

## Observation on oceanographic parameters of nearshore waters off Yanam, during the cyclonic storm

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**The current and temperature at different levels were measured at 75 m water depth off Yanam, which is 12 km away from the coast for a period of 40 days during August–October 2005. The tides and winds were measured at 60 m water depth during the same period. A cyclonic storm developed in the Bay of Bengal on 18 September 2005 and crossed the coastline at 250 km northeast of the measurement location on 19 September 2005. Variations in the oceanographic parameters near the measurement location during the passage of the cyclone are described in this communication. The measured currents were mainly non-tidal. The measurements show a decrease of 8.6–11.5°C in sea-water temperature at different depths and the currents were in the direction of the wind during the cyclonic storm.**

**Keywords:** Cyclone, sea-level pressure, sea-water temperature, wind and current speed.

A study on the response of the Bay of Bengal to the Gopalpur and Paradip super cyclones using buoy data<sup>1,2</sup> found that the decrease in sea surface temperature (SST) at the buoy location, which is 360 km away from the storm centre, was less than 1°C. Based on TMI SST images, Sadhuran<sup>3</sup> observed a decrease in SST up to 6°C during the passage of the super cyclone that crossed the coast of Paradip on 29 October 1999.

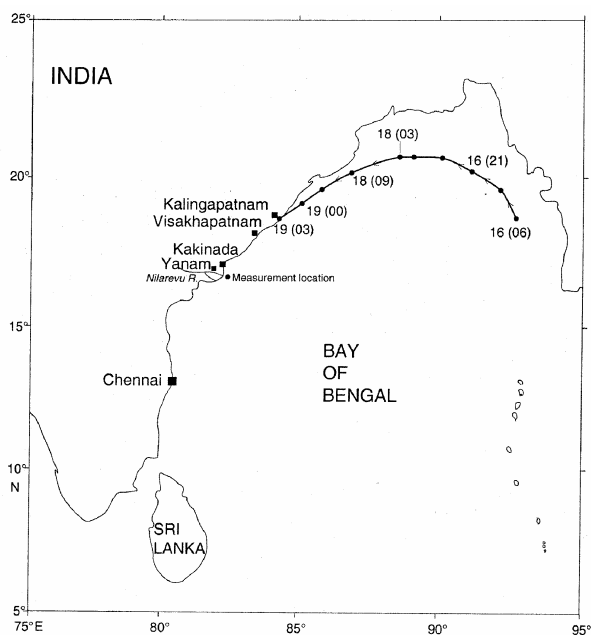
While carrying out oceanographic measurements using deployed equipment, we observed a large decrease in sea-water temperature at all levels in the water column during 17–20 September 2005. During this period a cyclonic storm crossed the coastline at 250 km northeast of the measurement location off Yanam (Figure 1). We have examined the variation of sea-water temperature, current speed and direction at different depths along with sea-level pressure and wind speed and direction. The results are reported here.

The study area is 35 km southeast of Kakinada and 12 km from the mouth of the Nilarevu river, a tributary of River Godavari. The continental shelf of the study region is relatively narrow. The 10, 20 and 50 m depth contours are 1.5, 4.5 and 9 km away from the shore, while the 100 and 200 m depth contours are 14 and 18 km from the shore. The average annual discharge<sup>4</sup> of the Godavari is

2690 m<sup>3</sup>/s. The annual sediment load<sup>5</sup> by the Godavari at terminal points is  $38.839 \times 10^9$  kg ( $38.839 \times 10^{12}$  m<sup>3</sup>).

