7.1 Introduction

Monsoon can be well defined as a seasonal reversing wind accompanied by corresponding changes in precipitation (Ramage, 1971; Bhattacharya and Bhattacharya, 1985, 1995). However, it is now used to focus seasonal changes in atmospheric circulation and precipitation due to the asymmetric heating of land and sea (Trenberth et al., 2000; Zuidema et al., 2007). Generally, the monsoon is referred to the rainy phase of a seasonally-changing pattern. In order to investigate the instability disturbances for the formation of the cyclonic storm, usually one analyzes the grid point values of wind and temperature at a particular resolution obtained at standard isobaric levels for a certain period (De and Biswas, 1994). This is assumed as the basic state for the formation of the system (Bhattacharya et al., 2014). The 2014 North Indian Ocean cyclone season is an ongoing event in the annual cycle of tropical cyclone formation (Bhattacharya et al., 2014). The North Indian Ocean cyclone season has no official bounds but cyclones tend to form between the months of April and December with the peak from May to November. The scope of this study is limited to the Indian Ocean in the Northern Hemisphere, east of the Africa and west of Peninsula. There are two main seas in the North Indian Ocean - the Arabian Sea situated to the west of the Indian subcontinent (abbreviated as ARB) and the Bay of Bengal to the east (abbreviated as BOB). This chapter is a case study to observe the influence of cyclonic circulation on monsoon wind.

7.2 Formation of Cyclone NAUNAK and its Development

Tropical Storm NAUNAK formed in the Arabian Sea was dissipating on
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June 13, 2014, as it ran into increasing vertical wind shear, dry air moving into the tropical cyclone and cooler sea surface temperatures. NASA's TRMM satellite recorded the soaking rains the day before that marked NAUNAK's "swan song." Figure 7.1 reveals TRMM satellite 3-D image of tropical storm NAUNAK. Tropical storm NAUNAK formed west of India on June 10, 2014 and thereafter it moved toward the northwest over the open waters of the Arabian Sea. NASA and the Japan Aerospace Exploration Agency's Tropical Rainfall Measuring Mission's (TRMM) satellite observed that NAUNAK contained powerful storms dropping rain at a rate of over 247.3 mm per hour when viewed on June 11, 2014 at 1549 UTC. At NASA's
Goddard Space Flight Center in Greenbelt, Maryland an analysis of rainfall from TRMM's Microwave Imager (TMI) and Precipitation Radar (PR) were overlaid on a 1530 UTC enhanced infrared image from the European Space Agency's METEOSAT-7 satellite. TRMM PR data were utilized for creating a 3-D view that found that NAUNAK contained powerful towering thunderstorms, reaching heights of up to 16.8 km. NASA's Aqua satellite passed over NAUNAK on June 11, 2014 at 08:29 UTC and the Atmospheric Infrared Sounder (AIRS) captured a near-infrared image of the storm. It provided an almost visible look at the clouds which showed a well-rounded tropical cyclone with good circulation. Figure 7.2 presents near-infrared image of tropical cyclone NAUNAK as taken by the AIRS instrument aboard NASA's Aqua satellite on June 11 at 08:29 UTC (Source: NASA)

![Near infrared image of tropical cyclone NAUNAK](image)

**Fig. 7.2** Near infrared image of tropical cyclone NAUNAK as taken by the AIRS instrument aboard NASA's Aqua satellite on June 11 at 08:29 UTC (Source: NASA)
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infrared image of tropical cyclone NAUNAK taken by the AIRS instrument aboard NASA's Aqua satellite on June 11 at 08:29 UTC.

June 13, 2014 proved unlucky for NAUNAK as environmental conditions worsened and tore the storm apart. By 09:00 UTC the Joint Typhoon Warning Center (JTWC) issued their final warning on the tropical cyclone when maximum sustained winds were near 35 knots and it was weakening quickly. The storm's last official position was at 21.3 north latitude and 64.3 east longitude about 285 nautical miles southwest of Karachi, Pakistan. At that time the dissipating storm was moving to the north at 9 knots. Figure 7.3 gives the type of cyclonic disturbances up to the NAUNAK formation in June 2014. Under the influence of an active Intertropical Convergence Zone (ITCZ), a low pressure system formed over the Bay of Bengal on January 2, which then moved into a favorable environment. A Tropical Cyclone Formation Alert (TCFA) was then issued by the Joint Typhoon Warning Center (JTWC). On January 4, the India Meteorological Department

