The Bay of Bengal and tropical cyclones

Chinthalu *et al.*[1] (hereafter C1) reported measurements of surface meteorological and oceanographic observations obtained on a moored data buoy in the central Bay of Bengal during the passage of 1999 Orissa cyclones. The data were analysed in conjunction with surface pressure charts of the India Meteorological Department. The authors state that the results of their analysis have shown a clear indication of air–sea interaction during the passage of two cyclonic storms. However, as stated in their paper, a close examination of the results shows that the drop in sea surface temperature (SST) is rather small. They also describe the opposite trends in currents and winds over the buoy location without providing an explanation for this behaviour. In this note I wish to bring to the readers' notice, a more appropriate set of earlier measurements that are used to study the response of the Bay of Bengal to the passage of a tropical cyclone[2]. A plausible explanation for the low SST reduction and opposite trends of currents and winds described in C1 is also provided.

A severe cyclonic storm (hurricane) is an intense localized source of surface wind stress and stress curl, and its passage over the ocean excites several modes of oceanic variability[3]. The ocean's response occurs in two stages. In the forced initial stage, the local response is mainly due to wind stress of the hurricane. This comprises baroclinic response that includes strong mixed layer currents and substantial cooling of the SST and mixed layer. The barotropic response is due to the geostrophic currents associated with a trough in the sea surface height. In the next stage, the response following the passage of a cyclone is a non-local baroclinic response to the wind stress curl. During this stage the energy is dispersed at near-inertial frequency. During the Bangladesh severe cyclonic storm from 23 to 27 September 1997, Rao and Premkumar[2] summarized the observations on data buoys, showing several features of local and non-local response of the ocean.

Figure 1 shows the track of the 1997 Bangladesh cyclonic storm. The National Institute of Ocean Technology (NIOT) installed several moored buoys fixed with sensors measuring surface meteorological and oceanographic parameters prior to this episode. All the observations were obtained at an interval of 3 h, and transmitted to the shore station using the INMARSAT satellite communication system. The air pressure and surface winds were measured over the buoy at 3.2 m above the buoy, and ocean currents and SST were measured at 3 m below the surface. The necessary corrections for wave-induced currents and mooring motions are included in the analysis. In this note, observations at two stations DS5(16°N, 82°E) and DS4 (19°N, 89°E) have been used to examine the response of the Bay of Bengal to the passage of the cyclone. These two stations were selected on the basis of their proximity to the cyclonic storm track and are also ideally suited for studying the upper ocean's response in the Bay of Bengal.

Figure 2 *a* and *b* shows the wind speed and direction at these locations, respectively. The peak observed wind speed at DS5 (18 m s^{-1}) on 24 September coincided with the observed low pressure (994.9 hPa). At this point the storm moved slowly to the right of the buoy, with a north-easterly translation. As the DS5 buoy is located to the left of the storm track, we observed the wind vector rotating in an anti-clockwise direction (Figure 2 *b*). At DS4, the peak wind speeds reached 17.5 m s^{-1} on 26 September as the storm reached this latitude. Although DS4 is located on the right side of the track, the observed wind speeds were slightly less mainly because of the larger distance (over 70 miles) between the storm position and the buoy. At this location the wind vector rotated in a clockwise direction as the cyclone passed this region. This type of clockwise rotation of the wind vector on the right and anti-clockwise rotation on the left side of the track is in correspondence with the general wind field in cyclones.