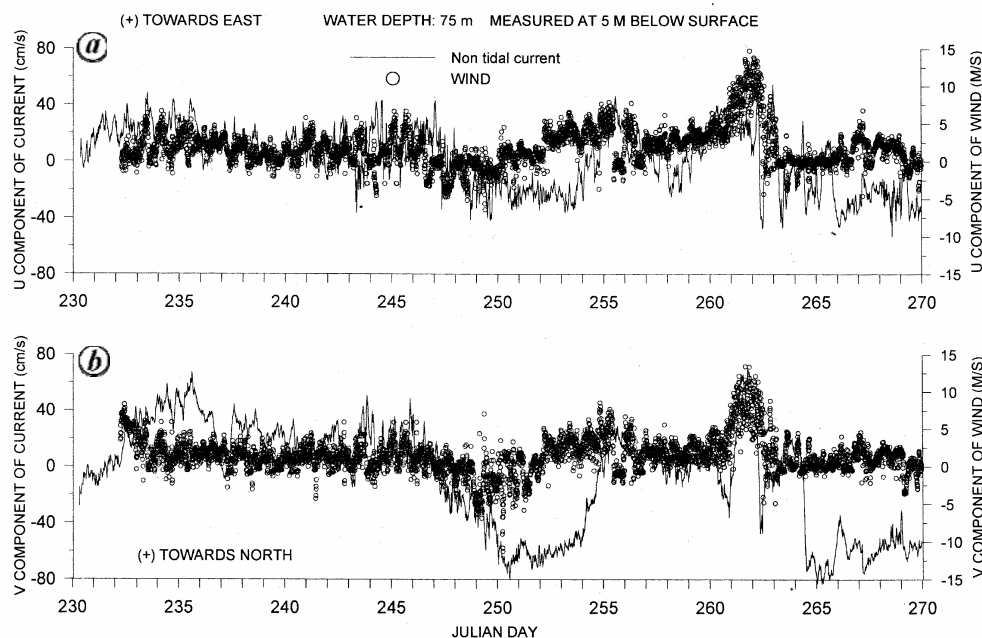
The current measurements were carried out at five levels using the self-recording current meter (RCM9 and RCM11; Aanderaa Data Instruments, Norway). RCM9 meter were installed at 5, 15, 30 and 47 m below surface and RCM11 current meter was installed at 61 m below surface in a mooring. Temperature sensor installed in the RCM 9 and RCM 11 current meter was used for measuring the sea-water temperature at different depths. Current meter data were recorded internally on a data storage unit at every 20 min interval during 230–270 Julian days (18 August–27 September). The time referred to here is the Greenwich Mean Time. The current data are the vector average of the data collected at every 2 s over a 20 min period. The accuracy and range of various parameters measured are given in Table 1.

Temperature and pressure sensor located on the body of a RDI 300 kHz ADCP (RD Instruments, USA) installed 2.5 m below surface at 60 m water depth, which is 1.5 km west of the current meter mooring, was used for measuring the sea-water temperature and water level variations at 20 min interval. The ADCP was installed looking downwards. From the measured water-level data, the tides were separated using standard harmonic method where a finite set of cosine functions with frequencies at the known astronomical forcing frequencies was fitted to the data using the least square method. Tidal Analysis Software Kit (TASK; developed by the Proudman Oceanographic Laboratory, UK)<sup>6</sup> was used for the analysis. The analysis was done with 24 independent constituents and



**Figure 1.** Track of the cyclone during 16–19 September 2005. The number indicated inside the bracket is the time in GMT.

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**Figure 2.** Time series plot of (a)  $U$ -component of non-tidal current and  $U$ -component of wind and (b)  $V$ -component of non tidal current and  $V$ -component of wind.

**Table 1.** Accuracy and range of various parameters measured

Instrument	Parameter	Accuracy	Range
RCM9	Current speed	$\pm 0.15$ cm/s	0–3 m/s
RCM9	Current direction	$\pm 7.5^\circ$	0–360°
RCM9	Temperature	$\pm 0.05^\circ\text{C}$	$-0.6$ – $32.8^\circ\text{C}$
RCM11	Current speed	$\pm 0.15$ cm/s	0–3 m/s
RCM11	Current direction	$\pm 7.5^\circ$	0–360°
RCM11	Temperature	$\pm 0.05^\circ\text{C}$	$-0.6$ – $32.8^\circ\text{C}$
ADCP	Temperature	$\pm 0.4^\circ\text{C}$	$-5$ – $45^\circ\text{C}$
ADCP	Water level	$\pm 0.1$ m	0–200 m
AWS	Wind speed	2% of the measured value	0–79 m/s
AWS	Wind direction	$\pm 5^\circ$	0–360°

eight related constituents recommended for one month data of tides and currents. Currents were resolved into cross-shore (east-west with east-going as positive),  $U$  and alongshore (north-south with north-going as positive),  $V$  and analysed separately.