![Fig. 7.3 Season summary map](image-url)
commenced its advisories on the storm, designating it as Depression BOB 01, followed by the JTWC classifying the storm as a tropical cyclone. The storm intensified a little further, before it made landfall over north Sri Lanka on January 6 and degenerating into a low pressure area during the following day (IMD report, 2014). A low pressure area formed over the Bay of Bengal owing to the influence of a monsoonal trough on May 19, 2014 which slowly consolidated, prompting to classify it as a Depression on May 21, named as Depression BOB 02 followed by JTWC issuing a Tropical Cyclone Formation Alert (TCFA) in the following hours (IMD and JTWC report, May 2014). Over the following day, the depression continued moving north-northeastwards towards an area of high vertical wind shear. The JTWC cancelled the TCFA issued for the system, stating that high wind shear was responsible for the convection to start dissipating (JTWC Report, May 2014).

Fig. 7.4 IR satellite imagery Tropical Cyclone "NAUNAK" (Source: JTWC/SATOPS)
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The storm continued losing convection, until it weakened into a well-marked low pressure area on May 23, 2014 (RSMC Report, May 2014). The remnant system persisted for several more days and thereafter moved over the Indian state of Odisha late on May 25, before dissipating on the following day (JTWC Report, May, 2014). A low pressure area was developed over the Arabian Sea on June 9, 2014 which then slowly organized and was classified tropical storm 02A by the JTWC in the early hours of June 10. In the following hours, it was upgraded to a depression and then as a deep depression, designating it "ARB 01". On June 11, the system was further upgraded to cyclonic storm and was named NAUNAK by the IMD as it continued to intensify. NAUNAK subsequently, in the next day reached its peak intensity with a minimum central pressure of 986 hPa and 3-minute sustained winds of 85 km/h. As it tracked further northwestwards, the storm

![Fig. 7.5 Rainfall observed from Satellite and gauge data (Source: IMD)](image-url)

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encountered moderate vertical wind shear, producing it to weaken rapidly. A low-level steering flow deflected the storm to take a northward path and the system was finally observed as a well-marked low pressure area on June 14. Figure 7.4 and 7.5 reveals IR satellite imagery of Tropical Cyclone NAUNAK and rainfall observed from composite satellite and gauge observations.

7.3 North Indian Ocean Cyclones

Table 2 shows a list of dominant North Indian Ocean cyclone season up to the month of June 19, 2014. It mentions storms and their names, durations, peak intensities (according to the IMD storm scale), wind speeds, pressure, area affected and damages.

Table 7.1 Dominant pre-monsoon storms in 2014 over North Indian Ocean

<table>
<thead>
<tr>
<th>Initiation Date</th>
<th>Duration Days</th>
<th>Storm Name</th>
<th>Class</th>
<th>Maximum Wind Speed (kts)</th>
<th>Minimum Pressure (hPa)</th>
<th>Rainfall</th>
<th>Affected Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 04</td>
<td>4</td>
<td>BOB 01</td>
<td>Depression</td>
<td>45</td>
<td>1004</td>
<td>Moderate North Sri Lanka; Low: Puducherry, Anuradhapura, Trincomalee</td>
<td>Sri Lanka</td>
</tr>
<tr>
<td>May 21</td>
<td>3</td>
<td>BOB 02</td>
<td>Depression</td>
<td>45</td>
<td>1000</td>
<td>Heavy Escapades of Baphore</td>
<td>Andaman and Nicobar Islands, Odisha</td>
</tr>
<tr>
<td>June 19</td>
<td>5</td>
<td>NAUNAK</td>
<td>Cyclonic Storm</td>
<td>85</td>
<td>986</td>
<td>Heavy: Pununai, Tamil Nadu, Erode/Chennai, Tadopamboo, Shirali, Cheruvathur</td>
<td>Pakistan, Oman, India</td>
</tr>
</tbody>
</table>

7.4 Unusual Monsoon of 2014

The southwestern monsoons in West Bengal occur from June through September. The Thar Desert and adjoining areas of the northern and central Indian subcontinent heats up significantly during the hot summer causing a low pressure area over the northern and central Indian subcontinent. In order
to fill this void, the moisture-laden winds from the Indian Ocean rush in to the subcontinent. These winds, rich in moisture, are drawn towards the Himalayas. The Himalayas takes the role like a high wall, blocking the winds from passing into Central Asia and forcing them to rise. The southwest monsoon is usually expected to start around the beginning of June and fade away by the end of September. The moisture-laden winds on reaching the southern most point of the Indian Peninsula, owing to its topography, become divided into two parts: (i) the Arabian Sea Branch and (ii) the Bay of Bengal Branch. The Arabian Sea Branch of the Southwest Monsoon first hits the Western Ghats of the coastal state of Kerala, India, and hence making this area the first state in India to receive rain from the Southwest Monsoon. This branch of the monsoon moves northwards along the Western Ghats with rainfall on coastal areas, west of the Western Ghats. The Bay of Bengal Branch of Southwest Monsoon flows over the Bay of Bengal heading towards North-East India and Bengal, picking up greater amount of moisture from the Bay of Bengal. The winds reach at the Eastern Himalayas with huge rain.

