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Impact of the cold water band and the Sri Lanka Dome on the Biogenic fluxes in the Southern Bay of Bengal

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Abstract

Time series of biogenic fluxes from sediment trap samples collected at a water depth of 1518 m in the southern Bay of Bengal (5°N, 87°E) during 5 February – 16 December 1992 showed a significant seasonality with higher (175-280 mg m^{-2} d^{-1}) fluxes during South West Monsoon (SWM). The Ocean General Circulation Model (OGCM) for Earth Simulator (OFES) simulated temperature and currents in the upper 100 m, observed data on surface winds and nutrients and satellite derived chlorophyll-*a* revealed advection of cold (<27°C), nutrient and chlorophyll-*a* rich waters from southeastern Arabian Sea and Sri Lanka Dome (SLD, *Vinayachandran et al*., 2004) into the southern Bay which facilitated high primary productivity resulting in the observed higher biogenic fluxes during SWM.

Key words: South West Monsoon, OFES, Sri Lanka Dome, Sea Surface Temperature, Bay of Bengal, chlorophyll-*a*, biogenic fluxes, dissolved oxygen (DO),

1. Introduction

The monthly maps of climatological Sea Surface Temperature (SST) in the Indian Ocean [*Hastenrath and Greischar*, 1989] and the near-synoptic distribution of SST during SWM in the Bay of Bengal [*Murty et al.*, 1992] documented the presence of a cold water band in the southern Bay of Bengal during SWM. The recent studies, based on satellite remote sensing data products, by *Joseph et al.* [2005] and *Rao et al.*

[2006] also reported the presence of a cold water band (or mini cold pool) at the sea surface in the southern Bay of Bengal during SWM. *Murty et al.* [1992] opined that the upwelling of cold waters from the southeastern Arabian Sea and their eastward advection through the Southwest Monsoon Current (SMC) might be responsible for the observed lower SST (<26.5°C) during September. *Joseph et al.* [2005] proposed that the cold water band affected the atmospheric convection over the southern Bay and contributed to the active and break cycles of the SWM. *Smitha et al.* [2006] reported SST cooling due to tangential wind-stress-driven coastal upwelling off Kanyakumari coast (southern tip of India) and the elevated chlorophyll-*a* during SWM. Based on OGCM simulations, *Vinayachandran et al.* [2004] demonstrated the presence of SLD represented by the upward rise of isotherms from the mid-thermocline which was manifested as cold water cell off the east coast of Sri Lanka during SWM.

Several authors [*Nair et al.*, 1989*; Ittekkot et al.*, 1991*; Rixen et al., 1996; Guptha et al.*, 1997*; Unger et al.*, 2003; *Mergulhao*, 2006; *Mergulhao et al.*, 2006] studied the seasonal and interannual variability of particulate fluxes comprising the biogenic fluxes, collected as part of the Indo-German collaborative program on Biogeochemical Processes in the northern Indian Ocean using many sediment trap moorings with two traps located at varying depths between 1000 and 3000 m in each mooring in the Arabian Sea and the Bay of Bengal during 1986-2001. The particulate fluxes settling in the sediment traps comprised largely of aggregates *i.e.*, marine snow and fecal pellets formed in the upper ocean with the sinking rates ranging from 400 m day^{-1} to >1000 m day^{-1} and could reach a 3 km water column in about a week [*Alldredge and Silver*, 1988]. *Mergulhao* [2006] reported that biogenic fluxes measured at three trap locations in the Bay of Bengal during 5 February – 16

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December 1992 contributed immensely to the total particulate fluxes which increased from northern to southern Bay, and documented further that the biogenic fluxes at the Southern Bay of Bengal Trap (SBBT: 5°N, 87°E) were about 4-5 times higher during SWM of 1992 compared to the fluxes measured simultaneously at the central and northern Bay sediment traps.

