Observations on extreme meteorological and oceanographic parameters in Indian seas

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Extreme observations of few met–ocean parameters during the passage of various tropical cyclones or during specific regional dynamics recorded by moored buoys after their implementation in 1997 are presented. Maximum wave height of 13.93 m was observed during Orissa supercyclone in October 1999 and high current speed of 300 cm/s (5.83 knots) observed off Car-Nicobar during June 2000. During the cyclonic storms over the Arabian Sea, lowest pressure of 991.76 mb (May 2004) and high wind speed of 35.26 m/s (May 1999) were recorded. Also low sea surface temperature (SST) of 20.41°C was observed associated with winter cooling phenomenon in February 2002. A maximum SST of 31.7°C was observed in the Arabian Sea warm pool in April 2003.

LONG-term time series *in situ* measurements of meteorological and oceanographic parameters over the Indian seas became a reality with the implementation of National Data Buoy Programme (NDBP) in 1997 by Department of Ocean Development at National Institute of Ocean Technology (NIOT), Chennai. Initially 12 moored buoys were deployed and later it was increased to a 20-buoy network. These moored buoys have successfully recorded various parameters such as wind, wave, air pressure, sea surface temperature (SST) and current during extreme weather conditions or during specific regional phenomena. Most of these extreme observations require continuous monitoring and observations are often difficult, especially during bad weather. In this context, moored buoys have brought out some rare observations which occurred in the Indian seas. Locations of moored data buoys and the specifications of sensors used in this study are given in Figure 1 and Table 1 respectively.

The highest wind speed was recorded during the very severe cyclonic storm which occurred in the Arabian Sea in May 1999. This cyclone developed in the southeast Arabian Sea on 15 May, intensified into a deep depression the next day and moved in a northwestward direction. The system further intensified to the stage of very severe cyclonic storm on 17 May. By 18 May, a mid-latitude trough passing through the Middle East significantly weakened the subtropical ridge, making the system to move in a northeastward direction. The landfall occurred near Karachi, Pakistan by 20 May. During this very severe cyclonic storm, a deep water buoy DS1 (lat. 15.509°N; long. 69.254°E) deployed in central Arabian Sea had recorded the maximum wind speed of 35.26 m/s (68.54 knots) at 12 GMT on 17 May 1999 (Figure 2). Wind direction was north–northwesterly before the passage of the cyclone, which abruptly changed to southerly under the cyclonic influence. Earlier reported maximum average wind speed was 24.47 m/s (47.57 knots)[1] during the Arabian Sea cyclone in 1998 by the buoy at the same location.

Maximum significant wave height was recorded during the Orissa supercyclone which occurred in the Bay of Bengal in October 1999. This was the most intense tropical cyclone in the history of India during the last 100 years. Initial vortex was observed over the Gulf of Thailand on 24 October morning and emerged in north Andaman Sea as a well-marked low-pressure area the next morning. The system intensified further and turned to be a severe cyclonic storm on 27 October morning at about 750 km southeast of Paradip. At midnight of 28 October, it moved about 90 km southeast of Paradip as a supercyclone. The system was at its peak intensity on 29 October morning before crossing the land (Figure 3). The system achieved severe cyclonic intensity while crossing the buoy location. During this most intense tropical cyclonic phase, a deep water buoy DS4 (lat. 17.999°N; long. 88.091°E) deployed in northern Bay of Bengal recorded the extreme wave characteristics. Wind measurements at DS4 failed due to sensor damage. The mean direction of waves at DS4 before the cyclonic disturbance was predominantly southerly; due to the cyclonic influence the wave direction rapidly changed to northerly. Significant wave height (Hm0) of 8.44 m (12 GMT on 28 October 1999) was recorded during this storm (Figure 3 *d*). Using the relation derived by Sanil Kumar *et al.*[2], maximum wave height (H_{max}) was computed to be 13.93 m. Earlier recorded[3] maximum wave height was 8.2 m during the storm in November 1982. Mukherjee and Sivaramakrishnan[4] have reported approximately 15 m wave height during