Wind speed and direction were measured at 33 m above msl by installing an automatic weather station (Aanderaa Data Instruments, Norway) in a rig stationed at 60 m water depth. Archived sea-level pressure data at  $17.5^\circ\text{N}$ ;  $82.5^\circ\text{E}$  from the National Centre for Environmental Prediction and National Centre for Atmospheric Research (NCEP/NCAR), USA were also used in the analysis.

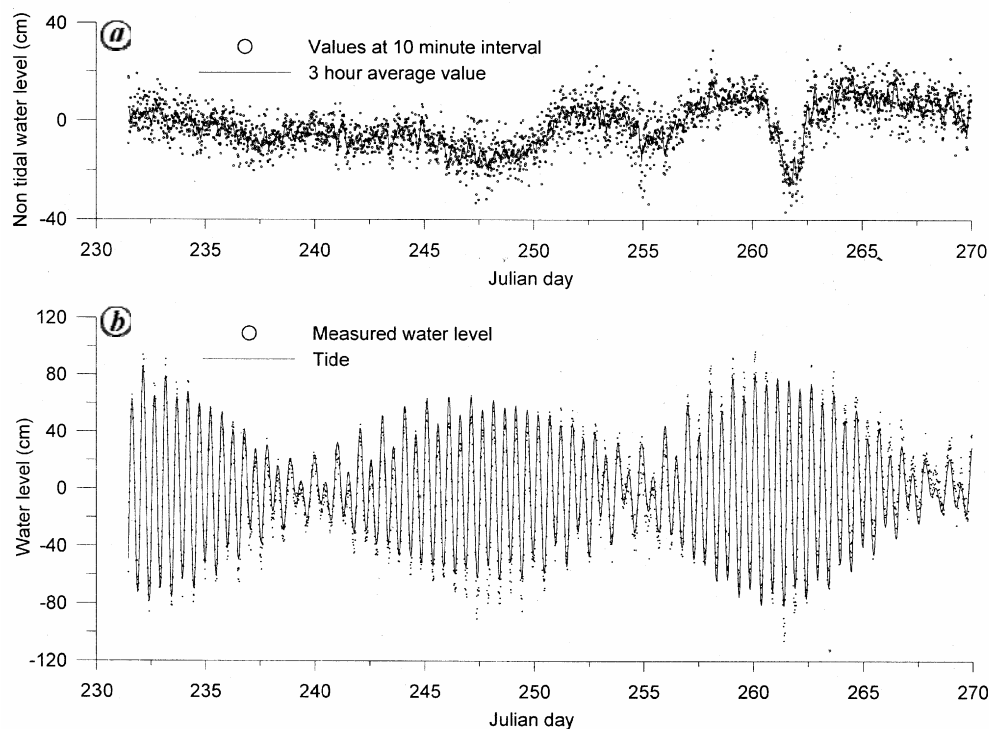
A low-pressure area formed on 16 September 2005 over the east-central Bay, and the adjoining northeast Bay, concentrated into a depression on 17 September 2005. The depression moved northwesterly and intensi-

fied into a deep depression. It moved westwards and intensified into a cyclonic storm<sup>7</sup> on 18 September 2005. The cyclonic storm crossed the north Andhra coast near Kalingapatnam at 0300 h and weakened into a deep depression at 2100 h on 19 September 2005. The track of the cyclonic storm during 16–19 September 2005 is shown in Figure 1.

The wind during the measurement period was predominantly from southwest. The southwest wind was stronger than the north-east wind. During the cyclone period, the wind was consistently from southwest (Figure 2). The maximum wind speed measured was 17.3 m/s on 19 September 2005, when the centre of the cyclone was approximately 250 km away from the measurement location (towards northeast direction).

The measured water level was 0.37 m less than (below) that due to tide at 1200 h on 19 September 2005 (Figure 3a). The water level varied from  $-1.06$  to  $0.96$  m during the study period (Figure 3b). The predominant tidal constituents based on the measured water-level data are presented in Table 2. Primary lunar semi-diurnal constituent M2 was the strongest and amplitude was found to be around 3.8 times stronger than that of the major diurnal constituent K1. Amplitude of S2 was found to be around 48% of M2.