In this study, we demonstrate the impact of the southern Bay of Bengal cold water band (or mini cold pool) and the SLD, affecting the biogeochemistry of the southern Bay of Bengal, on the observed higher biogenic fluxes during SWM of 1992 at SBBT. For this purpose, we made use of the time series of biogenic fluxes and fluxes of planktic foraminiferal and coccolithophore species at SBBT during 1992, the OFES monthly simulations of temperature and currents in the Bay of Bengal in the upper 100 m during 1991-93, the Sea-viewing Wide Field-of-view Sensor (SeaWiFs) derived surface chlorophyll-*a* during 1997-2000 (http://jisao.washington.edu/data_sets/Seawifs), the optimally interpolated (OI) monthly averaged SST data in 1°x1° grids [*Reynolds and Smith*, 1994] during 1991-93 (http://www.cdc.noaa.gov/cdc/reynolds_sst.info.html), the National Centre for Environmental Prediction (NCEP) archived reanalysis of surface winds during 1991-93 (http://www.cpc.ncep.noaa.gov/products) and the measured nutrients and dissolved oxygen in the upper 200 m during SWMs of 1984 and 1993.

2. Data

Samples were collected by using the PARFLUX Mark VI time-series sediment traps deployed at the Northern Bay of Bengal Trap (NBBT: 16°N, 89°E), Central Bay of Bengal Trap (CBBT: 11°N, 84°E) and at SBBT during 5 February – 16 December 1992. The methods of collection and analyses of biogenic fluxes, foraminifera and coccolithophores were adopted from *Unger et al.* [2003] and *Mergulhao et al.* [2006].

The wind stress curl in 2.5°x2.5° grids was computed using the NCEP archived monthly mean surface winds [*Kalnay et al.*, 1996].

We also analyzed the Modular Ocean Model version 3 (MOM 3) [*Pacanowski* and *Griffies*, 2000] based OFES simulated monthly mean temperature and currents [*Masumoto et al.*, 2004; *Sasaki et al.*, 2006] at 5 levels (2.5 m, 7.4 m, 24.3 m, 54 m and 95.6 m depths) for the years 1991-1993. The model ocean was driven by wind stress, and the calculated surface heat flux from the atmospheric fields and the simulated SST using the same bulk formula of *Rosati and Miyakoda* [1988]. The salinity flux was obtained from the rates of precipitation and evaporation data obtained using the bulk formula. In addition to the salinity flux, the surface salinity was restored to the climatological monthly mean value of the World Ocean Atlas 1998 (WOA98) [*Antonov et al.*, 1998a,b,c and *Boyer et al.*, 1998a,b,c], with the restoring time-scale of 6 days. Impact from river run-off was adjusted by restoring the surface salinity field. The spin-up integration was forced by monthly mean atmospheric fields averaged for 1950-1999 of the NCEP reanalysis products [*Kalnay et al.*, 1996], but the hindcast simulation for the period from 1950 to 2003 was forced by the reanalysis daily mean fields.

3. Results and Discussion

3.1. Seasonal variation of biogenic fluxes at the SBBT location

Figure 1a shows the temporal (26 day interval) variation of biogenic fluxes in the shallow trap of SBBT (1588 m) during 5 February – 16 December 1992. The biogenic fluxes obtained in the shallow traps at the CBBT (1518 m) and NBBT (1156 m) were also included for comparison. The fluxes displayed a distinct seasonality at all three trap locations. Biogenic fluxes at SBBT exhibited a bimodal distribution with relatively higher fluxes (~90 mg m^{-2} d^{-1}) during North East Monsoon (NEM)

