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Suppressed biological production in the coastal waters off Visakhapatnam, India under the impact of the very severe cyclonic storm *Hudhud*

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Tropical cyclones generally enhance biological production due to the increase in nutrients input due to vertical mixing. In contrast, the very severe cyclonic storm (VSCS) *Hudhud* decreased primary production due to the strong stratification associated with torrential rainfall and high suspended load from the major city where the cyclone made landfall. The study region received nutrients from the cold core eddy and coastal upwelling in the offshore and inshore regions, respectively, during pre-cyclone period and the same was suppressed under the influence of cyclonic winds led to convergence by shoreward Ekman transport. The land run-off brought nutrients to the coast during cyclone Hudhud; however, their concentrations were less than that during other cyclones (Orissa supercyclone, Sidr and Phailin). Such low nutrient levels resulted from the VSCS Hudhud crossing the urban region (Visakhapatnam city) whereas other cyclones crossed the coast over fertile agricultural lands which led to high nutrients input associated with phytoplankton blooms. Therefore, the biological response to a cyclone not only depends on the intensity of the cyclone but also on the region of the land it crosses.

Keywords. Biological production; Hudhud; TSM; biogeochemistry; BoB.

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1. Introduction

Atmospheric extreme events, such as deep depressions, cyclones and heavy precipitation, occur at variable time scales from a few hours to several days, but the perturbations of these events may last for several days to months (Dagg 1988; Furnas *et al.* 1989; Gagan *et al.* 1990). Episodic heavy precipitation associated with land run-off brings substantial amount of nutrients to the coastal ocean (Paerl 1985; Pant and Desai 1992; Willey and Paerl 1993) leading to the formation of phytoplankton blooms for several weeks (Tummala *et al.* 2009; Maneesha *et al.* 2011; Lotliker *et al.* 2014). On the other hand, strong winds, associated with cyclones, churn up the upper ocean resulting in the vertical entrainment of cold and nutrient-rich

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waters to the surface along the cyclonic track (Malone *et al.* 1993; Shiah *et al.* 2000; Naik *et al.* 2008; Chiang *et al.* 2011; Vincent *et al.* 2012). Enhanced phytoplankton biomass was reported in association with cyclone/supercyclones due to increased nutrients input (Di Tullio and Laws 1991; Subrahmanyam *et al.* 2002, 2005; Naik *et al.* 2008; Lotliker *et al.* 2014).

The Bay of Bengal experiences tropical cyclones throughout the year with its minimal frequency in December–February and maximum in April–May and October–November (Varkey *et al.* 1996). The impact of a cyclone on the occurrence of phytoplankton blooms was studied in the coastal Bay of Bengal (Nayak *et al.* 2001; Madhu *et al.* 2002; Maneesha *et al.* 2011; Lotliker *et al.* 2014; Piontkovski and Al-Hashmi 2014). A several-fold increase in chlorophyll was observed off the Orissa coast after the supercyclone hit the Paradip coast (Orissa, East coast of India) in October 1999 (Nayak *et al.* 2001). Madhu *et al.* (2002) noticed an increase in phytoplankton biomass and primary productivity in the southeast coast of India about 15 days after the supercyclone hit the Orissa coast, and it was attributed to nutrients brought through landfall to the coastal Bay of Bengal. Similarly, an increase in phytoplankton biomass was noticed after cyclone 'Sidr' hit the Bangladesh coast due to the spreading of nutrient-rich water along the east coast of India through the equatorward-flowing East India coastal current (EICC) (Maneesha *et al.* 2011). Recently, Lotliker *et al.* (2014) observed a 295% increase in Chl-a after cyclone 'Phailin', that hit the Gopalpur coast (Orissa, East coast of India), compared to the pre-cyclone period. Chakraborty *et al.* (2018) also pointed out that light is one of the key factors controlling the oceanic primary production during and after a cyclone. In all these cases, an increase in nutrients, relative to pre-cyclone conditions, was associated with low saline waters, suggesting that landfall brought significant amounts of nutrients to the coast, leading to enhanced phytoplankton biomass in the coastal Bay of Bengal.

The very severe cyclonic storm (VSCS) *Hudhud* crossed the Visakhapatnam coast on 12 October 2014 and it was the strongest and most destructive tropical cyclone of 2014 in the North Indian Ocean. Before landfall, winds reached their peak strength of 217 km/h over a period of 2–3 min with a minimum central pressure of 960 hPa. This is the first cyclone that ever hit a major coastal city along the east coast of India as other cyclones crossed the coast over fertile lands. Hence, it can be hypothesised that landfall during cyclone Hudhud might not have brought significant amount of nutrients to the coast and its impact on phytoplankton biomass might have been weaker than when other cyclones crossed the east coast of India. In order to test this hypothesis, field observations were carried out four days after the VSCS Hudhud crossed Visakhapatnam coast and the changes in the biogeochemical processes were compared with the data collected during same period about 1 yr before the cyclone (i.e., October 2013).