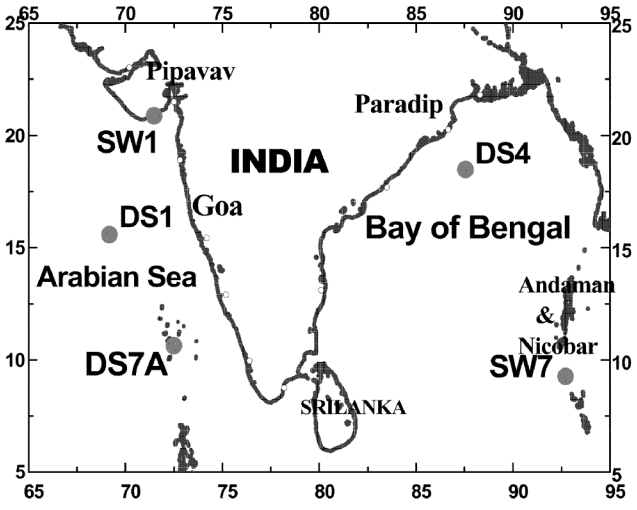

Figure 1. Buoy locations.

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Table 1. Sensor specification

Sensor	Make	Range	Accuracy	Resolution
Air pressure	Vaisala	500–1100 hPa	± 0.1 hPa	0.01 hPa
Wind (speed, direction)	Lambrecht	0–70 ms^{-1}, 0–360°	± 1.5% FS, ± 1°	0.07 ms^{-1}, 0.1°
Sea surface temperature	Sensortec	–5– +45°C	± 0.1°C	0.01°C
Current (speed, direction)	Sensortec	0–3 ms^{-1}, 0–360°	± 5 mms^{-1}, ± 1°	1 mm s^{-1}, 0.1°
Wave (full spectrum)	Seatex	± 20 m, 0–360°	± 10 cm, ± 0.3°	0.006%, 0.1°

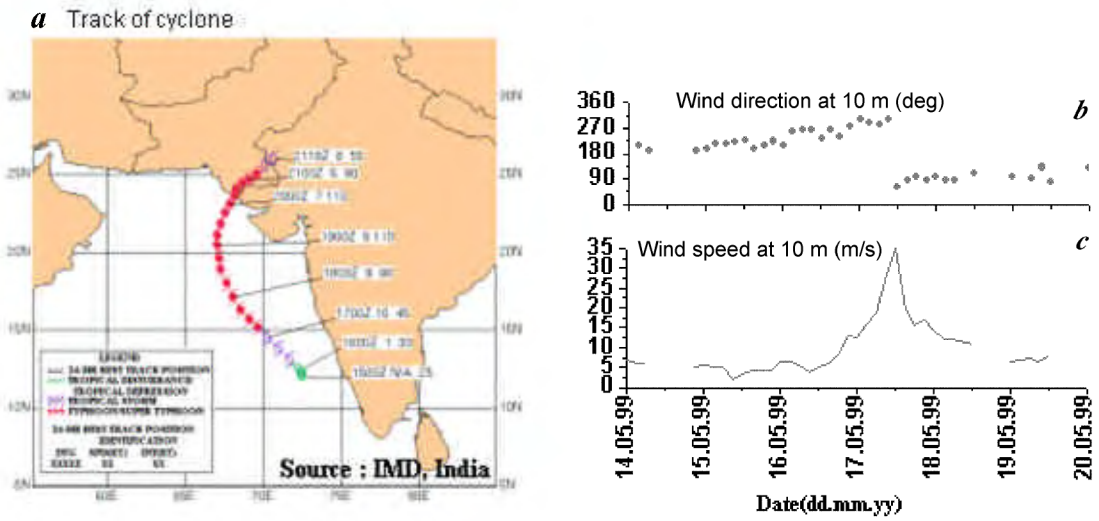

Figure 2 *a–c*. Track, wind direction and speed during the Arabian Sea cyclone in May 1999.