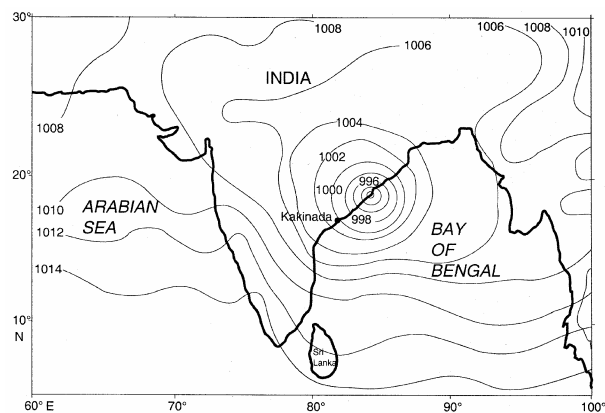
The pressure distribution at 0300 h on 19 September 2005 according to IMD<sup>7</sup>, when the cyclone crossed the north Andhra coast near Kalingapatnam, is presented in Figure 4. The sea-level pressure data (NCEP/NCAR re-analysis dataset) at  $17.5^\circ\text{N}$ ;  $82.5^\circ\text{E}$  averaged over  $2.5^\circ \times$



**Figure 3.** Time series plot of (a) non-tidal water level and (b) measured water level and that estimated based on tide.

**Table 2.** Predominant tidal constituents based on the measured water-level data

Tidal constituent	Amplitude (m)	Phase (°)
O1	0.039	241.149
K1	0.110	249.504
N2	0.091	71.285
M2	0.419	75.394
S2	0.202	101.359



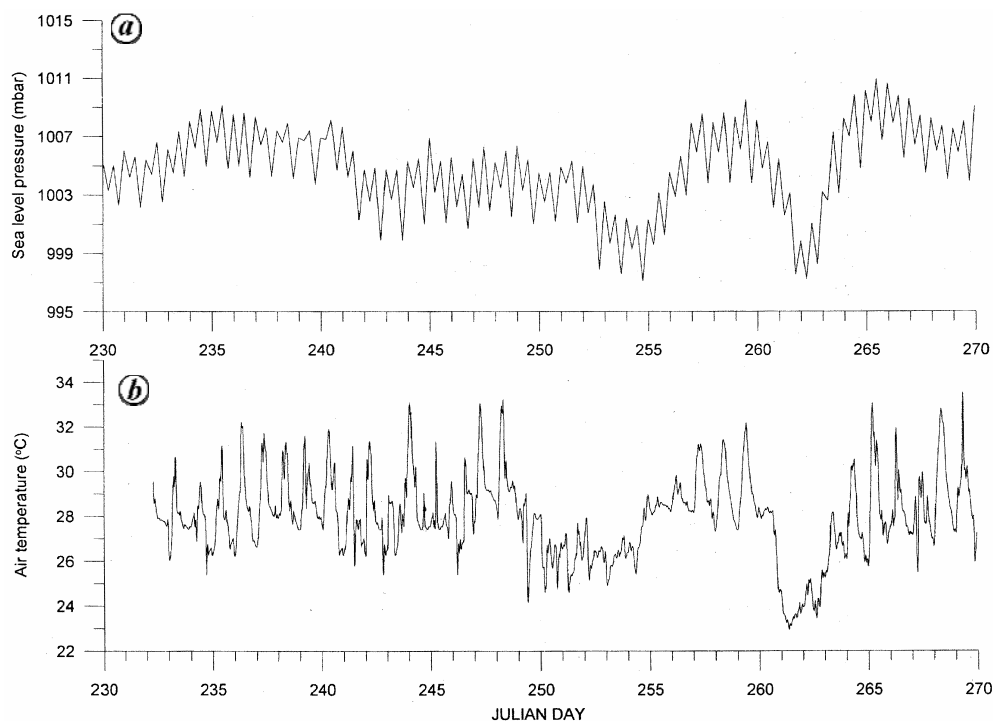
**Figure 4.** Pressure distribution at 0300 h GMT on 19 September 2005 (source: IMD<sup>7</sup>).

2.5° shows that the drop in pressure is 12 mbar from 1200 h on 17 September 2005 to 1800 h on 19 September 2005. The sea-level pressure was 997.5 mbar during 1800 h on 19 September 2005 (Figure 5 a).

