

# First results from a new observational system over the Indian seas

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**The Department of Ocean Development has recently installed several moored met-ocean buoys in the Bay of Bengal and Arabian Sea to measure sea surface temperature (SST) and other near-surface atmospheric and oceanic variables every three hours. We present here a preliminary analysis of the data from one buoy in the Arabian Sea and three buoys in the Bay of Bengal, during June–August 1998, along with daily INSAT data on outgoing longwave radiation at the buoy locations. Data show that SST dropped abruptly in the eastern Arabian Sea during passage of the June 1998 cyclone. In the Bay of Bengal, SST shows prominent intraseasonal oscillations at all three buoy locations. The SST variation seems to be determined by variations in cloudiness and wind speed at the buoy location.**

UNDERSTANDING and predicting the variation of rainfall in different spatio-temporal scales is undoubtedly one of the most important problems in monsoon meteorology. Most of the rainfall over the Indian region is associated with cumulus clouds organized in synoptic scale vortices such as lows, depressions and cyclones. A vast majority of these synoptic scale systems are generated over warm oceans around the subcontinent.

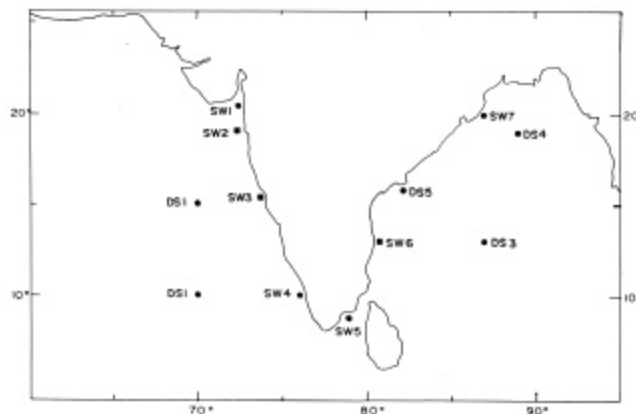
The advent of satellites which transmit images of clouds over the tropical oceans had a major impact on our understanding of the genesis and propagation of synoptic scale systems and of the planetary scale cloud bands in which they are often embedded. In fact, the first such imagery from the mid-sixties led to Bjerknes<sup>1</sup> seminal paper on the ocean–atmosphere coupling over the Pacific and its role in El Niño. A major advance in understanding the nature of ocean–atmosphere coupling over the Pacific has come from data generated from the moored buoy network set up in the last decade<sup>2</sup>.

Satellite imagery also had a major impact on our understanding of the role of oceans in maintaining the monsoon over the subcontinent, and of monsoon fluctuations within a season and between years<sup>3,4</sup>. The contribution of the INSAT series of satellites to short-range prediction has been enormous. Several studies have shown that INSAT

imagery is extremely valuable for monitoring development of tropical cyclones<sup>5</sup>. Important quantities such as rainfall over the continent and surrounding oceans have been derived from INSAT data on outgoing longwave radiation (OLR)<sup>6</sup>.

