Synoptic weather conditions during BOBMEX

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We document the flow features, which are associated with the important synoptic systems that affected the Bay of Bengal (BoB) and its neighbourhood and controlled the convective activity there during BOBMEX. The monsoon during July and August, 1999 was subdued. It was slightly more active in the initial phase of BOBMEX that commenced on 15th July 1999 and continued up to first week of August 1999 but weakened during the second half of August. The convection was accordingly affected, reducing the rainfall over India. There were several active and weak spells of convection over the Bay of Bengal that manifested in five low pressure systems, of which two became depressions.

1. Introduction

The Bay of Bengal Monsoon Experiment (BOBMEX) was organised to understand the variability of convection over the BoB. One of the main objectives of the experiment was to understand the coupling between the atmosphere and the ocean and to monitor the development of convective systems of different spatial and temporal scales. In this paper we document the general performance of the monsoon during BOBMEX and the flow features associated with the synoptic systems. This is intended to provide material about the evolution of the large scale monsoon for the use of investigators to interpret the special data collected during BOBMEX.

The study is based on the India Meteorological Department (IMD) charts of Northern Hemisphere Analysis Centre (NHAC), New Delhi, INSAT visible and infrared cloud imageries, daily INSAT OLR charts at $2.5^\circ \times 2.5^\circ$ grid interval, satellite-derived cloud motion vectors, Regional Specialised Meteorological Centre (RSMC), New Delhi analysis and forecast charts at various levels and daily analysis of National Centre for Medium Range Weather Forecasting (NCMRWF) for 925, 850, 500 and 200 hPa level. Weekly mean flow patterns at 850 hPa are included in figure 1 for

the 8 weeks in the months of July and August 1999. These are based on RSMC initial analysis. There are practically no easterlies in the first two weeks of July 1999 at 850 hPa indicating a break/weak monsoon phase before the commencement of BOBMEX. These easterlies are seen in the next two weeks, thus reviving the active monsoon conditions. This scenario of good monsoon conditions continues until 11th August and covers the first phase of BOBMEX. The next two weeks of August 1999 again depict a poor monsoon scenario. Ultimately the monsoon revived again in the last week of August 1999. The performance of the monsoon in the different meteorological subdivisions during July–August 1999 is shown in figure 2.

The variation of the outgoing longwave radiation (OLR), derived from INSAT, averaged over $2.5^\circ \times 2.5^\circ$ boxes in the north and south Bay of Bengal are shown in figure 3. These boxes correspond to the locations of the met-ocean buoys DS3 and DS4 (figure 4). There were several active spells of convection with low OLR occurring at intervals varying between 5 and 9 days (Bhat *et al* 2001). The duration of each of these spells varied from 2 to 5 days. Between these active spells there were spells with almost cloud free conditions i.e., with high OLR, which lasted for 2–7 days.

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Figure 1. (Continued)

2. Synoptic-scale activity over the Bay

The pressure gradient continued to be strong over the Bay of Bengal during the first phase of BOBMEX which included the first week of August 1999. Figure 5 gives the tracks of the synoptic systems that formed during July and August 1999. Four low pressure systems (LPSs) formed during the first phase. Two of these lows became depressions. These depressions were relatively weak systems as the pressure falls as well as the pressure departure did not exceed 4 to 6 hPa. No system formed during the weak phase from 10th–22nd August.

Thus a quasi-biweekly variation between active and weak phases of monsoon occurred during BOBMEX.

2.1 Low pressure system (14th–18th July)

An LPS that formed in the northwest Bay on 14th July had moved on to Orissa and neighbourhood on 15th July. A large area in the head Bay in the rear of this low was clear on 15th July. A convective cloud cluster was seen in the central Bay where pressure gradient continued to be strong (figure 6). There was a gradient of 12 hPa over the Bay

Figure 1. Weekly mean flow pattern for July and August 1999.

on this day. The LPS moved north westwards and merged with the seasonal trough on 18th July. The pressure gradient across the Bay continued to be of the order of 10 hPa until 19th July. The surface wind strength during this period over the BoB was of the order of 20–30 knots, as seen in the NCM-RWF 850 hPa analysis of 17th and 18th July (figure 7). The strength of the cross equatorial flow was of the order of 15–20 knots just off northeast Africa. The associated Somali jet was strong with wind speeds of the order of 40 knots over south Arabian Sea. The strong wind zone also extended

eastward across the peninsula into the southwest BoB.

2.2 Weak intra-seasonal oscillation (19th–28th July)

The eastern end of the seasonal shear line at 0.9 km (above mean sea level) moved northward on 19th July. Significant rain belt had moved by this time to the northeast whereas the rainfall over the rest of the country had considerably got reduced in accordance with this development. First

Figure 2. Mean sub-divisional rainfall.