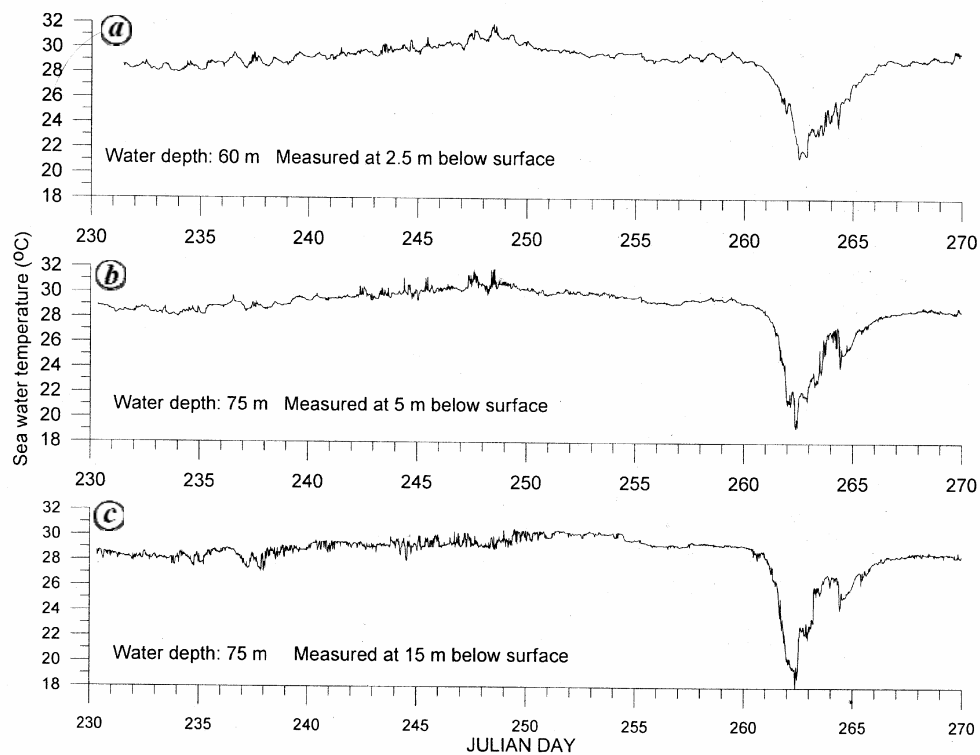
As the pressure level dropped by 12 mbar, the sea level also dropped. Normally for such a drop in pressure level, the sea level would have increased resulting in storm surge. Since the location is close to the coast, the drop in sea level is due to wind stress. The wind during the same period was towards northeast (from southwest). Sundar *et al.*<sup>8</sup> observed similar changes during the passage of storms at Paradip during 6–10 August 1979.

The measured air temperature dropped by 9.8°C from 32.4°C to 22.6°C during the period between 1030 h on 17 September 2005 and 0810 h on 19 September 2005 (Figure 5 b), due to the passage of the weather system.

During the measurement period, sea-water temperature increased gradually and the maximum temperature was found on 6 September 2005. A Datawell directional waverider buoy was deployed within 1 km distance from the current meter mooring and the SST recorded on 6 September 2005 was 32.2°C. The buoy drifted from its moored location on 18 September 2005 and was lost. Hence the minimum SST could not be measured on 19 September 2005. The highest SST based on the data buoy network deployed along the Indian seas<sup>9</sup> is 31.7°C. The change in sea-water temperature during 17–20 September



**Figure 5.** Time series plot of (a) sea-level pressure based on NCEP/NCAR reanalysis dataset at 17.5°N, 82.5°E and (b) air temperature measured at 33 m above msl at 16.67°N, 82.43°E.