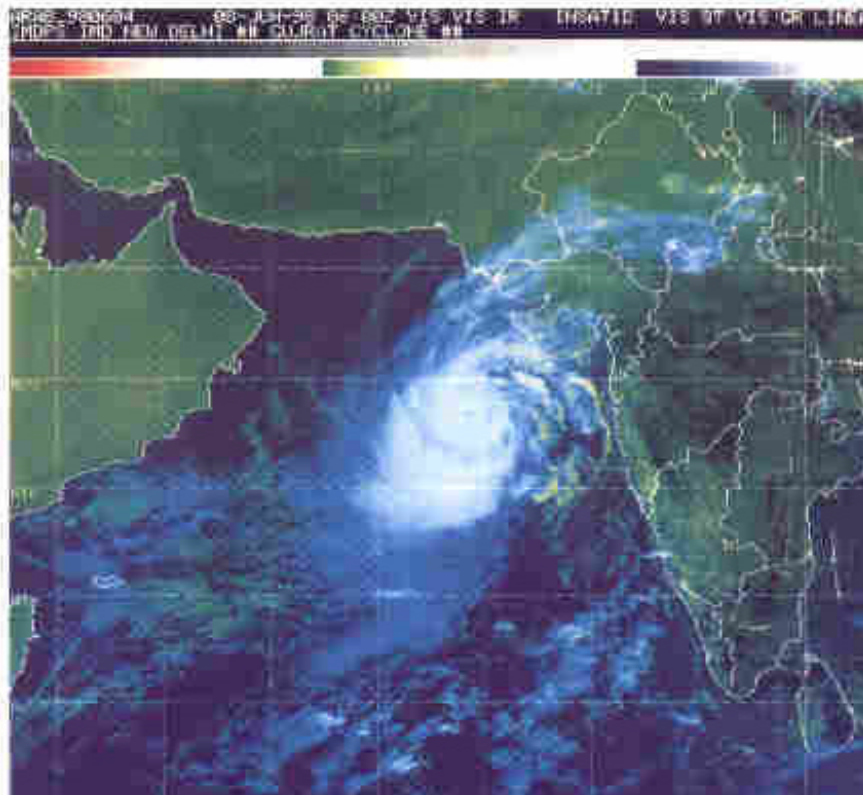
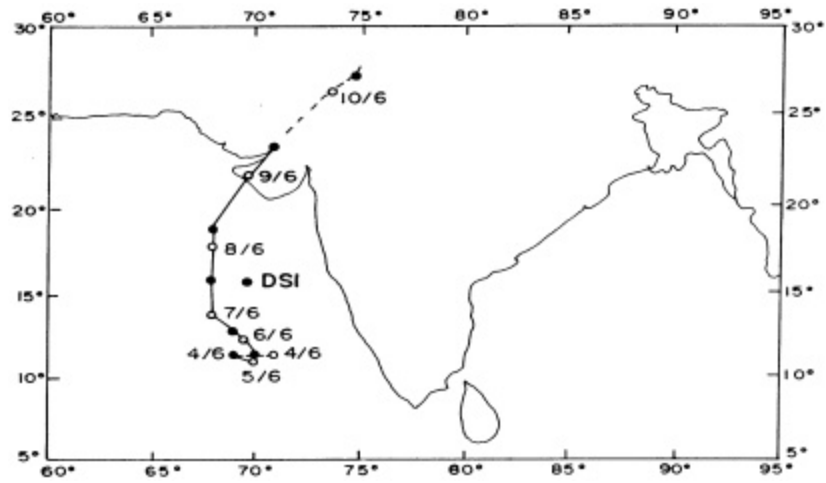
While clouding over the Indian seas is now monitored by satellites, the observations of the state of the ocean have been largely restricted to oceanographic cruises, drifting buoys and ships of opportunity. In a major new initiative, the Department of Ocean Development has set up, through the National Institute of Ocean Technology, a network of moored buoys over the Indian seas under the National Data Buoy Programme (Figure 1). Data for the first monsoon season from these new observational platforms are now available. Here, we present the first analysis of some data from four deep ocean buoys (one in the Arabian Sea and three in the Bay of Bengal) along with the INSAT data for  $2.5^\circ \times 2.5^\circ$  boxes around the buoys for June–August 1998.

First, the data analysed are briefly described. The observed variation of the ocean–atmosphere system derived from buoy and satellite data is then presented. Next, the implications for coupling of the Indian seas and the monsoonal atmosphere are discussed.



**Figure 1.** Location of DOD met-ocean buoys. DS, deep sea; SW, shallow water.

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**Data**

The National Data Buoy Programme was launched for generating continuous meteorological and oceanographic data on the Indian seas. Under this programme, twelve met-ocean buoys have been deployed in shallow and deep waters of the Arabian Sea and Bay of Bengal (Figure 1) by the National Institute of Ocean Technology. Sensors for wind, atmospheric pressure, air temperature, water temperature, salinity, currents and wave parameters have been installed on these buoys. The details of buoy configuration and sensors, including their accuracy and range, are available from Rao and Premkumar<sup>7</sup>.

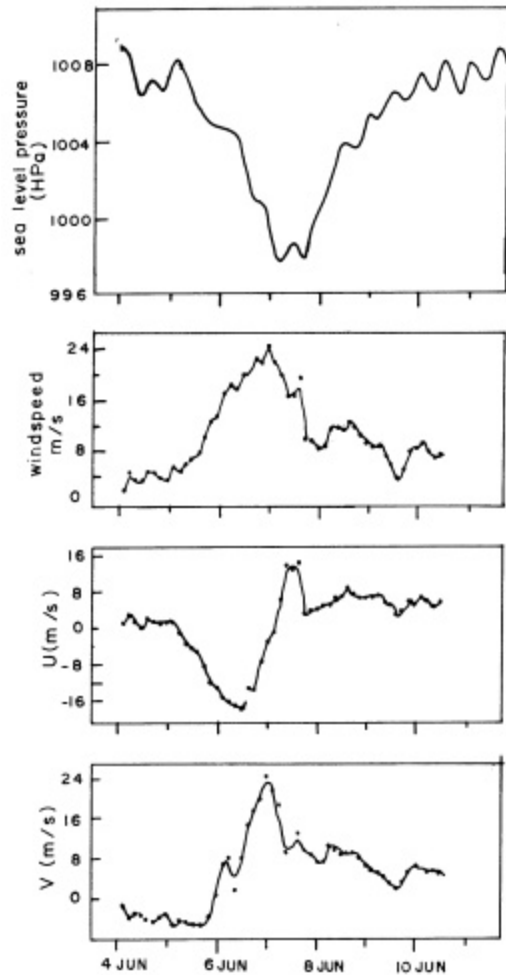
Here we present preliminary analysis of the data from buoys DS4 (head Bay), DS3 (central Bay), DS5 (western-central Bay) and DS1 (eastern Arabian Sea) during the summer monsoon of 1998, along with daily mean values of OLR from INSAT for 2.5° boxes around the buoys DS1, DS3, DS4. We also make use of pentad OLR data from the NOAA satellites and the weekly sea surface temperature (SST) analyses from NCEP, USA. These analyses use data from satellites, ships and buoys in an algorithm due to Reynolds and Smith<sup>8</sup> to yield weekly SST fields. For simplicity, we refer to these as Reynolds SST. The Indian buoy data does not enter the Reynolds SST analyses.