1.1 *Description of cyclone Hudhud*

The VSCS Hudhud hit the east coast of India recently on 12 October 2014 and it was the strongest tropical cyclone of 2014 within the North Indian Ocean, as well as the most destructive tropical cyclone that ever crossed India since the past two decades. Cyclone Hudhud originated from a low-pressure system that formed under the influence of an upper-air cyclonic circulation in the Andaman Sea on 6 October 2014. Hudhud intensified into a cyclonic storm on 8 October and as a severe cyclonic storm on 9 October 2014. Hudhud underwent rapid strengthening in the following days and was classified as a VSCS by the Indian Meteorological Department (IMD). Shortly before landfall near Visakhapatnam city, Andhra Pradesh, on 12 October, Hudhud reached its peak strength with 3-min wind speeds of 217 km h^{-1} and a minimum central pressure of 960 mbar. After the landfall, the system drifted northwards towards Chhattisgarh, Uttar Pradesh and Nepal, causing widespread rains in those areas and heavy snowfall in Nepal. Hudhud caused extensive damage to the city of Visakhapatnam and the neighbouring districts of Vizianagaram and Srikakulam of Andhra Pradesh.

2. Materials and methods

2.1 *Sampling and methods*

As a part of Ocean Finder program, in situ measurements were carried out in the coastal Bay of Bengal, off Visakhapatnam (transect A) and off Atchutapuram (transect B), from close to the coast to about 22.5 and 30 km offshore, respectively where the water depth was up to 75 m (figure 1). The transect A is our

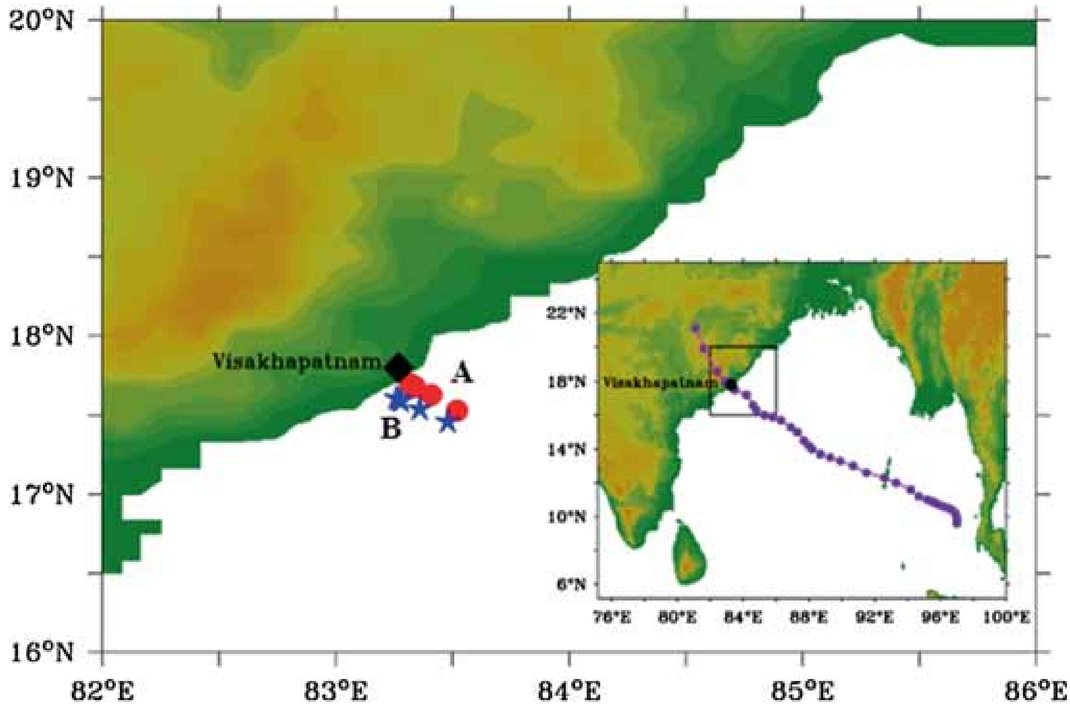

Figure 1. Sampling stations occupied along transects A (red filled circle) and B (blue star) in the coastal Bay of Bengal. The track of cyclone Hudhud is also shown.

time-series observation region since 2007 (Sarma *et al.* 2013) and transect B is sampled during this period as the cyclone crossed coast at this location. Five stations were occupied along each transect and water samples were collected at standard depths from the surface to the bottom of the water column using a 10 l Niskin sampler. Water column temperature and salinity were measured using a portable conductivity–temperature–depth (CTD) profiler (Sea Bird Electronics, USA). Vertical variations in the photosynthetically active radiation (PAR) were measured using a sensor mounted on the CTD (QCP 3600; Biospherical Instrumentation, USA). Dissolved oxygen was measured using the Winkler titration method following the automated potentiometric detection technique (Carritt and Carpenter 1996) and the nutrients (nitrate, nitrite, ammonium, phosphate and silicate) were measured following the spectrophotometric method (Grasshoff *et al.* 1983). About 3 l of water was filtered through a glass fibre filter (GF/F; 0.7 μm; Whatman) and the pigment retained on the filter was extracted using dimethyl formamide (DMF) and the fluorescence of the extract was measured using a spectrofluorophotometer (Varian Instruments, USA) following Suzuki and Ishimaru (1990). About 1 l of the sea water sample was filtered through a pre-weighted 0.22-μm polycarbonate (Millipore) filter and dried at 60°C and reweighted. The weight of the material retained on the filter was taken as the total suspended particulate matter (TSM; mg l^{-1}).