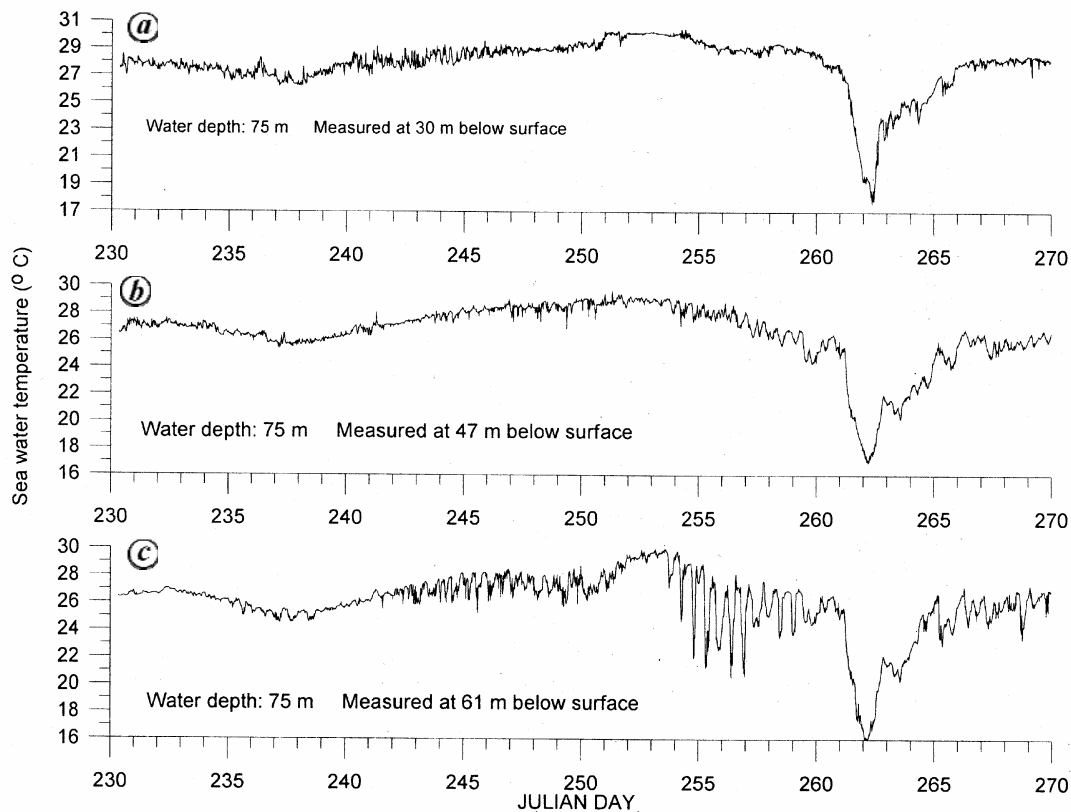
**Figure 6.** Time series plot of sea-water temperature measured at (a) 2.5 m below surface at 60 m water depth, (b) 5 m below surface and (c) 15 m below surface at 75 m water depth.

**Table 3.** Sea-water temperature at different depths below the surface before, during and after the cyclonic storm at the measurement location

Measurement location below surface (m)	Sea-water temperature (°C)			Maximum during measurement period
	17.9.2005	20.9.2005	24.9.2005	
2.5	29.8	21.2	29.2	31.9
5	29.8	19.2	28.4	31.9
15	29.4	18.0	28.4	30.5
30	29.1	17.6	28.3	30.4
47	26.8	17.0	26.8	29.7
61	27.1	16.0	27.2	30.0

**Table 4.** Maximum and average value of *U* and *V* components of current speed measured at different depths

Measurement location below surface (m)	Maximum <i>U</i> current speed towards west (cm/s)	Maximum <i>U</i> current speed towards east (cm/s)	Average <i>U</i> current speed (cm/s)	Maximum <i>V</i> current speed towards south (cm/s)	Maximum <i>V</i> current speed towards north (cm/s)	Average <i>V</i> current speed (cm/s)
5	54.5	58.3	19.2	82.0	69.8	33.7
15	55.7	36.1	14.6	95.4	73.8	33.7
30	71.9	25.4	14.6	99.5	62.5	28.4
47	73.2	63.8	12.5	102.5	64.9	26.0
61	53.0	25.8	9.9	100.5	55.9	26.0



**Figure 7.** Time series plot of sea-water temperature measured at (a) 30 m, (b) 47 m and (c) 61 m below surface at 75 m water depth.

## RESEARCH COMMUNICATIONS

**Table 5.** Maximum and average value of  $U$  and  $V$  components of tidal current speed estimated from the measured data at different depths

Measurement location below surface (m)	Maximum $U$ current speed towards west (cm/s)	Maximum $U$ current speed towards east (cm/s)	Average $U$ current speed (cm/s)	Maximum $V$ current speed towards south (cm/s)	Maximum $V$ current speed towards north (cm/s)	Average $V$ current speed (cm/s)
5	9.4	12.6	3.1	11.5	11.8	3.1
15	7.8	8.2	2.2	11.9	10.7	3.4
30	7.1	7.2	2.2	11.0	14.1	2.7
47	11.4	9.9	2.4	11.7	11.6	3.0
61	10.3	10.2	2.4	11.2	14.9	3.9

2005 was 8.6°C, 10.6°C, 11.4°C, 11.5°C, 9.8°C and 11.1°C at different depths (Table 3). The lowest temperature was measured on 20 September 2005 (Figures 6 and 7). This indicates that at the measurement location, the change in temperature is not only for the surface layer, but for the entire water column.