**Variation of ocean-atmosphere system during summer monsoon of 1998**

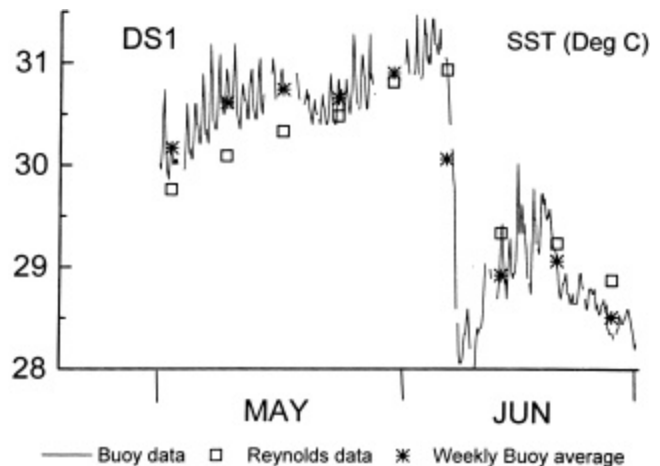
It is believed that the SST is the most important oceanic variable for deep convective clouds over oceans. Several studies<sup>9,10</sup> have shown that almost no deep clouds occur over cool oceans (SST below 26°C), whereas the propensity of deep convection is very high over warm oceans (SST above 28°C). On the other hand, SST is determined by the atmospheric circulation (which drives the oceanic circulation) and heat and freshwater fluxes at the surface of the ocean. Thus intense atmospheric systems such as tropical cyclones have a large impact on SST via enhanced evaporation, upwelling and upper ocean mixing<sup>11</sup>. We first describe the impact of the tropical cyclone over the Arabian Sea in June 1998. Then we present an analysis of the variation of selected oceanic and atmospheric parameters measured by the buoys and of INSAT-derived OLR during July–August 1998.

*Arabian Sea cyclone during June 1998*

The spectacular impact of the tropical cyclone in the Arabian Sea during 5–8 June 1998 (Figure 2 a and b)<sup>12</sup> is seen in the variation of SST measured by the met-ocean buoy DS1 (Figure 2 c). SST decreased by about 3°C, from a value of over 31°C before the cyclone to about 28°C after the cyclone. This is consistent with earlier results: Rao<sup>13</sup> observed a 3–4°C fall in SST in association with a tropical cyclone in



**Figure 2 b.** Sea level pressure (in HectaPascal), wind speed at 10 m height, eastward and northward component of wind (all in m/s) at the buoy DS1 during passage of the cyclone.