The response of the surface ocean to this asymmetric wind stress and stress

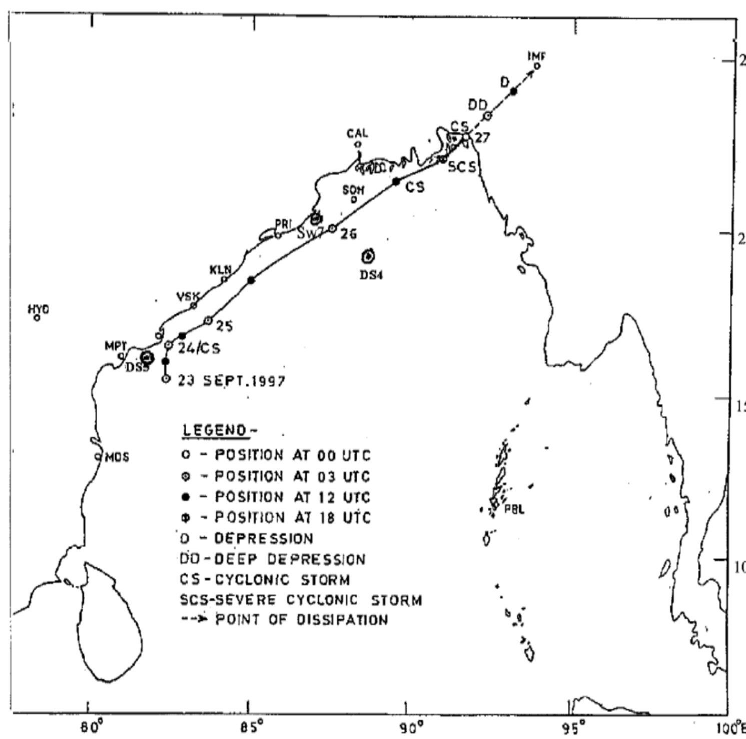

Figure 1. Location of NIOT met–ocean buoys and track of the Bangladesh severe cyclonic storm, 23–27 September 1997.

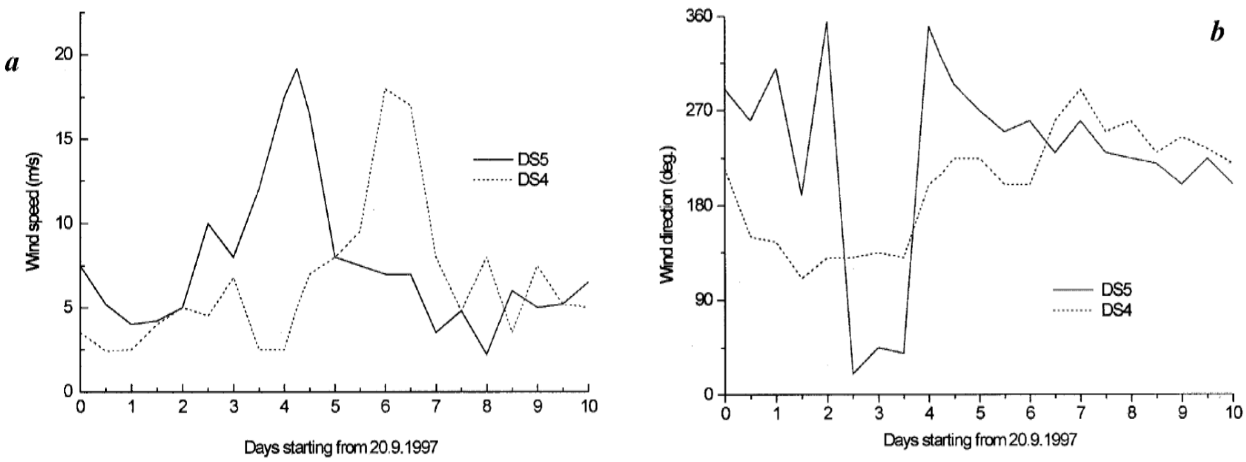

Figure 2. Observation of (***a***) wind speed (m/s) and (***b***) direction (from north) at the two data buoy locations.