2.2 *Primary production incubation measurements*

Sea water samples from the surface, at a depth of 5 and 10 m were collected in transparent 1-l acid-cleaned polycarbonate bottles and were spiked with 1 ml of 2 mM $^{13}C-NaHCO_3$ (99 atm% ^{13}C; Sigma-Aldrich Chemicals, Lot no#MBBB2161Vp Code:1001847725) solution. The ^{13}C enrichment was about 10% of the total inorganic carbon in the ambient water. The samples were incubated for 24 h on a deck and the same temperature of water was maintained by passing surface water into the incubation chamber. Initially, the vertical profile of the PAR was measured and the irradiance at the original sampling depths was determined and the same was maintained by the use of various combinations of neutral-density filters in the deck incubation. Immediately following incubation, the samples were filtered directly through pre-combusted (450°C for 4 h) Whatman GF/F

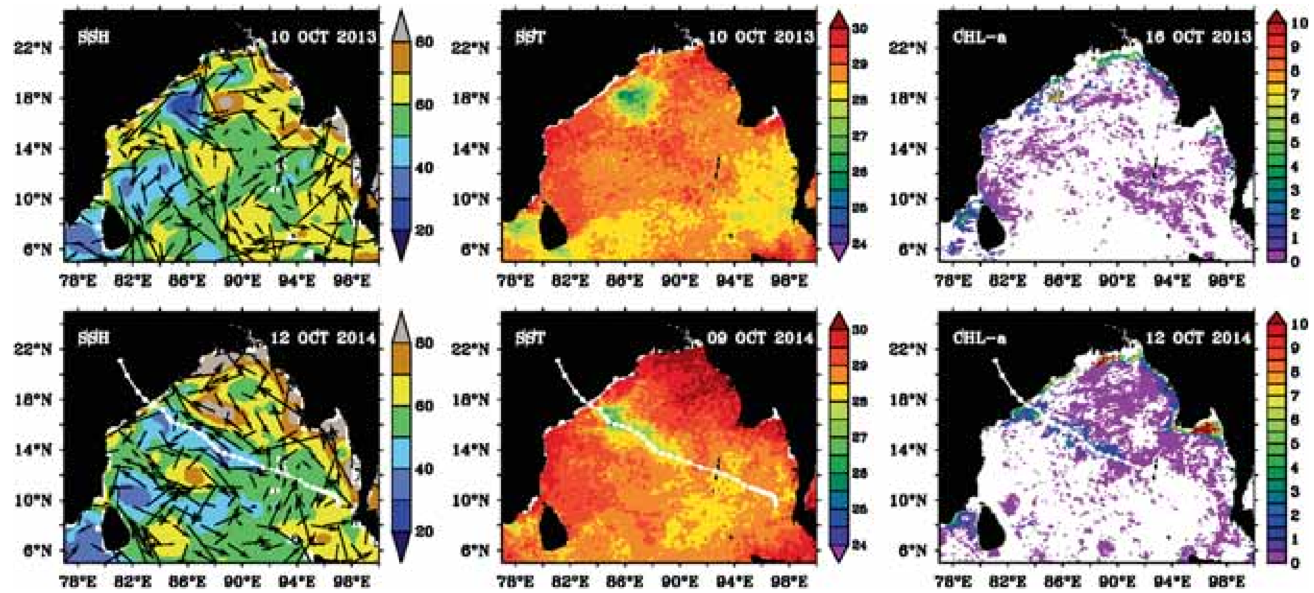

Figure 2. Comparison of the satellite imageries of merged SSH (mm) and the derived geostrophic currents, SST (°C) and surface chlorophyll (mg m^{-3}) about 1 yr prior to cyclone Hudhud in October 2013 (upper panel) and about 4 days after Hudhud in October 2014 (lower panel). The cyclonic track is also shown.

filters under gentle vacuum (<200 kPa), and the particulate matter on the Whatman GF/F filters was rinsed with prefiltered seawater. The filters were treated with hydrochloric acid fumes for 4 h to remove inorganic carbon and were completely dried in vacuum desiccators. The isotopic ratios of $^{13}C-^{12}C$ and concentrations of particulate organic carbon were determined by a combined system of an elemental analyser and an isotope ratio mass spectrometer (DELTA V Plus; Thermo Electron, Germany). The primary productivity was calculated according to the equation described by Hama *et al.* (1983).

2.3 *Satellite remote sensing data*

Weekly mean advanced very high resolution radiometer (AVHRR) measured sea surface temperature (SST), merged sea surface height (SSH) and the derived geostrophic currents and Ocean Colour (chlorophyll) data using an aqua moderate resolution imaging spectroradiometer (MODIS) were obtained from the National Ocean Atmospheric Administration (NOAA) (http://oceanwatch.pifsc.noaa.gov/las/servlets/dataset). High-resolution ocean surface current analyses real-time (OSCAR) zonal and meridional currents data in the upper 15 m were obtained from Bonjean and Lagerloef (2002) (http://www.esr.org/oscar/oscar-main.html).