Figure 3. Cruise track of Sagar Kanya (SK) and Sagardwani (SD) along with the positions of DS3 and DS4.

signal for commencement of intra-seasonal oscillation was discerned through strengthening of winds at Minicoy which became 30 knots at 0.9 km on 19th July. Stronger wind zone was seen roughly along 13°N on 21st July morning which shifted to 15°N by 22nd July afternoon. There were occasions when the strong wind field appeared spread over the peninsula and central India. This was also seen both in OLR and in vertical velocity fields prepared by National Centre for Medium Range Weather Forecasting (NCMRWF). A band of low OLR (150–160 watts/sqm) could be seen in the south and adjoining central Bay on 21st and 22nd July 1999 (figure 8). Rainfall activity got enhanced in the Andaman and Nicobar islands particularly in the southern side on 21st/22nd July. A seat of action therefore existed in the lower latitudes in the Bay in accordance with the secondary trough (Gadgil 2000). A patch of low OLR is also seen in the head Bay on both the days. In fact it existed even on 19th and 20th July in the north Bay. Figure 8 shows OLR minima in the south Bay expanding northward in the central Bay in which the cluster seen earlier in the north Bay stands almost merged. This OLR minima remains more or less in the east central Bay on 23rd and 24th July (figure not shown) when a low forms in the north-west Bay. Later on the OLR field gets tremendously modulated by the depression discussed in

the next section. There is some signal on the northward propagating mode in association with weak intra-seasonal oscillation (Sikka and Gadgil 1980).

It is apparent that deep convection is getting forced not only by the low frequency mode but also by the synoptic and sub-synoptic scale perturbations. In fact at one particular instance at 06 UTC of 21st July, three to four clusters are seen in the Bay of Bengal in figure 9. The average daily OLR of that day shows one main OLR minima in the south and adjoining central Bay extending westward across south peninsula into the Arabian Sea corresponding to low frequency intra-seasonal mode and other minima in the north Bay refers to the synoptic scale oscillation encountered in the monsoon trough zone. Joseph *et al* (2001) also talked of two resting positions of the maximum cloudiness zone. The northward drift of the main OLR minima across the Bay seems to be due to the weak intra-seasonal oscillation. But the overall revival/strengthening of monsoon seems to be a mixed affair.

The southern hemispheric equatorial trough (SHET) was inactive during this spell. This did not hamper the cross equatorial flow into the southwest Arabian Sea which continued to be of the order of 15–20 knots. The low level jet speeds of about 40 knots were seen on many days in the southern

Figure 4. Active and weak spells of convection in the northern and southern Bay of Bengal during BOBMEX.

areas of the Arabian Sea. The maintenance of the strong monsoon epoch even over the BoB seems to be linked with these developments.

2.3 Low/Depression (25th July – 3rd August)

As explained earlier, the northward propagating convection interacted with the synoptic scale cluster in the head Bay leading to an increase in the convection over central and adjoining northwest Bay on 25th July. This gave rise to development of an LPS in the head Bay on 25th July that concentrated into a depression on 27th July (figure 10). The formation of the depression had significant control on convective activity in the BoB. A deep layer cluster about 2° in extent was seen to the west of the circulation centre of the depression in which an OLR minima of 135 watts/sq metre was

noticed. High OLR emanated from the south and central Bay indicating absence of any convective activity. The depression became deep on 28th July just before making landfall. There was practically no convection in the Bay of Bengal on this day. The entire cloudiness associated with the system moved over land. It was a case of weak development in which pressure fall before crossing was not more than 2 hPa. It increased to 4 hPa on land after crossing the West Bengal coast on 28th July. The pressure departure in the central region ranged between 4 and 6 hPa. The deep depression weakened into an LPS on 30th July over northwest Madhya Pradesh. It continued to move west north-westwards and weakened over west Rajasthan on 3rd August.

It may be interesting to point out here that some cloud patches were seen moving to the north of

Figure 5. Tracks of synoptic systems during BOBMEX.

40°N latitude during the course of this development. They were associated with a westerly trough in the higher latitudes which however did not affect the course of the depression/low discussed above. The strength of the monsoon in the Bay continued to be moderate to strong till 29th July. The monsoon weakened for a day or two and revived again on 31st July.

2.4 LPS development over the head Bay (2nd - 4th August)

Even in the wake of depression, the seasonal trough of LPS became well marked over the head Bay

on 31st July when DS4 reported westnorthwesterly winds of only 10 knots. The seasonal sea-level trough evolved into a well marked LPS on 2nd August in the northwest Bay when the wind strength rose to westerly 20 knots at the latitude of the buoy (DS4). It crossed West Bengal coast on 3rd August when the Bay of Bengal became devoid of any convection. The system moved westnorthwestward and was seen on 4th August over northeast Madhya Pradesh. Winds at that stage became westerly 25 knots at DS4. This low pressure merged with the seasonal trough on 5th August. The monsoon further strengthened over central and adjoining north BoB as seen through DS3 and DS4 wind

Figure 6. INSAT picture of 15th July 1999, 0600 UTC.

reports. There was simultaneous increase in the cloudiness over central Bay of Bengal. This was accompanied with the development of another low on 5th August.