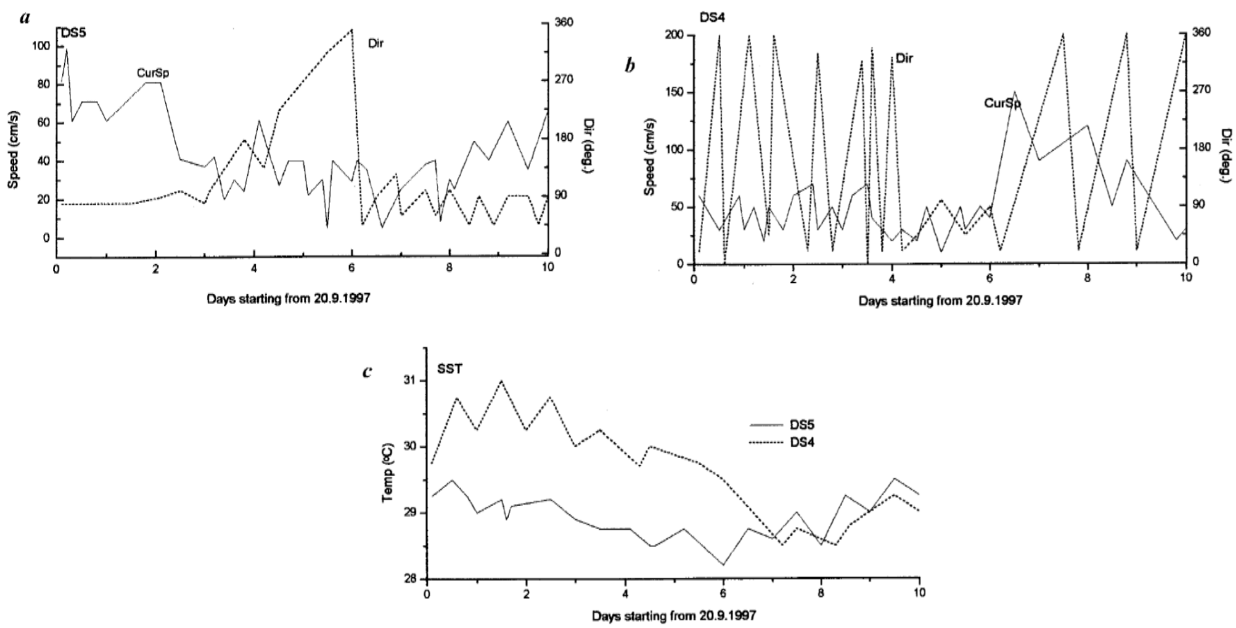

Figure 3. Observation of current speed (cm/s) and direction (to north) at (***a***) DS5 and (***b***) DS4, and (***c***) SST at the two data buoy locations.

curl is an active area of research[3,4]. Figure 3 *a* and *b* shows the observed current speed and direction at DS5 and DS4, respectively. As the storm intensified and crossed DS5, the currents slowly rotated in a clockwise direction, with a pronounced southward transport for a brief period. This was mainly because in a cyclone-forced current field, the currents tend to rotate inertially in a clockwise direction in the northern hemisphere, since the pressure gradient force in the open ocean is generally smaller than the Coriolis force. This implies that during the passage of the cyclone at this location, which is to the left of the track, currents are antiparallel to the predominant winds. We also observe that the current speeds tend to be weak because of less efficient coupling between wind stress and currents. On the right side of the track at DS4, both the wind stress rotation and current rotation are in clockwise direction, and hence the currents are roughly aligned with the winds. As the storm has passed this location the current vector rotated clockwise with a typical period of 32–38 h, which is close to the calculated inertial frequency at this latitude. This can be clearly noticed from the observed current speed and direction.

Tropical cyclone-forced cooling of the SST is a striking phenomenon that is of central importance to the interaction between ocean and cyclones[5]. Figure 3 *c* shows the SST variability during the passage of the cyclone at these locations. During the pre-storm conditions the SST was found to be around 29.2°C at DS5, and 30.5 to 31°C at DS4. As the deep depression near DS5 intensified into a cyclonic storm, a temperature drop of nearly 1°C was observed at this location. However, on the right side of the storm track at DS4, the SST reduction was more pronounced with a drop of 2.2°C in a time period of 3 days. The cooling of the SST can be attributed to the vertical turbulence, and associated upwelling due to the influence of the cyclonic storm. The rightward bias in the SST was also observed elsewhere and was attributed to left-to-right asymmetry in the cyclonic wind field[3].