3. Results and discussion

3.1 *Variations in the observed surface water properties before and after cyclone Hudhud*

In order to understand the different oceanographic conditions that prevailed in the upper ocean and to examine the impact of the VSCS Hudhud, the weekly mean AVHRR SST, SSH and chlorophyll (as phytoplankton biomass) were analysed before (September 2014) and after cyclone Hudhud. The AVHRR SST showed a patch of cooler waters by 0.3–0.5°C than the surrounding waters, coinciding with the lower SSH (30 ± 3 cm) off Visakhapatnam. The geostrophic current patterns suggested the existence of a cyclonic eddy leading to the divergence of cold subsurface waters to the surface (figure 2). The time-series variations in SSH at a location along the east coast of India during October 2009–2013 suggest the persistent existence of the cold core eddy at round the study regions (Supplementary figure S1). The satellite chlorophyll images suggest six times higher chlorophyll concentrations in the region of the cold core eddy compared to the surrounding region, suggesting that the eddy-derived nutrients supported phytoplankton biomass during September 2014 (figure 2). On the other hand, the region of low SSH along the cyclone track during October 2014 was associated with westward flowing surface currents on the north of the cyclone track and eastward flowing on the south of the track. These surface currents form the cyclonic circulation that lead to divergence and vertical mixing in the upper layer in the open sea region (figure 2). The cooling of surface water temperature by ∼1.6°C and shallow SSH (15–25 mm) were observed along the Hudhud cyclone track compared to that outside suggesting the divergence of water from the subsurface layers in the offshore region. Enhanced Chl-a concentrations by 200% were seen along the cyclone track in offshore Bay of Bengal (figure 2). A cooling by ∼2°C was noticed along the track of the cyclone 'Sidr' associated with an increase in chlorophyll by 2–3 times (Maneesha *et al.* 2011) in the central Bay of Bengal. In contrast, the influence of cyclonic winds, shoreward Ekman transport and equatorward flow of coastal currents led to the accumulation of low saline waters and convergence at the coast (figure 3 and supplementary figure S2). As a result, the cyclonic eddy was absent during October 2014 when higher SSH was observed by ∼20 cm compared to October 2013, suggesting that the supply of nutrients from the subsurface was inhibited due to the VSCS Hudhud. The weakly mean concentration of MODIS chlorophyll at the study region about 1 week prior to the VSCS Hudhud was 0.26 mg m^{-3} on 5 October and it was increased to 2.76 mg m^{-3} on 13 October 2014 soon after Hudhud crossed the coast at Visakhapatnam. Chlorophyll then decreased sharply to 0.88 mg m^{-3} by 17 October 2014 and further decreased to almost initial chlorophyll concentrations (0.33 mg m^{-3}) in 3 weeks, i.e., by 25 October 2014. This suggests that the land runoff associated with cyclone Hudhud might have brought nutrients to the coast to support the phytoplankton biomass for about 2 weeks, i.e., 17 October 2014.

3.2 *Modification of water column characteristics in the coastal Bay of Bengal after the VSCS Hudhud*

The mean water temperature and salinity in the upper 10 m were 29.1°C and 31.57, respectively, during October 2013 (figure 3). The thermal structure along the transect showed upsloping of isotherms towards the coast, indicating signatures of upwelling from a depth of 20 m during September 2014 (pre-cyclone period). The hydrographic features just before the cyclone were not measured. Hence, we compared with the hydrographic features measured during (October 2013) the same period, a year before. In order to examine the variations in hydrographic properties during October, the time-series observations from 2007 to 2014 are depicted in Supplementary figure S3. This figure suggests that the lowest salinity was observed during October 2014 with cyclone where relatively lower salinity was observed during 2007, associated with heavy local rainfall (Maneesha *et al.* 2011). Therefore, the hydrographic feature during October 2013 may represent non-cyclonic features. The study region received substantial amount of precipitation (145–527 mm; www.vagaries.in/2014/10/) during the VSCS Hudhud that rendered the hydrography in the study region complex. The surface currents, as derived from the SSH variations, during this period, were towards the coast (westward flowing) that led to the advection of low saline waters to the coast (middle and lower panels in figure 4). The salinity in the entire water column, up to 75 m, was freshened during October 2014 due to the convergence of waters towards the coast. The water column temperature in the upper 50 m was warmer by >1°C and freshened by ∼10 during October 2014 compared to October 2013 (figure 3). The suppression of upsloping of isolines can be noticed during October 2014 due to the convergence of low salinity surface waters in the upper 40 m of the water column along the transects A and B (middle and lower panels of figure 3). The freshwater lens was thick until 25 km from the coast and then slowly thinned towards offshore along the transect B. Relatively warmer and fresher waters were noticed along transect A compared to transect B and such spatial variations could possibly be related to variations in local precipitation and mixing patterns.