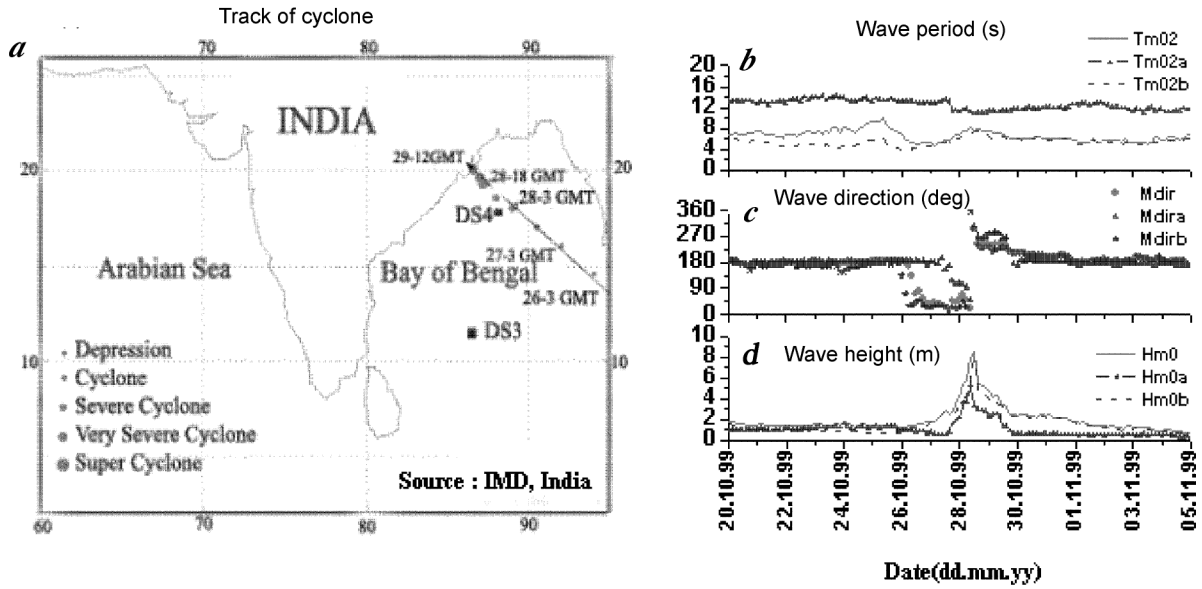

Figure 3 *a–d*. Track, significant wave height, period and direction of supercyclone in October 1999.

a cyclonic storm in June 1976. However, the reliability of observation is doubtful since the wave measurements were taken with reference to the markings on the legs of an oil rig.

The highest current speed was recorded in June 2000 near Nicobar Islands, which is a region of high currents and strong tides owing to the presence of the ten-degree channel. The literature corresponding to *in situ* observations of current

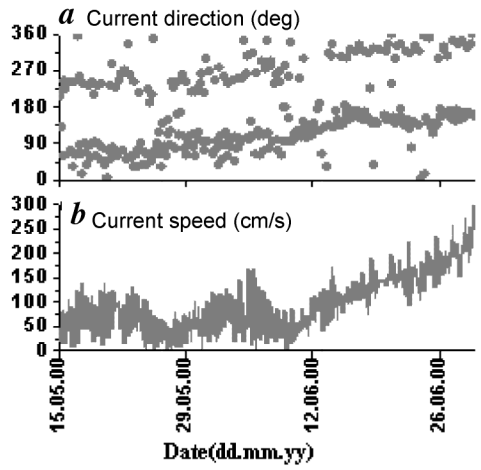

Figure 4 *a*, *b*. Current speed and direction observed near Nicobar Islands in May 2000.

from this area is rare and the previous reported high current speed is ~110 cm/s off Little Andaman, by Radhakrishnan *et al.*[5]. Surface meteorological and oceanographic parameters off Car-Nicobar were recorded by a moored buoy SW7 (lat. 9.262°N; long. 92.729°E) during May–June 2000. The buoy was deployed at the northwestern side of the island (south of ten degree channel) and was 4 nm away from the coast. The current measurements showed tidal oscillation with an average speed of 50 cm/s (~1 knots) during the initial period of observation. The buoy drifted 720 m towards northeast during the first week of June 2000 and continued transmitting data from the new position (lat. 9.265°N; long. 92.736°E). The current speed was similar to the previous location for one week and started increasing thereafter. An unusual high current speed of more than 150 cm/s (2.92 knots) has been observed for a period of two weeks from the 2nd week of June 2000. The speed was