(February), and very higher fluxes during SWM (June – September) with a peak abundance (280 mg m^{-2} d^{-1}) in September. During intermonsoon periods (March – June and October – November) the fluxes were low and uniform. The bimodal distribution in the fluxes was less prominent at NBBT and CBBT. Interestingly, the fluxes at SBBT were about 4-5 times higher than those at NBBT and CBBT during SWM. Figure 1b displays a temporal variation of *Globigerina bulloides* and *Gephyrocapsa oceanica* fluxes only at SBBT, resembling the pattern of biogenic fluxes. *Gg. bulloides*, a planktic foraminiferal species and an indicator of upwelling [*Guptha et al*., 1997 and references therein] showed a greater preference for SWM with a prominent peak flux associated with the SWM (July-August). Similarly, coccolithophore species, *G. oceanica* was commonly found in the tropical–subtropical waters in a temperature range of 12° to 30°C and showing its affinity for high-nutrient environments such as upwelling areas [*Guptha et al.*, 2005; *Mergulhao et al*., 2006]. The *G. oceanica* also displayed a distinct seasonality with higher fluxes occurring during SWM. Thus, it was inferred that the elevated occurrences of these species together with biogenic fluxes were due to high productivity resulted from various surface layer processes that were prevalent during SWM of 1992.

3.2 Seasonal variation of OFES simulated upper ocean temperature and currents

We examined the OFES simulated monthly mean temperature and currents at the above 5 depths in the upper 100 m during 1991-93 years. Figures 2a and 2b display the seasonal cycles of OFES temperature at 2.5 m depth and OI SST at SBBT during 1991-93. Both the OFES temperature and the OI SST showed similar seasonal cycle during all the 3 years, but the OFES temperature at 2.5 m depth was found cooler by ~1.5°C than OI SST, for the obvious depth difference. Both the seasonal cycles showed warmer temperature (>27°C) during March-May, corresponding to the Indian

Ocean Warm Pool in the southern Bay of Bengal [*Vinayachandran and Shetye*, 1991]. During SWM, surface layer cooling was evident in both the OFES temperature and OI SST from May through August.

Figures 3a-b show the OFES temperature superimposed on simulated currents at 2.5 m depth in the Bay of Bengal during January (North East Monsoon) and July (SWM), 1992. In January 1992, the SST gradient was northward with warmer (>27°C) waters in the southern Bay of Bengal (Figure 3a). The lower SST (<25°C) in the northern Bay was due to net heat loss across air-sea interface under the influence of reduced incoming solar radiation and increased latent heat flux when the cold, dry northeasterlies blew over the Bay of Bengal. The northeasterly winds drive a southerly flow in the Andaman Sea which in turn feeds the westward flow in the eastern Bay to form the westward flowing Winter Monsoon Current (WMC) between 4° and 8°N (Figure 3a). A part of the west/northwestward flow east of 88°E from equatorial region joined the WMC encompassing SBBT. The WMC bifurcated into the western Bay feeding the poleward flowing East India Coastal Current (EICC) [*Shankar et al.*, 2002] and also continued as the WMC south of Sri Lanka. The simulated currents during March showed intense anticyclonic circulation in the central Bay (not shown). In April 1992, a cold water (<28°C) cell occurred south of Sri Lanka, while a large warm (>28.5°C) water cell occurred in the central Bay covering CBBT. By May, the temperature gradient reversed southward (from northern to southern Bay) with the cold water band (<27.6°C) extending from south of Sri Lanka towards east along 5°N. With the advent of SWM, the WMC in the southern Bay was replaced by the eastward flowing SMC encompassing SBBT. By July, the cold-water band in the southern Bay intensified and extended eastward up to SBBT (Figure 3b). During this period, the simulated currents displayed a strong eastward flow south of