The delayed Monsoon of 2014 has slowed down due to an unexpected Cyclone NAUNAK. The cyclone in the Arabian Sea interrupted the advancement of the monsoon. The cyclone extracted moisture, brought by the monsoon, due to which less rain was expected in some parts of West coast and Western Ghats of India. After a delay of nearly a week, the southwest monsoon arrived in Kerala. However, as the conditions were not favorable for further advancement, it took brief halt there and advanced towards Karnataka, Goa and finally entered Maharashtra. On Wednesday, the monsoon entered parts of south Konkan and Goa but it could not made further advancement as the NAUNAK cyclone gained strength. A deep depression over the Arabian Sea may impact the progress of monsoon. The
Circulation of cyclone and monsoon wind

depression was intensifying into a severe cyclonic storm NAUNAK. Figure 7.6 shows the advancement of South West monsoon of 2014. The monsoon also likely to be below normal in 2014 due to the evolving El Niño, a warming of the Pacific Ocean that upsets weather patterns across the globe. Rain during the four months of monsoon in India beginning June is expected to be 94 per cent of the average of the past 50 years, called long-period

Fig. 7.6 The advancement of South West monsoon of 2014. Red line showing the normal advancement of the monsoon while green line shoeing the actual advancement of monsoon 2014 (Source: IMD)
average. Monsoon rain in the range of 96-100 per cent of the long-period average is considered normal. Overall, there is a 40 per cent chance of rain being below normal in 2014, a 34 per cent chance of a normal monsoon, a 25-per cent chance of a drought and a one-per cent chance of rain being above normal [http://www.skymet.net/reports.php].

7.5 Comparison with Previous Monsoons

July and August are the major rainy months over Northwestern (NW) parts of India. Investigations by De and Biswas (1994) and Puvaneswaran and Smithson (1993) have revealed that end of July/August rainfall is important in deciding the seasonal rainfall of the year. By the end of August one may get a clear indication of the performance of monsoon of the year. Frequency of breaks exhibits maximum in July and August. As a matter of fact, the correct prediction of weekly rainfall in July and August can be a useful input for the long-range prediction also. Monsoon being the result of land-sea

Table 7.2 Pre monsoon low pressure systems and rainfall

<table>
<thead>
<tr>
<th>Year</th>
<th>Low Pressure System</th>
<th>Duration</th>
<th>First Rainfall Date</th>
<th>First rainfall (mm)</th>
<th>Arrival of monsoon Date</th>
<th>Rainfall on Arrival Date (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Severe Cyclone, ‘GONU’</td>
<td>June 1-7</td>
<td>June 13</td>
<td>78.99</td>
<td>June 13</td>
<td>78.99</td>
</tr>
<tr>
<td>2008</td>
<td>Depression</td>
<td>June 5-7</td>
<td>June 10</td>
<td>12.95</td>
<td>June 10</td>
<td>12.95</td>
</tr>
<tr>
<td>2009</td>
<td>Severe cyclone, ‘AILA’</td>
<td>May 23-26</td>
<td>May 24</td>
<td>1.016</td>
<td>May 25</td>
<td>53.09</td>
</tr>
<tr>
<td>2010</td>
<td>Very severe Cyclone, ‘AILA’</td>
<td>May 30-June 7</td>
<td>June 12</td>
<td>Trace</td>
<td>June 13</td>
<td>2.03</td>
</tr>
<tr>
<td>2011</td>
<td>Depression, Deep Depression</td>
<td>June 11-12, June 16-23</td>
<td>June 15</td>
<td>7.112</td>
<td>June 15</td>
<td>7.11</td>
</tr>
<tr>
<td>2012</td>
<td>No Low pressure system till October</td>
<td>-</td>
<td>June 07</td>
<td>14.99</td>
<td>June 17</td>
<td>7.87</td>
</tr>
<tr>
<td>2013</td>
<td>Depression</td>
<td>May 29-31</td>
<td>June 14</td>
<td>24.89</td>
<td>June 8</td>
<td>Nil</td>
</tr>
<tr>
<td>2014</td>
<td>Cyclone, ‘NAUNAK’</td>
<td>June 10-14</td>
<td>June 27</td>
<td>0.254</td>
<td>June 18</td>
<td>Nil</td>
</tr>
</tbody>
</table>
heating contrast involving large-scale seasonal reversal of pressure, temperature and winds, many investigations have been carried out for identifying useful predictors based on the pressure and thermal fields during antecedent winter and pre-monsoon seasons (De et al, 2005). Table 7.2 gives a simple comparison of the present and past monsoons since 2007. Figure 7.7 shows the comparison of rainfall amount during the monsoon from 2007 to 2014. It is clear from the figure that during 2009 rainfall is maximum and minimum in 2010.