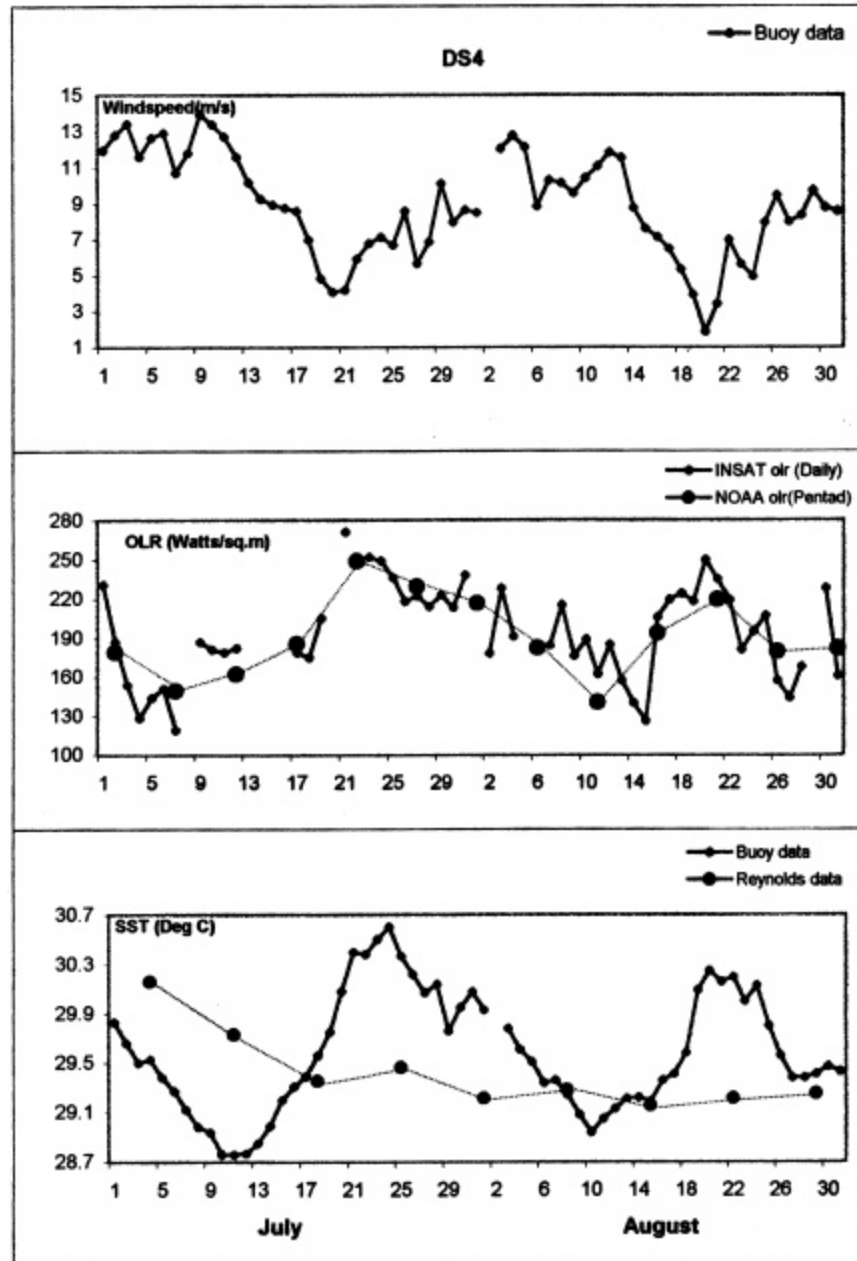
**Figure 2 c.** SST (temperature at 3 m depth) in °C measured by DS1, and Reynolds SST in May–June 1998. The 3-hourly buoy SST is shown as a thin line; weekly averages of the buoy SST are shown by asterisks and weekly Reynolds SST by open squares.

the Bay of Bengal; SST decreased by about  $2.5^{\circ}\text{C}$  at the buoys DS4 and DS5 during the passage of a tropical cyclone over the Bay in September 1997 (ref. 7). Note that the Reynolds SST is within  $0.5^{\circ}\text{C}$  of the weekly average of SST measured by the buoy, except during the phase of rapid decrease due to the cyclone. Figure 2d shows the variation of atmospheric pressure, wind speed and eastward and northward components of wind measured by DS1 during June. The northward component of the wind built up as the centre of the cyclone crossed the

latitude of the buoy. After the cyclone moved to the north, the eastward wind continued to increase for three days.

#### *Variation of atmospheric and oceanic parameters during July–August 1998*

Deep convective clouds over oceans, which are often organized over scales of hundreds of kilometers in synoptic scale systems such as lows and depressions, reduce the



**Figure 3.** Wind speed, OLR (in  $\text{Watts/m}^2$ ) and SST at the buoy DS4 in the north Bay during July–August 1998. Daily average wind speed and SST measured by the buoy are shown. Daily OLR from INSAT and pentad (five-day mean) OLR from NOAA satellite are superposed in the centre panel. Daily buoy SST and weekly Reynolds SST are shown together in the bottom panel. There are some gaps in all the daily data. OLR is for the box  $18.75^{\circ}$ – $21.25^{\circ}\text{N}$ ,  $88.75^{\circ}$ – $91.25^{\circ}\text{E}$ .