From figure 1 in C1 it may be observed that the location of data buoy (DS3) is significantly far from the radius of maximum winds of both cyclonic storms. Furthermore, the buoy is located to the left of the storm tracks. Based on these two characteristics it is possible to explain the observed low reduction of the SST and the opposite trends of currents and winds. This is mainly due to the asymmetry of the wind stress field, and weak coupling between the prevailing wind stress and surface currents. Finally we would like to clarify that the data transmission from buoys to the shore station is still being carried through the INMARSAT satellites, unlike that stated in C1 (Premkumar, pers. commun.).

1. Chinthalu, G. R., Seetaramayya, P., Ravichandran, M. and Mahajan, P. N., *Curr. Sci.*, 2001, **81**, 283–291.
2. Rao, Y. R. and Premkumar, K., NIOT Tech. Note TR001/98, 1998, p. 44.
3. Price, J. F., Sanford, T. B. and Forristal, G. Z., *J. Phys. Oceanogr.*, 1994, **24**, 233–260.
4. Greatbatch, R. J., *ibid*, 1983, **13**, 357–367.
5. Emanuel, K. A., *J. Atmos. Sci.*, 1995, **52**, 3969–3976.

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Response:

Rao has given three comments: (a) The results show that the drop in SST is rather small; (b) Description of opposite trends in currents and winds over the buoy location without providing explanation for their behaviour and (c) clarification of data transmitted from buoys to shore station is still being carried through INMARSAT satellite, unlike as stated by us.

While explaining the plausible reasons for the small SST drop and the opposite trends in the currents and winds, Rao has stated that the ocean's response occurs in two stages, the first being the forced initial response and the second being the response following the passage of a cyclone, a non-local baroclinic response to the wind stress curl. He has cited Price *et al.*[1] to this effect. While this reference is acceptable, the problem is whether the above two processes can be taken into cognizance or not, for explaining the above features observed by us. Rao has given his comment for the 'opposite trend of currents to wind speed' in forced response stage and not for the second stage. We discuss here the former mode only. First, let us consider the model of Price *et al.*[1] which is more or less similar to the model of Chang and Anthes[2]. This model simulates the upper ocean vertical mixing processes (currents and transport) in the forced stage response. Chang and Anthes[2] have also noticed right-ward bias as reported by Price *et al.*[1]. Second, before finding out the plausible reasons for the 'opposition of current speed to low wind speed' at the buoy, we have compared the above phenomenon with Chang and Anthes' model results and found that there is no match. Chang and Anthes' model is based on the Ekman transport model, which illustrates that the speed of the surface ocean currents is directly proportional to the surface wind stress field. But our observations showed an opposite trend which is different from the Ekman transportation model. Finally, as stated in our article, Kraus and Businger[3] and Bye[4] have demonstrated that the surface ocean water transport (current) is not only dependent on the Ekman model but also dependent on the Stokes drift, under pronounced low wind conditions. It is important to note here that both the model domains of Price *et al.*[1] and, Chang and Anthes[2] are less than 500 km from the cyclone centre, whereas the observed distance between the buoy and the cyclone at the time of the above observed phenomenon is more than 500 km. Hence we thought that the above discussion is not important in the present case. Presentation of observed results is more important than the processes involved. So, we have not added the above features cited by Rao.

Regarding the first comment, we have already given the plausible reason for noticing 'small response' in our article (see lines 3–9, right panel, p. 291).

It is true that the data transmission from the buoy to the shore station had been carried out through the INMARSAT satellite.

1. Price, J. F., Samford, T. B. and Forristal, G. Z., *J. Phys. Oceanogr.*, 1994, **24**, 233–260.
2. Chang, S. W. and Anthes, R. A., *ibid*, 1978, **8**, 468–480.
3. Kraus, E. B. and Businger, J. A., *Atmosphere–Ocean Interaction*, Clarendon Press, 1994, 2nd edn, pp. 166–168.
4. Bye, A. J., *J. Mar. Res.*, 1988, **46**, 457–472.

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Study of Bay of Bengal cyclones using buoy data

The article by G. R. Chinthalu *et al.* (*Curr. Sci.*, 2001, **81**, 283–291) is perhaps the first study about the Bay of Bengal cyclones using buoy data and is to be welcomed. Unfortunately, the paper contains several errors of fact as well as speculative and unsustainable inferences from the data of a single buoy, without considering other major data sources. Only a few salient examples are given below.