The upsloping of nitrate from 25 m depth was observed resulting in higher concentrations (2−3 μM) close to the coast (up to 5 km) than offshore (∼0.5 μM) during October 2013 (figure 4). The concentrations of nitrate were relatively lower (0.5−1.5 μM) in the upper 25 m of the water column along transect A than those along transect B (2.2−4 μM) with weaker vertical gradients in the upper 50 m. In contrast, the concentrations of nitrate below 50 m were significantly lower during October 2014 than October 2013. The down-sloping of nitrate contours during October 2014 suggests the convergence of surface waters from the coast to over a distance of 20 km. This is further evident from the salinity which was significantly lower by 1 unit in the upper 75 m during October 2014 than in 2013 (figure 3).

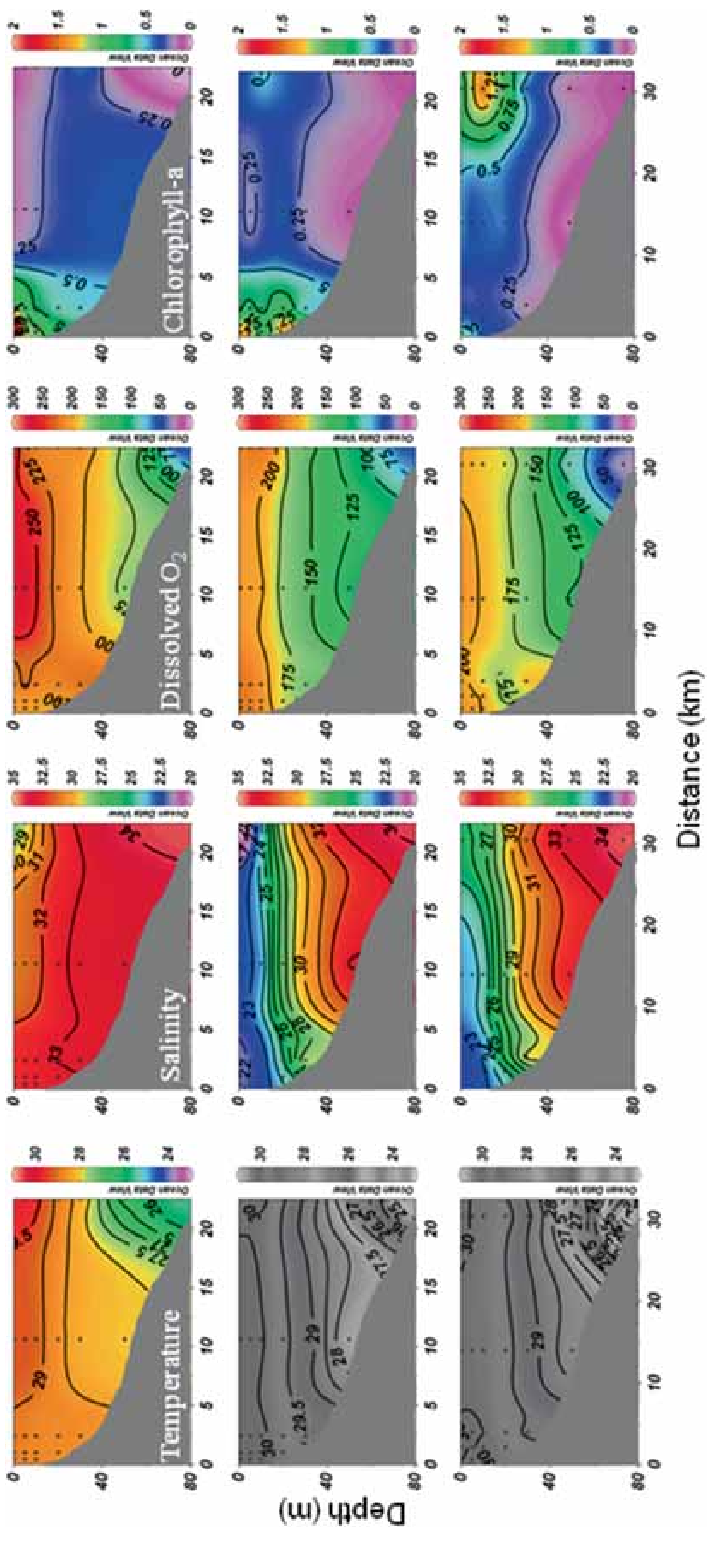

Figure 3. Comparison of the water column temperature (°C), salinity, dissolved oxygen (µM) and chlorophyll-a (mg m^{-3}) in the coastal Bay of Bengal about 1 yr prior to cyclone Hudhud in October 2013 (upper panel) and about 4 days after Hudhud in October 2014 along the transect A (middle panel) and the transect B (lower panel) in October 2014.