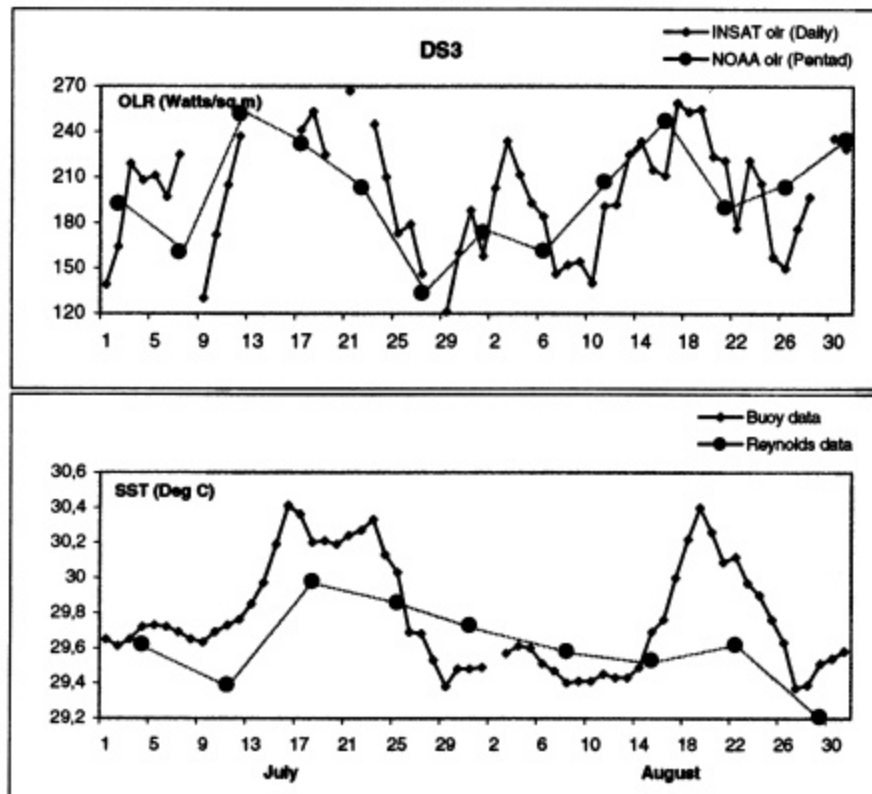
shortwave radiation incident at the surface of the ocean. The evaporation from the surface of the ocean, and hence evaporative cooling, depends on SST and humidity as well as wind speed. The strong winds associated with monsoon disturbances lead to enhancement of evaporative cooling. In addition, cooling can also occur due to entrainment of deeper water into the mixed layer. All these factors lead to a decrease of SST.

Deep convective clouds are characterized by low values of OLR and high values of albedo. Hence low values of OLR are taken to be indicative of the presence of deep clouds. Since these clouds reflect a large fraction of the solar radiation there is a decrease in the short wave radiation incident at the surface of the ocean under such clouds. Under clear skies and low winds, incoming solar radiation at the surface is high and evaporative cooling is low. Hence SST may be expected to increase. It is of interest to see the extent to which the Indian seas respond in this manner to variation in cloudiness and wind speed, and to determine the time scales of the response.

The variation of OLR, wind speed and SST during July and August 1998 at the buoys DS4, DS3, DS5 and DS1 is shown in Figures 3–6, respectively. Note that whereas

the variation of daily OLR from INSAT and the pentad OLR from NOAA are consistent, there are differences between the buoy SST and Reynolds SST during July and August. Sometimes the variation is out of phase with that of the buoy SST. This discrepancy may be due the problem of determining SST from satellites during the monsoon months when conditions are cloudy and the water vapour in the atmosphere is high.

The major feature of all the time-series at the head Bay (DS4, Figure 3) is an oscillation with two maxima/minima separated by about one month. SST changes in phase with changes in OLR, decreasing as OLR decreases (e.g. 25 July–10 August) and increasing as OLR increases (e.g. 15–20 August). This suggests a strong impact of clouds and the associated decrease in radiation. In general, it can be seen that winds are relatively strong when OLR is decreasing rapidly (i.e. when clouds are intensifying) and weak when OLR is high (no deep clouds). Thus the impact of wind speed on SST adds to that of clouds. The fact that SST changes are large suggests that the effective mixed layer is rather thin. This could be because of the presence of a turbid, freshwater layer near the surface<sup>14</sup>.



**Figure 4.** As in Figure 3, but for DS3 in the central Bay. Buoy wind speeds are not shown because they are not reliable during this period.

Over the central Bay (DS3, Figure 4) and the western Bay (DS5, Figure 5) the variation is similar to that over the head Bay. In July and August, the variations of OLR and wind speed at the Arabian Sea buoy (DS1) do not appear to have a large impact on SST (Figure 6). This may be because the effective mixed layer at this location is much deeper than at the Bay of Bengal buoys<sup>15</sup>.