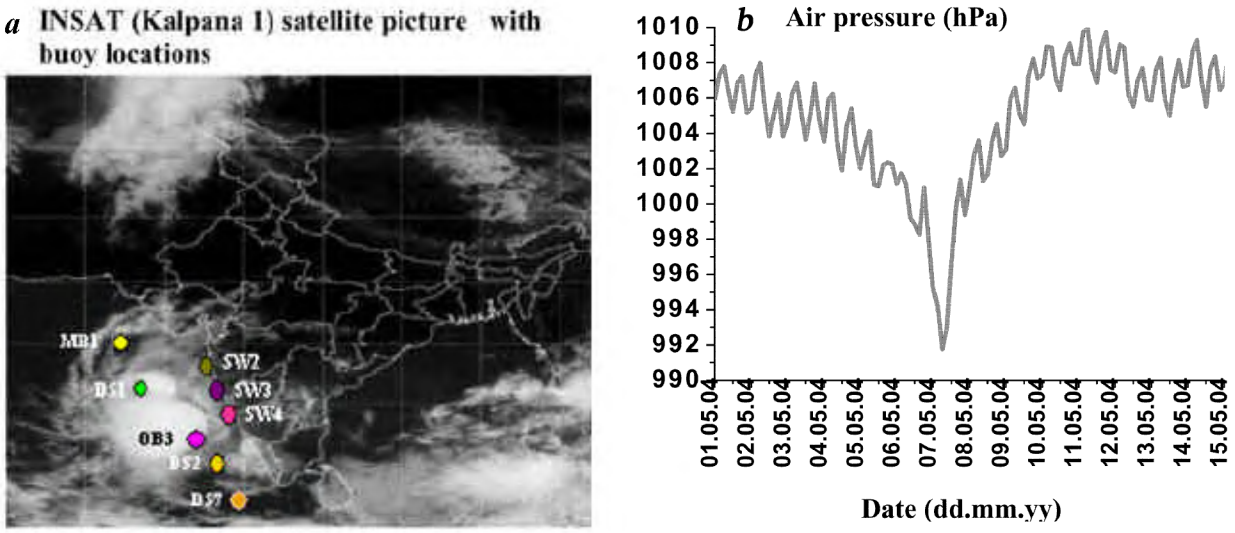

Figure 5 *a*, *b*. Satellite picture (INSAT) and air pressure observed during Arabian Sea cyclone in May 2004.