The intense upwelling due to the cyclone may be the cause for the observed drop in water temperature in the water column. Apart from the influence of the cyclonic storm, the other reason for large decrease in the sea-water temperature is due to the large quantity of discharge from the river Nilarevu. The rainfall at Kakinada was 53 and 282 mm on 18 and 19 September 2005. Sadhuram<sup>3</sup> observed a decrease of about 6°C in SST due to the passage of the super cyclone that crossed the coast of Paradip on 29 October 1999. Rao<sup>10</sup> observed a drop of 2.2°C in SST in a time-period of three days during the passage of the 1997 Bangladesh cyclonic storm. Subrahmanyam *et al.*<sup>11</sup> observed that the SST cooled by 0.5–0.8°C during the two intense cyclones over the Bay of Bengal during 1999, and it took seven days for the SST to return to normal conditions. In the present case it took only four days to return to normal sea-water temperature at different depths.

The currents changed their direction from northeast to southwest during the first week of September. They were predominantly towards southwest just before and after the cyclone (Figure 2). During the cyclone, the current direction changed to northeast and was in the direction of the wind. The estimated tidal currents were less than 0.15 m/s, whereas the measured currents were up to 1 m/s (Tables 4 and 5).

The maximum SST recorded was 32.2°C. Measurements show a decrease of 8.6–11.5°C in sea-water temperature at different depths during the cyclonic storm. The measured currents were mainly non-tidal and maximum currents measured were 1 m/s. The currents were predominantly towards southwest just before and after the cyclone. During the cyclone, the current direction changed to northeast and was in the direction of the wind.

super cyclones during 15–31 October 1999. *Curr. Sci.*, 2001, **81**, 283–291.

- Jayanthi, N. and Raghavan, S., Study of Bay of Bengal cyclones using buoy data. *Curr. Sci.*, 2002, **82**, 382.
- Sadhuram, Y., Record decrease of sea surface temperature following the passage of a super cyclone over the Bay of Bengal. *Curr. Sci.*, 2004, **86**, 383–384.
- UNESCO, River inputs to ocean systems: Status and recommendations for research. UNESCO Technical Papers in Marine Science, No. 55, Final Report of SCOR Working Group 46, Paris, 1988, p. 25.
- Rama Sarma, D. V. and Ganapathi, P. N., Hydrography of the Kakinada Bay. *Bull. Natl. Inst. Sci. India*, 1968, **38**, 49.
- Bell, C., Vassie, J. M. and Woodworth, P. L., POL/PSMSL Tidal Analysis Software Kit 2000 (TASK-2000), Permanent Service for Mean Sea Level, CCMS Proudman Oceanographic Laboratory, UK, 2000.
- IMD, All India weather report. India Meteorological Department, 19 September 2005.
- Sundar, D., Shankar, D. and Shetye, S. R., Sea level during storm surges as seen in tide-gauge records along the east coast of India. *Curr. Sci.*, 1999, **77**, 1325–1332.
- Rajesh, G., Jossia Joseph, K., Hari Krishnan, M. and Premkumar, K., Observations on extreme meteorological and oceanographic parameters in Indian seas. *Curr. Sci.*, 2005, **88**, 1279–1282.
- Rao, Y. R., The Bay of Bengal and tropical cyclones. *Curr. Sci.*, 2002, **82**, 379–381.
- Subrahmanyam, B., Murthy, V. S. N., Sharp, R. J. and O'Brien, J. J., Air–sea coupling during the tropical cyclones in the Indian Ocean: A case study using satellite observations. *Pure Appl. Geophys.*, 2005, **162**, 1643–1672.

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1. Chinthalu, G. R., Seetaramayya, P., Ravichandran, M. and Mahajan, P. N., Response of Bay of Bengal to Gopalpur and Paradip