Variation of SST during the summer monsoon at the deep ocean buoys in the Bay is depicted in Figure 7. Note that the intraseasonal oscillation is coherent throughout the Bay, although the amplitude is smaller at the buoy DS3 in

the central Bay. The diurnal variation is also clearly seen in Figure 7. The amplitude of the diurnal cycle is large during periods of clear skies and low winds, whereas the diurnal cycle is suppressed under cloudy and/or windy conditions. This is consistent with results from the Pacific warm pool region<sup>16</sup>.

Thus a large part of the variability of buoy SST analysed here appears to be a response to local changes in atmospheric conditions – primarily cloudiness and wind speed.

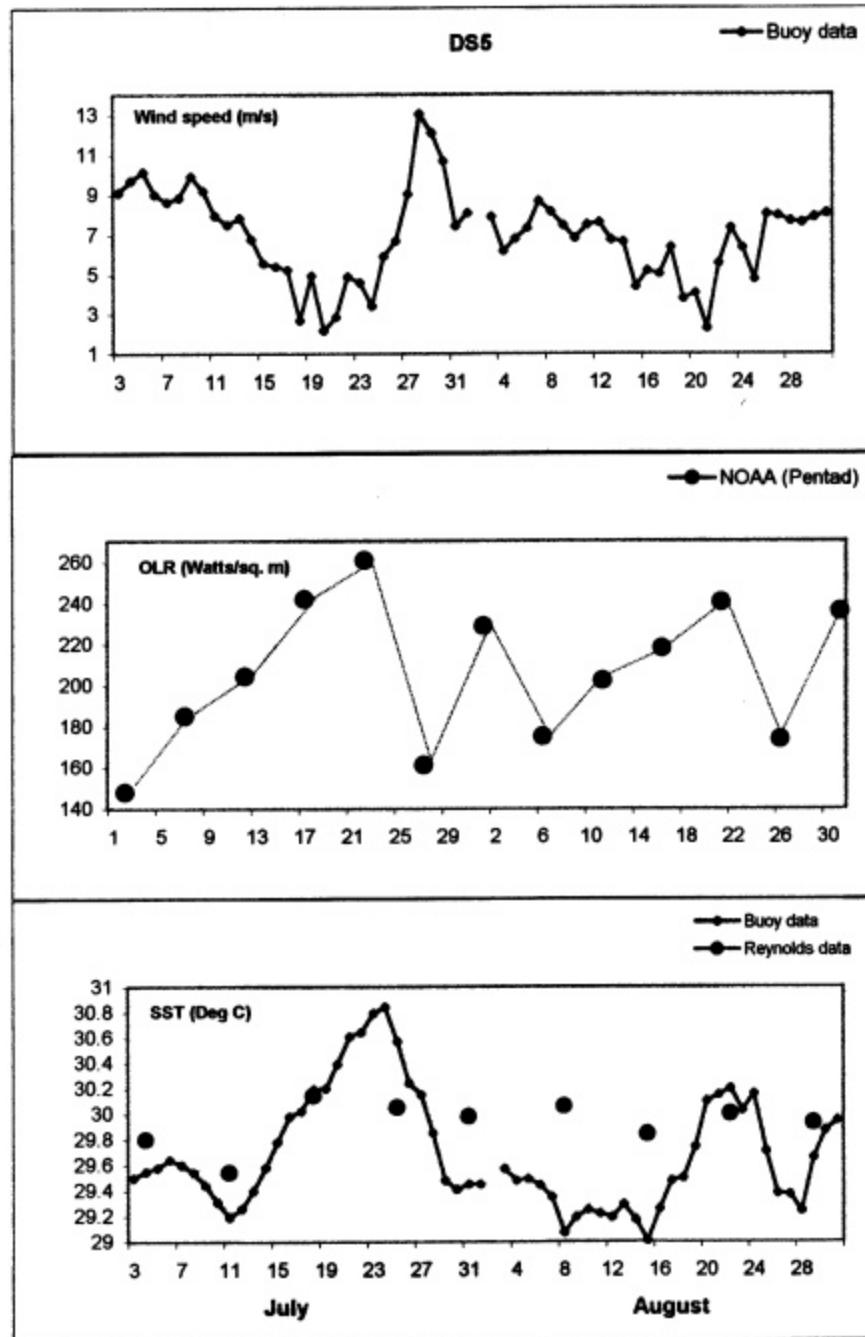


Figure 5. As in Figure 3, but for DS5 in the western-central Bay. Daily OLR is not available at this location.