2.5 Development of low/depression (5th – 10th August)

The monsoon was strong over south and central Bay, where winds of about 25 knots were being

reported. Another low pressure formed over the northwest Bay on 5th August and concentrated into a depression on the evening of 6th August (figure 11). A solid intense cloud cluster was seen in the central and north BoB on this day. This system crossed West Bengal coast on 7th morning. Strongest wind was recorded onboard ORV SK in this episode as wind strength rose to 42 knots on 7th August. After crossing land the depression weakened into an LPS that first moved west-

Figure 7. NCMRWF analysis.

northwestwards into central Madhya Pradesh up to 10th August and later moved northeastwards under the influence of a westerly wave.

2.6 Weak monsoon phase (10th – 22nd August)

The pressure gradient slackened on 10th August over the Bay of Bengal as DS4 reported westsouth-westerly wind of 15 knot strength due to movement of the low towards westnorthwest. This weakened the monsoon over the Bay. There was further reduction of wind speed on 19th August when it became just 10 knots. This heightened phase of weak monsoon continued up to 22nd August. This is also seen in the poor rainfall distribution over most parts of the country in the weeks ending 18th and 25th August, and in the absence of easterlies at 850 hPa level over the Gangetic Plains (figure 1).

A trough in the upper tropospheric westerlies was also seen extending into northwest India from 12th–16th August. It developed along 70°E longitude on 11th August and amplified over northwest India on 13th August. The northern part moved away eastward on 16th August. SHET was quite active during August 1999. SHET activity during August hampered the cross equatorial flow whose strength was generally less than 20 knots as seen from the NCMRWF 850 hPa level analysis. All these factors were responsible for the weak/break monsoon conditions over India.

2.7 2nd Intra-seasonal oscillation (20th – 30th August)/Low pressure development (24th August – 4th September)

This intra-seasonal oscillation was well captured in the BOBMEX operational phase. As early as 17th August there were signs of development

Figure 8. OLR in watt/metre square on (a) 21st July and (b) 22nd July 1999.

Figure 9. INSAT picture of 21st July 1999, 0600 UTC.

of maximum cloudiness zone in the lower latitudes in the BoB. The continental trough over Gangetic plains was also present but the eastern end was not dipping into the Bay. The surface pressure gradient over the Bay was of the order of 5 hPa, and the wind strength was 15 knots as described in the earlier section. The continental trough became somewhat inactive on 22nd August. The southern maximum

cloudiness zone shifted to about 13°N on 24th August (figure 12) when a low pressure area formed over west central Bay south of the zone where cyclogenesis normally takes place during peak monsoon months of July and August. The convective cloud cluster in the west central Bay was seen in the belt of westerly flow. The wind strength in the central BoB was 20 knots at this stage. This LPS moved northward and lay over

Figure 10. INSAT picture of 27th July 1999, 0600 UTC.

northwest and adjoining west central Bay on 26th August. The associated upper air circulation continued to extend up to mid-troposphere. The low pressure further shifted northward and lay over north BoB on 27th August. Northward advance of maximum cloudiness from south Bay to north BoB is discernible in NCMRWF charts at 850 hPa level in figure 13 that shows northward advance of strong wind zone in association with another weak

intra-seasonal oscillation which revived the monsoon from the weak phase.

SHET data set (personal communication with Dr. O. Prasad) revealed intra-seasonal oscillation migrating northward across the equator into the BoB particularly during the month of August. Intra-seasonal variability during the BOBMEX period was also studied by Kar *et al* (2001) who found a few occasions of northward propagating

Figure 11. Mean sea level analysis for 6th August 1999, 1200 UTC.

wind anomalies. This study also brings out two epochs of weak intra-seasonal oscillations during BOBMEX.

3. Summary

There were several spells of active and suppressed convection which were controlled by developments of 5 low pressure systems out of which 2 became depressions. In general the monsoon was relatively weak; this culminated in deficient rainfall in July and August 1999 over the country. The convection was very strongly modulated by synoptic settings that included 2 weak intra-seasonal oscillations which were accompanied with cyclogenesis in the west central Bay of Bengal. Both the

depressions were weak systems but had tremendous control on the development of convection in the Bay. A long weak monsoon phase during the period 10th–22nd August 1999 was practically devoid of any convection in the Bay of Bengal. This was accompanied with highly reduced rainfall activity over the country during this period.

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Figure 12. INSAT picture of 24th August 1999, 0600 UTC.

closely associated with the field phase of BOB-MEX. He would like to acknowledge with thanks Shri D R Sikka, chairman ICRP programme and (Retd) Director, IITM Pune and Prof. S Gadgil, IISc Bangalore for going through the manuscript and giving him important suggestions for improvement. The author also acknowledges with thanks the use of NCMRWF products for this study.

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Figure 13. NCMRWF 850 hPa winds from 24th–27th August 1999.

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