Sri Lanka emerging from the southeastern Arabian Sea. This southeastward flow together with the southerly flow off the east coast of Sri Lanka intensified the SMC between 5°N and 8°N (Figure 3b). The surface conditions of temperature and currents with cold water band south of Sri Lanka and the SMC were discerned up to the simulated depth of 25 m. Whereas the simulated temperature and currents at the depth of 54 m during NEM exhibited the occurrence of warm waters (~26.5°C) within the WMC between 2°N and 10°N in January 1992 (Figure 3c). On the contrary, an intense cold water cell (~19°C), representing the SLD, appeared off the east coast of Sri Lanka in July (Figure 3d). The monthly mean wind stress curl fields during May – July indicated divergence (positive curl) from the base of Ekman layer in the southern Bay (not shown). The centers of maximum divergence and the associated sub-surface cold water cell shifted from southern Bay to the east coast of Sri Lanka by July, coinciding with the SLD [*Vinayachandran et al.*, 2004]. At the same time, field of negative curl (convergence) encompassed SBBT. The computed vertical velocity from the curl field showed maximum upward velocity (upwelling) of about 10 m/day in the SLD in July 1992. The OFES simulated currents at and below 25 m depth showed the southeastward flow emerging from the SLD advecting the upwelled cold waters towards SBBT. Further, the wider cold water band which occurred at shallow depths tapered downward, as cold waters from the SLD spread outward into the southern Bay up to SBBT. This is more evident from the simulated currents at 54 m depth wherein a narrow SMC at 5°N and a cyclonic circulation associated with the SLD were noticed (Figure 3d). The simulations at 54 m depth during August – September also showed the cold-water cell associated with the SLD and cyclonic circulation off the east coast of Sri Lanka (Figures not shown). The SBBT experienced relatively lower temperatures and the presence of SMC up to September.

The curl-induced divergence in the SLD brings in upwelling of cold, nutrient rich waters to the surface, and the prevalent cyclonic circulation off Sri Lanka coast and the SMC effected the advection of upwelled waters towards SBBT during July - September.

3.3 Seasonal variation of surface chlorophyll-*a* and nutrients

An examination of SeaWiFs derived monthly mean sea surface chlorophyll-*a* during July 1997 – December 2000 revealed the presence of a band of higher chlorophyll-*a* emerging from the western part of Nicobar Islands (4°-7°N) up to SBBT during NEM (January – February) and from south of Sri Lanka towards SBBT and central Bay during SWM. This is further substantiated by the seasonal distributions of chlorophyll-*a* during January and July 1998 and 2000 (Figures 4a-d). Owing to the fact that the entire northern Indian Ocean experienced a large scale influence of the Indian Ocean Dipole (IOD) event during 1997-98 [*Saji et al.*, 1999], the SeaWiFs surface chlorophyll for a non-IOD year (2000) was also included. The concentration of chlorophyll-*a* was relatively high in 1998 compared to that in 1999 and 2000. It is interpreted that the prevailing surface currents at 2.5 m depth in January 1992 (Figure 3a) and February 1992 advected the nutrient rich waters with elevated chlorophyll-*a* from the Nicobar Islands through WMC between 5° and 8°N which triggered high primary productivity leading to higher biogenic fluxes at SBBT during NEM (February) (Figures 1a-b). Despite the fact that the WMC continued until April/May, the advected chlorophyll-*a* depleted waters after February hampered the primary productivity resulting in lower biogenic fluxes at SBBT during March – June (Figure 1a). Nevertheless, the surface waters replenished with higher concentrations of chlorophyll-*a* during SWM (July – August) in a wide band (Figures 4b & 4d) that extended from south of Sri Lanka up to SBBT and northward into central Bay. The

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high chlorophyll-*a* band coincided with the cold-water band that emerged from south of Sri Lanka and the SLD with eastward/southeastward currents flowing towards SBBT. The available *in situ* profiles of measured nutrients (nitrate, silicate, phosphate) and dissolved oxygen (DO) at the hydrographic stations in the vicinity of SBBT during the SWMs of 1984 and 1993 (Figures 5a-d) were assumed to be the representative of the general nutrient distributional patterns in the southern Bay of Bengal during the SWM. Figures 5a-d showed the availability of higher concentrations of nutrients (2 µM in nitrates) in the euphotic layer in the southern Bay of Bengal during SWM.

4. Conclusions

The OFES simulated cold water band and the SMC, the measured high nutrients and the SeaWiFS derived higher chlorophyll-*a* in the southern Bay of Bengal during SWM confirmed that the SMC advected the upwelled nutrient-rich and chlorophyll elevated waters from the southeastern Arabian Sea (including the southern tip of India) during May – June and from the east coast of Sri Lanka (SLD) during July – September. Besides, the higher concentrations of DO in September (Figure 5d) suggested the enhancement of primary productivity (oxygen is released to the water column) in the southern Bay of Bengal during SWM. Thus, it is concluded that the prevailing surface layer processes obtained from the wind induced divergence and OFES simulated cold water band, the SLD and the SMC showed their tremendous influence on the biogeochemistry of the southern Bay of Bengal which was well evident from the measured higher biogenic fluxes during the SWM of 1992 in the southern Bay of Bengal.