1. According to the paper, the central pressure of the two cyclones was 998 hPa or higher. Obviously, a very severe cyclone or a super cyclone cannot have such a high central pressure. The extreme winds and pressures in tropical cyclones over the ocean are derived from satellite imagery. The lowest estimated central pressures were 968 hPa for the 15–19 October cyclone and 912 hPa for the 25–31 October cyclone, according to the Regional Specialized Meteorological Centre, New Delhi[1]. (Incidentally, the Gopalpur cyclone was not a super cyclone as mentioned in the title.)
2. It is not correct to say that the area of genesis of these cyclones was unusual for October. More than twenty cyclones or severe cyclones had their origin in October in the Bay, east of 90°E and north of 13°N, during the period 1909 to 1985 (refs 2 and 3).
3. Data of only one buoy have been used. It is not clear how one buoy can represent the whole of the Bay. Also on most of the days considered, the buoy was very far away from the cyclones. The buoy data need to be integrated with other information, e.g. satellite data.
4. The article (p. 287) speaks of a 'sharp fall in SST' on 15 October. But the 'sharp fall' is only 0.1°C, which is the limit of accuracy of the observation. To derive conclusions about 'horizontal transport of warm water' from such minute temperature changes does not seem justified.
5. The authors state that in a 'trough line, the weather is typically cloud-free' (p. 287). Trough lines are associated with clouds giving rise to rainfall over a widespread area. Perhaps the authors mean a 'col' region between the two systems.
6. An increase of wind speed from 2 to 4 m s^{-1} on the 15 October at the buoy site (about 360 km from the storm centre) is interpreted (p. 287) as rapid intensification of the system. An increase of 2 m s^{-1} is not a significant change in a storm field.
7. On the same page the authors discuss the wind and current measurements at the buoy site on 18 October, in relation to the cyclones. The storm was already over land in Orissa (about 7° of latitude north of the buoy) and the buoy data have little relevance.
8. The inference (p. 288) on sporadic cloud movement being responsible for fluctuations in SST and air temperature is speculative, in the absence of data from other sources. The range of variation of SST during the whole period covered by figures 4 and 5 is only 1°C. In any case, no evidence is presented to link the fluctuations to cyclogenesis.
9. There appears to be no basis for inferring 'the existence of a high pressure area' near the buoy (p. 288) based on observation at a single site. Such deduction also has no relevance to the cyclone.
10. The wind changes at the buoy site on 28 and 29 October (p. 288) also do not give any significant information relating to the cyclone. The wind direction change on 30 October to 230° at the buoy site is consistent with the *position* of the cyclone at that time and gives no clue about *recurvature*, as claimed.
11. The signs of U and V components (p. 289) merely indicate a cyclonic wind which is consistent with the position of the cyclone.
12. The sentence beginning 'There was again a sudden lull …' at the end of page 289 and the following sentence beginning on page 290 seem mutually contradictory.
13. There are also some errors which cause confusion. (a) Page 287 left column, line 28: current speed should be 80 cm s^{-1} and not 80 m s^{-1}; (b) Page 287 left column, penultimate line: 16 October, not 15 October; (c) Page 287 right column, line 2: 'between 03 UTC…' and not 'after 03 UTC…'.

The phrase 'none dare to venture' (p. 283) is not apt, as there have been many cases of ships passing through the core of the cyclone and transmitting valuable data. This is not to belittle the importance of the network of buoys established by NIOT to give *in situ* data over the whole Bay. The paper might have given more valid results if data from more buoy sites had been available. The authors may be able to come up with more comprehensive studies when the expanded DOD network of buoys and 'Argo' floats is established in the Bay, and the available satellite data are also made use of.

1. Report, Regional Specialized Meteorological Centre for Tropical Cyclones, IMD, New Delhi, 2000, p. 70.
2. India Meteorological Department, 'Tracks of Storms and Depressions in the Bay of Bengal and Arabian Sea', 1970.
3. India Meteorological Department, Addendum to 'Tracks of Storms and Depressions in the Bay of Bengal and Arabian Sea', 1997.

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Response:

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