7.6 Analyses of Sferics record

The monsoon rolled into Kolkata of West Bengal on June 18, 2014 over a week behind schedule but brought 39 mm of rainfall that submerged several parts of the city. The monsoon beat the mercury down to 32.1 degrees Celsius on June 18, a notch below normal, with clouds shutting out the Sun for almost the entire day. The northern limit of the south-west monsoon covered
most of Bengal on June 17, except some districts in the extreme west. In fact, the monsoon’s northern limit crossed Visakhapatnam, Bhubaneswar, Bankura and Darbhanga on June 18, 2014. Figure 7.8 reveals some typical records of sferics as recorded over Kalyani, West Bengal, at 27 kHz. Figure 7.8 (a) shows regular variations on an undisturbed day. It exhibits all the

Fig. 7.8 Sferics record at 27 kHz at Kalyani, West Bengal: (a) Showing regular variations in the noise level, (b) and (c) during cyclone and (d) after the onset of monsoon (ordinate is in dB above 1 micro-volt/meter)
characteristic features *viz.* sunrise effect (A), first minimum (B), recovery effect (C), morning minimum (D), afternoon maximum (E), late-afternoon minimum (F) and night maximum (G). The regular behavior also reveals upper nighttime level and lower daytime level of sferics caused by the presence of D-layer at daytime making the propagation poor compared to that occurs at night when the D-layer disappears and the propagation mainly occurs due to nighttime E-layer (Bhattacharya and Bhattacharya, 1984,1985). Figure 7.8(b) and 7.8(c) respectively represents the sferics record on June 10 and June 13, 2014 accompanied by cyclone at the background which largely contributes in obstructing the appearance of SW monsoon in time over Kolkata and other parts of South Bengal. Both the figures [Figure 7.8(b) and 7.8(c)] exhibit remarkable higher noise level with similar characteristic variations. Figure 7(d), on the other hand, is a typical record of sferics as recorded on June 17, 2014, showing less fluctuation in the level.

### 7.7 Discussion

Rainfall in 2014 due to monsoon may be very typical of the season: summer-like thunderclouds working in tandem with layered, low-level monsoon clouds to bring long spells of drizzle rather than high-intensity downpour. Also one may expect below-normal rainfall in June because of the monsoon’s late arrival.

In 2013, the monsoon had arrived on schedule (June 8) in Kolkata and many parts of South Bengal but the cumulative rainfall from June 1 to June 17 was 141.5mm. The aggregate of 159.3mm for the corresponding period in the year 2014 is better from that point of view, owing to a trough of low pressure over Bangladesh and adjoining areas that brought a few smart spells of thundershowers. In many cases the onset of Indian Monsoon is found to be
sudden and the onset phase is associated many times with some form of transient disturbances (Bhattacharya et al, 1985). In most of the cases the disturbances originate in the Arabian Sea and very rarely they originate in the Bay of Bengal. Once the monsoon sets, its further progress takes place due to rain bearing systems like monsoon trough, lows, depressions, mid tropospheric cyclones, etc. These synoptic scale systems are considered as perturbations embedded in the basic monsoon current. Many attempts have been made to explain the monsoon disturbances of the Bay of Bengal in terms of dynamic instability. Some scattered studies are available for the systems in the Arabian Sea. The onset phase differs in each year but after the onset a low-pressure area develops in the Arabian Sea, which later develops into cyclonic storm. In 2014 monsoon, a cyclonic circulation over the Bay of Bengal that drifted towards Myanmar has shifted course back to the Bengal-Odisha coast. The weather system is pulling monsoon winds towards it which may be considered as an adding strength to the monsoon of this year.

The delayed arrival of the annual rain-bearer, may be due to Cyclone NAUNAK over the Arabian Sea which slowed down the monsoon winds on the west coast. However, the cyclonic circulation active on the Bengal-Odisha coast is subsequently acted as the catalyst, pulling the winds northward. The rain distribution could remain skewed for some time at the very onset of monsoon as the weather has just entered its transitional phase.
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