**Discussion**

As mentioned earlier, met-ocean buoys provide a new tool in our efforts to document and understand the variability of the atmosphere and ocean over the Indian seas. The preliminary analysis reported here indicates the immense potential of this relatively new technology. To take only one example, these data reveal the existence of distinct intraseasonal oscillations in SST that are present at all three buoy locations in the Bay of Bengal during July–August 1998

(Figure 7). The amplitude of these oscillations is substantial, but they are not well represented in any other data currently available. For instance, note from Figures 3–5 the inadequacy of Reynolds analysis in capturing the SST variability.

This study has clearly brought out the effect of variations in the atmosphere (particularly cloudiness and wind speed) on SST. We expect the genesis, intensification and propagation of convective systems such as monsoon disturbances or tropical convergence zones<sup>17</sup> to depend on SST field – in particular on SST gradients and location of

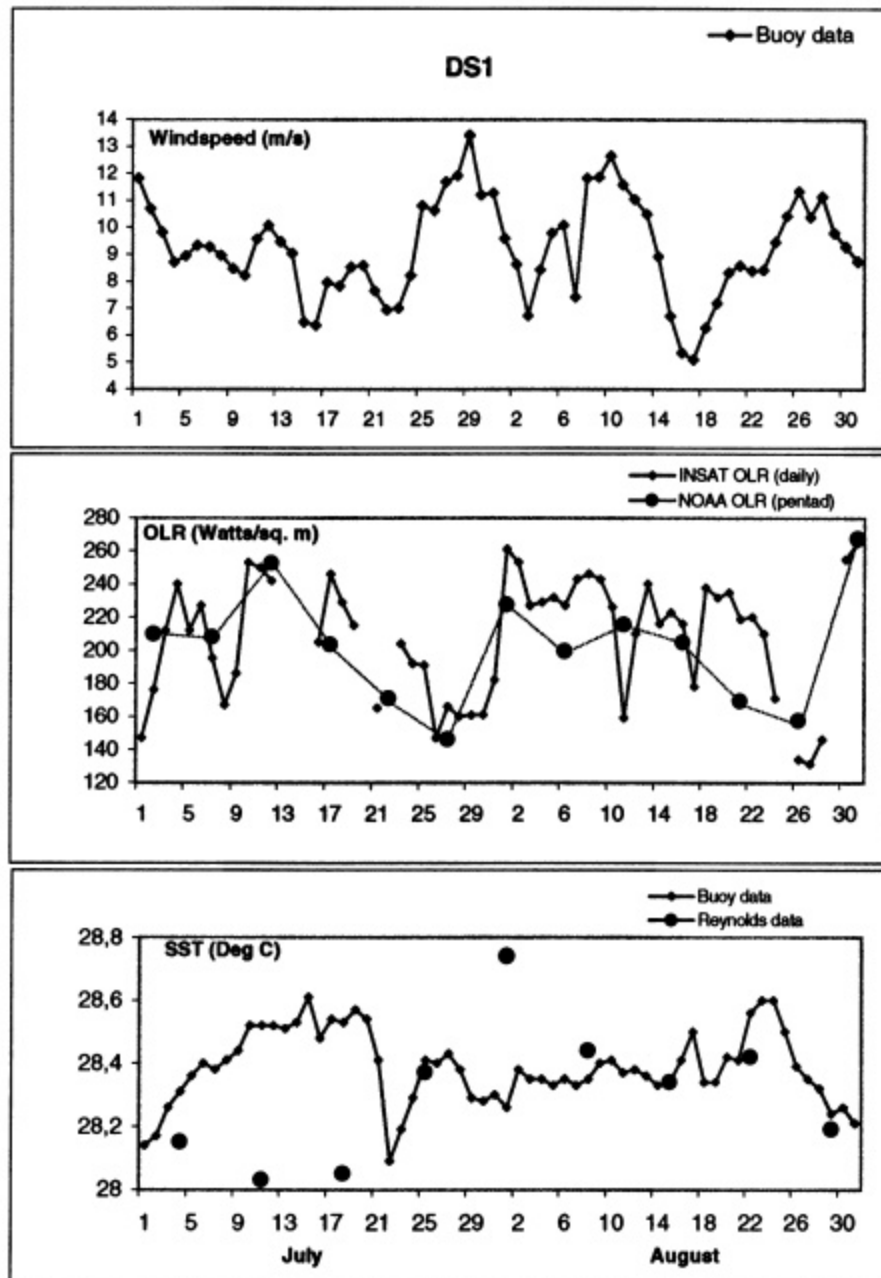
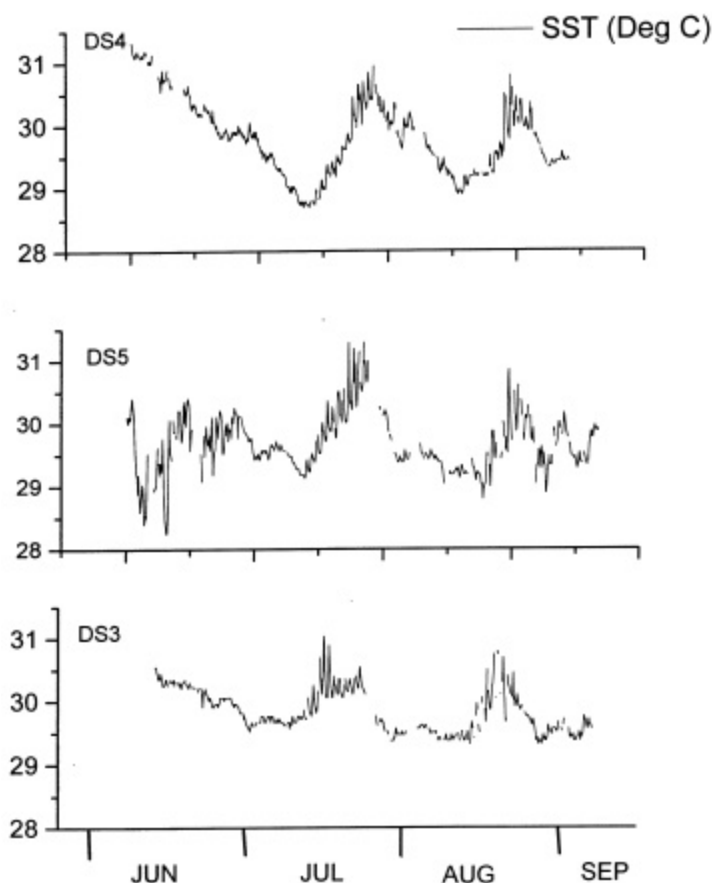