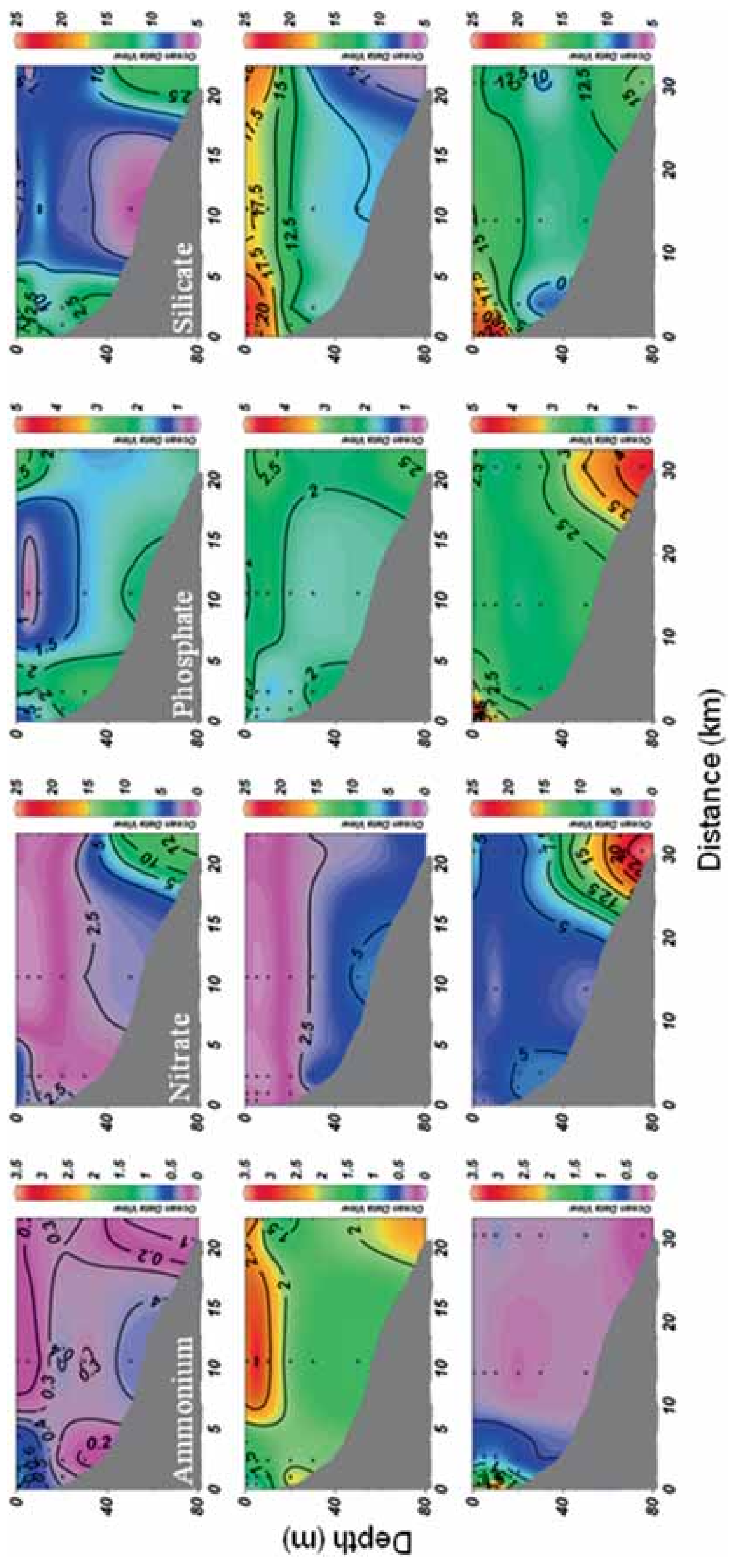

Figure 4. Comparison of the concentrations of ammonium (µM), nitrate (µM), phosphate (µM) and dissolved silicate (µM) in the coastal Bay of Bengal about 1 yr prior to cyclone Hudhud in October 2013 (upper panel) and about 4 days after Hudhud in October 2014 along the transect A (middle panel) and the transect B (lower panel) in October 2014.