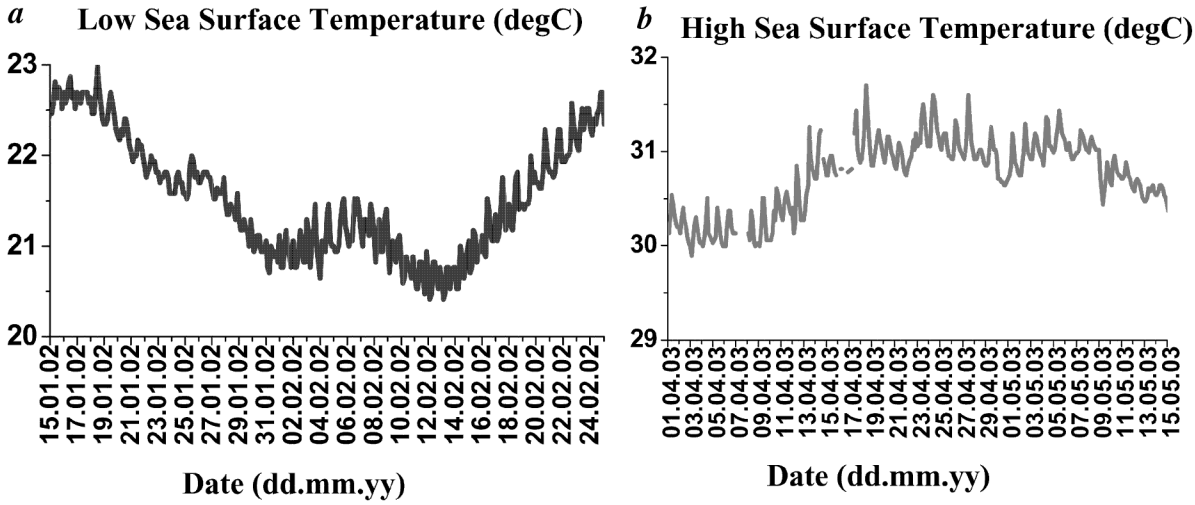

Figure 6 *a*, *b*. Sea surface temperature observed during winter cooling in February 2002 and warm pool phenomenon in April 2003 respectively.

increasing steadily till the end of observation and the highest value recorded was 300 cm/s (5.83 knots), which is the upper limit of the measurable range of the instrument (Figure 4). Thereafter, no data transmission was received at NIOT and the buoy was reported missing, which might have lost its mooring and drifted due to this high current. There was no significant variation in surface met observations, indicating that high current speed was not due to local wind forcing. Presence of an outflow from the Bay of Bengal triggered by the southwest monsoon may be the cause of this unusual current speed.

The lowest pressure recorded was during the severe cyclonic storm which occurred in the Arabian Sea in May 2004. This cyclone formed as a low pressure area over Kerala and its neighbourhood on 4 May 2004. It emerged at the southeast and adjoining eastcentral Arabian Sea, concentrated into a deep depression and intensified into a cyclonic storm by the evening of 5 May 2004. It moved northwestwards and further intensified into a severe cyclonic storm by 7 May 2004. This severe cyclonic storm weakened into a cyclonic storm by 8 May evening and slowly moved in a north–northwesterly direction. The storm weakened and crossed the Gujarat coast by 10 May 2004. During this severe cyclonic storm, a deep water buoy OB3 (lat. 12.489°N; long. 71.997°E) deployed off Mangalore had recorded the lowest air pressure of 991.76 mb at 06 GMT on 7 May 2004 (Figure 5). Earlier reported[1] low pressure was 997.39 mb during the Arabian Sea cyclone in 1998.

The lowest SST was recorded in February 2002 near Pipavav port due to winter cooling. This phenomenon was observed in the northern Arabian Sea during winter season, when cold air from north increases the density of surface waters, forcing it to sink and bringing cold subsurface water to the surface. A shallow water buoy, SW1 (lat 20.875°N; long 71.492°E) deployed at Pipavav port recorded the lowest SST of 20.41°C (03 GMT on 12 and 13 February 2002) as a result of this phenomenon (Figure 6 *a*). Previous reported lowest SST during this phenomenon was 24.5°C during February 1995 by Madhupratap *et al.*[6]. Darbyshire[7] reported the lowest SST (~22°C) along the west coast of India between lat. 8 to 12°N due to upwelling.

The highest SST was recorded in May 2003 in the southeastern Arabian Sea associated with warm pool phenomenon. The warm pool is a unique phenomenon of anomalous warm surface water in the southeastern Arabian Sea that collapses due to the onset of the southwest monsoon. The warm pool extends as a tongue of warm surface water of more than 30°C, in the southeastern Arabian Sea during the pre-monsoon period. It is observed that the surface water in the warm pool is less saline, which favours the accumulation of heat in the upper mixed layer. The warmer and less saline water acts as a thin stable surface layer that inhibits mixing with the deeper cooler and high saline water. Time series observations of SST by a moored buoy DS7A (lat. 8.31°N; long. 72.65°E) deployed off Minicoy, clearly exhibits the warming of surface waters attaining maximum SST of 31.7°C at 12 GMT on 18 April 2003 (Figure 6 *b*). Previous reported[8] highest SST was 31.2°C during May 2000.

Moored buoys have brought out rare observations from this region that facilitate better understanding of the north Indian Ocean dynamics and the processes associated, which has wide implications in various fronts. However, observations exceeding these reported extremes will be occurring in this region and may not be observed due to the lack of a close network of observing platforms, and there lies the demand for increased observing platforms in the Indian seas.

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