Figure 6. As in Figure 3, but for DS1 in the eastern Arabian Sea.



**Figure 7.** Three-hourly SST measured by the buoys DS4, DS5 and DS3 in the Bay of Bengal during July–August 1998.

SST maxima. To study the influence of the ocean on the atmosphere, more buoys are needed to yield data with improved spatial and temporal resolution. Further, the buoys need to be equipped with additional sensors for humidity, radiation, rain and turbidity. It is important to have several ~~buoys with measurements of subsurface temperature, salinity and currents.~~ Analysis of data from a network of such buoys, in conjunction with satellite data and models, will lead to new insights about coupling of the monsoon to the ocean.

1. Bjerknes, J., *Mon. Weather Rev.*, 1969, **97**, 163–172.
2. McPhaden, M. J. *et al.*, *J. Geophys. Res.*, 1998, **103** (C7), 14169–14240.
3. Sikka, D. R. and Gadgil, Sulochana, *Mon. Weather Rev.*, 1980, **108**, 1840–1853.
4. Gadgil, S., *Aus. Meteorol. Mag.*, 1988, **36**, 193–205.
5. Kalsi, S. R., *Advances in Tropical Meteorology* (eds Keshavamurthy, R. N. and Joshi, P. C.), 1993, pp. 289–300.
6. Kelkar, R. R. and Rao, A. V. R. K., *J. Meteorol. Soc. Jpn.* 1992, **70**, 551–560.

7. Rao, Y. R. and Premkumar, K., NIOT Tech. Note TROO1/98, 1998.
8. Reynolds, R. W. and Smith, T. M., *J. Climate*, 1994, **7**, 929–948.
9. Gadgil, S., Joseph, P. V. and Joshi, N. V., *Nature*, 1984, **312**, 141–143.
10. Graham, N. E. and Barnett, T. P., *Science*, 1987, **238**, 657–659.
11. Anthes, R. A., *Meteorol. Monogr.*, 1982, **19**, 1–208.
12. *Climate Diagnostics Bulletin of India*, National Climate Centre, India Met. Dept., 1998, p. 18.
13. Rao, R. R., *Mausam*, 1987, **38**, 142–156.
14. Moshonkin, M. and Harenduprakash, L., *Okeanologiya*, 1991, **31**, 1991, 384–394.
15. Levitus, S., Burgett, R. and Boyer, T. P., *World Ocean Atlas*, National Oceanic and Atmospheric Administration, USA, 1994.
16. Anderson, S. P., Weller, R. A. and Lukas, R., *J. Climate*, 1996, **9**, 3056–3085.
17. Gadgil, S., *Curr. Sci.*, 1999, **78**, 309–322 (this issue).

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