Similarly, higher phosphate concentrations were noticed during October 2014 (2.1−3.2 μM) compared to those in 2013 (0.5−2.4 μM) with relatively higher concentrations along transect B than transect A (lower and middle panels in figure 4). On the other hand, silicate concentrations during 2014 were higher along transect A (17−23 μM) than transect B (11.5−21.1 μM) which was significantly lower by half (4.2−12.5 μM) compared to 2013. It can be noticed that higher concentrations of nutrients in the upper 40 m were associated with low salinity, suggesting that the land run-off that resulted from heavy precipitation during the VSCS Hudhud, could be a major source of nutrients to the study region. Maneesha *et al.* (2011) noticed increased silicate concentrations in the coastal waters off Visakhapatnam associated with heavy precipitation. Madhu *et al.* (2002) suggested that higher nutrients were associated with low salinity waters in the southeast coast of India and it was attributed to the land run-off associated with the Orissa supercyclone. Dissolved silicate is a good proxy for land run-off as the major source is from soil/rock dissolution and a higher concentration of silicate indicates a major source from land run-off during October 2014. The N:P ratio was relatively higher during 2013 (3.40) compared to that in October 2014 (1.20), suggesting that less nitrate was brought through land run-off relative to phosphate. However, Sarma *et al.* (2013) suggested that nitrate limited the growth of phytoplanktons during October in the coastal Bay of Bengal. In contrast, the Si:N ratios were significantly higher (4.1–9.3) during October 2014 than that in October 2013 (2.56) (table 1), suggesting that the land run-off brought higher silicates and it is much higher than the limiting level for phytoplankton growth. The concentrations of both nitrate and phosphate were higher along transect B than transect A. Although these two transects were apart by 25 km from each other, the VSCS Hudhud was reported to hit the land at the location of transect B. On the other hand, a lower consumption of nutrients at transect B may also lead to the accumulation of nutrients. In order to examine the same, the concentrations of phytoplankton biomass and TSM were measured in the study region. Relatively higher phytoplankton biomass (as chlorophyll-a) was observed at transect A (0.39 ± 0.2 mg m^{-3}) compared to transect B (0.18 ± 0.1 mg m^{-3}). Interestingly, phytoplankton biomass was significantly lower during October 2014 than that in 2013 (0.69 ± 0.3 mg m^{-3}), suggesting that VSCS Hudhud did not promote phytoplankton blooms unlike cyclone 'Sidr', Phailin and the supercyclone (Madhu *et al.* 2002; Tummala *et al.* 2009; Maneesha *et al.* 2011; Lotliker *et al.* 2014). In order to examine the potential reasons for low phytoplankton biomass, the turbidity (TSM) levels were examined. It was noticed that the mean concentrations of TSM almost doubled along the transect B (18.4 ± 3 mg l^{-1}) than along transect A (10.2 ± 4 mg l^{-1}) and it was much lower during 2013 (5.8 ± 1 mg l^{-1}), suggesting that the inhibition of light to the water column led to a decrease in the phytoplankton biomass. A significant decrease in PAR by more than 50% was observed during post-cyclone compared to the pre-cyclone period (Supplementary figure S4). It was further confirmed that dissolved oxygen concentrations were significantly higher along transect A compared to transect

Table 1. *Comparison of the mean physico-chemical characteristics of the coastal waters measured off Visakhapatnam four days after the Hudhud cyclone with those measured one year before (October 2013) Hudhud.*

Parameter (units)	One year before Hudhud (October 2013)	Four days after Hudhud (October 2014)	
	Transect A	Transect A	Transect B
SST (°C)	29.22 ± 0.4	30.02 ± 0.1	30.06 ± 0.1
SSS	31.06 ± 1.9	21.22 ± 1.6	23.29 ± 1.4
Chl-a (mg m^{-3})	0.69 ± 0.3	0.39 ± 0.2	0.18 ± 0.1
Turbidity (mg l^{-1})	7.6 ± 2	10.2 ± 4	18.4 ± 4
NO_3 (μM)	3.2 ± 2	0.79 ± 0.3	4.3 ± 2
NH_4 (μM)	0.5 ± 0.3	1.7 ± 0.7	0.9 ± 1
PO_4 (μM)	1.8 ± 0.8	2.3 ± 0.6	2.2 ± 0.4
SiO_4 (μM)	11.0 ± 4	20.9 ± 2	18.0 ± 2
N:P	3.4 ± 0.8	1.2 ± 0.3	1.4 ± 0.2
Si:N	2.6 ± 0.7	9.3 ± 1.0	4.1 ± 0.8
PP (mg C m^{-2} d^{-1})	552.3 ± 110	467.8 ± 240	389.2 ± 213

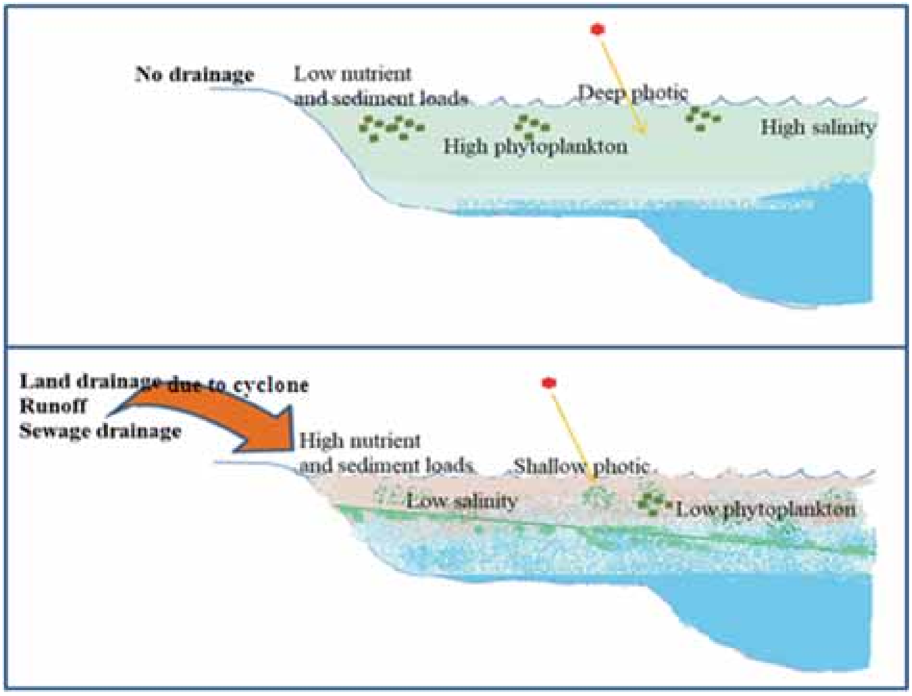

Figure 5. Comparison of the contrasting response of phytoplankton to cyclone Hudhud compared to other cyclones.

