 (26/1430 IST) satellite picture.

26/2130 IST. From 26/2230 IST the mesoscale convective systems over Central India and Mumbai were not seen, as these systems have a life of 7–10 h only[10]. (v) At 27/0830 IST the low pressure area and the associated clouding were seen over Vidarbha. (vi) At 28/0530 IST the low pressure area had moved further northwest and was located over north Gujarat and its neighbourhood. The feeder convective band from the Arabian Sea to the low pressure area has moved northwards and was seen extending from northeast Arabian Sea towards the low-pressure area across Saurashtra.

Summary and conclusion

It is seen from the analysis of the July 2005 exceptional rainfall event over Mumbai that: (a) Synoptic conditions of low pressure area over Bay of Bengal and its movement inland were present during 25–26 July. (b) Monsoon trough in the lower and middle tropospheric levels was very active between 2.1 and 4.5 km asl during 25–26 July. (c) Accentuation of the Arabian Sea monsoon current, formation of convective cloud band from the Arabian Sea towards the low pressure area in the Bay and its movement northward were observed during 25–26 July. Strengthening of low-level winds over Mumbai to 30–35 knots was noticed on 26/0530 IST compared to 25–30 knots on 25 July. (d) Development of mid-tropospheric dryness in the atmosphere with strong vertical wind shear over Mumbai from 26/0530 h IST led to high conditional instability and formation of super thunderstorm cells. Mesoscale intense convective system formed over Mumbai and resulted in very heavy convective rainfall from 26/1430 h IST.

It is evident from the above study that the exceptional rainfall event of 26 July 2005 over Mumbai occurred due to the interaction between mesoscale and synoptic scale systems. The study also brings out the need for development of regional mesoscale models and further research in the field of interactions between weather systems of different scales.

1. Srinivasan, V., Discussion of typical synoptic situations over Konkan and coastal Karnataka. In *India Meteorol. Department Forecasting Manual III-3.7*, 1972.
2. Apte, S. G., M Sc thesis, Bombay University, 1979.
3. Shyamala, B. and Mukerjee, A. K., Distant effects of monsoon depressions – Part I: Effect of formation of depressions on rainfall activity along west coast of India. *Mausam*, 1985, **36**, 429–434.
4. Prasad, T. and Agarwal, A. L., A day of exceptionally heavy rainfall over Mumbai. *Mausam*, 1996, **47**, 425–428.
5. Shyamala, B. and Shinde, G. M., Study of synoptic scale systems associated with intraseasonal variability of summer monsoon – A new perspective. *Mausam*, 1999, **50**, 31–36.
6. Shyamala, B. and Iyer, B. G., Impact of mesoscale systems on very heavy rainfall events along west coast of India. Communicated to *J. Earth Sci.*, 2005.
7. Joseph, P. V., A diagnostic study of very heavy rainfall event along the west coast of India during the SW monsoon. Paper presented in the National Workshop on Dynamics and Simulation of Extreme Rainfall, March 2006.
8. Mohanty, U. C., Challenges in simulation and forecasting extreme weather events. Paper presented in the National Workshop on Dynamics and Simulation of Extreme Rainfall, March 2006.
9. Jenamani, R. K., Bhan, S. C. and Kalsi, S. R., Observational/forecasting aspects of the meteorological event that caused a record highest rainfall in Mumbai. *Curr. Sci.*, 2006, **90**, 1344–1362.
10. Ludlam, F. H., *Weather*, 1952, **7**, 109.

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