B possibly due to active biological processes at transect A. Our observation suggests that light seems to be controlling the phytoplankton biomass after VSCS Hudhud hit the land than nutrients alone. In contrast to the observed Chl-a, increased satellite Chl-a on 13 October 2014 was observed (2.76 mg m^{-3}) than before the cyclone on 5 October 2014 (0.26 mg m^{-3}). Since the observations were carried out close to the coast (<30 km from the coast), the accurate measurements of satellite Chl-a are unlikely due to high TSM and coloured organic matter.

The photic depth in the study region varied between 8 and − 12 m during October 2014 and it increased from close to the coast to offshore. The integrated primary production in the upper 10 m of the water column showed significant spatial and temporal variability. The coastal (<5 km from the coast) production was five times higher than that offshore (>10 km from the coast) and it is consistent with the distribution of nutrients and phytoplankton biomass (table 1). The primary production along transect A during October 2014 was almost the same as that in October 2013 in the near-coastal region (<2 km from the coast) and decreased rapidly towards offshore (table 1). The primary production during October 2014 was far less along transect A in the offshore regions when compared to that along transect B. More interestingly, the production in the near-coastal region was higher 18 times than that offshore. The mean primary production in the upper 10 m along the transect in October 2013 was relatively higher (552.3 mg C m^{-2} d^{-1}) compared to 2014 (467.8 mg C m^{-2} d^{-1} along transect A and 389.2 mg C m^{-2} d^{-1} along transect B). This suggests that VSCS Hudhud decreased the primary productivity by 15–30% in the coastal Bay of Bengal. Though the VSCS Hudhud brought land-derived nutrients to the coast, a decrease in photic depth did not allow the phytoplankton to produce. In contrast, Madhu *et al.* (2002) observed an increase in primary production by two to three folds in the southeast coast of India after the super-cyclone was associated with the increase in the nutrients. Their study region received nutrients through advection from the cyclone-hit zone by the equatorward flowing of EICC. Although Madhu *et al.* (2002) did not measure the TSM during their study, it is also possible that most of it might have been settled en route as their study region was >300 km away from the cyclone-hit zone. As a result, an increase in phytoplankton biomass and primary production was noticed away from the cyclone-hit zone. Similarly, Maneesha *et al.* (2011) also noticed an increase in phytoplankton biomass off Visakhapatnam about 2 weeks after the cyclone 'Sidr' hit the Bangladesh coast. Our study suggests that cyclone suppressed the nutrients input through vertical mixing due to the strong stratification and convergence in the coastal Bay of Bengal and increased TSM load, resulting in a decrease in phytoplankton biomass and production. It was further observed that fishery catch significantly decreased after the VSCS Hudhud hit the Visakhapatnam coast due to low plankton biomass (scientist-in-charge, Central Marine Fisheries Research Institute, Visakhapatnam, personal communication, 2015). Our study further confirmed that the VSCS Hudhud deserted the land-hit zone of Visakhapatnam, Vizianagaram and Srikakulam districts of Andhra Pradesh, India by uprooting plants as well as decreased phytoplankton biomass due to the landfall in the coastal sea. The contrasting response of phytoplankton to cyclone Hudhud compared to other cyclones (Orissa supercyclone, Sidr, Phailin) could be due to the soil characteristics of the region where the cyclone hit the land. The regions where the Orissa supercyclone (Pradip village), Sidr (Bangladesh) and Phailin (Gopalpur village) occurred are highly fertile where significant amount of agricultural activities have been ongoing. As a result, the landfall brought significant amount of nutrients to the coastal Bay of Bengal close to the cyclone-hit zone. In contrast, cyclone Hudhud hit one of the major cities (Visakhapatnam) which is a completely concrete zone with no agricultural activities, resulting in less nutrients input (figure 5). Several civil engineering constructions and other sewage-related materials were flushed to the coast along with the landfall, leading to an increase in a suspended load, resulting in decreased phytoplankton biomass and productivity. This study suggests that not only the intensity of the cyclone but also the soil characteristics of the zone where the cyclone hits influence the biological response to the cyclone in the coastal region.

4. Summary and conclusions

The influence of VSCS Hudhud on hydrography and biogeochemistry of nutrients and phytoplankton production was studied after the cyclone and compared with pre-cyclone conditions. The cyclone Hudhud suppressed the nutrients input through the upwelling in the coast and the cold core eddy offshore due to the convergence of the waters in the coast. The land run-off brought low concentrations of nutrients and high concentrations of TSM led to a decrease in phytoplankton biomass and primary production by 15–20% compared to the pre-cyclone period. Our study suggested that the VSCS Hudhud did not increase primary production, unlike other cyclones that formed in the Bay of Bengal, due to having crossed a major city unlike other cyclones that crossed fertile lands.

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