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6. References

Alldredge, A. L., and M. W. Silver (1988), Characteristics, dynamics, and significance of marine snow, *Progr. Oceanogr.*, *20*, 41-80.

Antonov, J., S. Levitus, T. P. Boyer, M. Conkright, T. Oâ€™ Brien, and C. Stephens (1998a), World Ocean Atlas 1998, vol. 1, Temperature of the Atlantic Ocean, NOAA Atlas NESDIS 27, 166 pp., U.S. Gov. Print. Off., Washington, D. C.

Antonov, J., S. Levitus, T. P. Boyer, M. Conkright, T. Oâ€™ Brien and C. Stephens (1998b), World Ocean Atlas 1998, vol. 2, Temperature of the Pacific Ocean, NOAA Atlas NESDIS 28, 166 pp., U.S. Gov. Print. Off., Washington, D. C.

Antonov, J., S. Levitus, T. P. Boyer, M. Conkright, T. Oâ€™ Brien, C. Stephens, and B. Trotsenko (1998c), World Ocean Atlas 1998, vol. 3, Temperature of the Indian Ocean, NOAA Atlas NESDIS 29, U.S. Gov. Print. Off., 166 pp., Washington, D.C.

Boyer, T. P., S. Levitus, J. I. Antonov, M. E. Conkright, T. D. OxBrien, and C. Stephens, (1998a), *World Ocean Atlas 1998*, vol. 3, Temporal Distribution of Expendable Bathythermograph Profiles, *NOAA Atlas NESDIS 20*, 170 pp., U.S. Gov. Print. Off., Washington, D. C.

Boyer, T.P., M.E. Conkright, S. Levitus, C. Stephens, T. OxBrien, D.Johnson, R. Gelfeld, (1998b), World Ocean Database 1998, vol. 4, Temporal Distribution of Conductivity- Temperature-Depth Profiles. *NOAA Atlas NESDIS 21*, 163 pp., U.S. Govt. Print. Off., Washington, D. C.

Boyer, T.P., M.E. Conkright, S. Levitus, D. Johnson, J. Antonov, T. OxBrien, C. Stephens, R. Gelfeld (1998c), World Ocean Database 1998, vol. 5, Temporal Distribution of Ocean Station Data (Bottle) Temperature Profiles. *NOAA Atlas NESDIS 22*, 108 pp., U.S. Govt. Print. Off., Washington, D. C.

Guptha, M. V. S., W. B. Curry, V. Ittekkot, and A. S. Muralinath (1997), Seasonal variation in the flux of planktonic Foraminifera: Sediment trap results from the Bay of Bengal, Northern Indian Ocean, *J. Foraminiferal Res*., *27*, 5-19.

Guptha, M. V. S., L. P. Mergulhao, V. S. N. Murty, and D. M. Shenoy (2005), Living coccolithophores during the northeast monsoon from the Equatorial Indian Ocean: Implications on hydrography, *Deep Sea-Res. II, 52*, 2048-2060.

Hastenrath, S., and L. L. Greischar (1989), Climatic Atlas of the Indian Ocean, Part III: Upper-Ocean Structure. The University of Wisconsin Press, Madison, 247 charts.

Ittekkot, V., R.R. Nair, S. Honjo, V. Ramaswamy, M. Bartsch, S. Manganini, and B.N. Desai (1991), Enhanced particle fluxes in Bay of Bengal induced by injection of fresh water, *Nature*, *351*, 385-387.

Joseph, P.V., K.P. Sooraj, C.A. Babu, and T.P. Sabin (2005), A cool pool in the Bay of Bengal and its interaction with the active-break cycle of the monsoon, *CLIVAR Exchanges 34, 10*(3), 10-12.

Kalnay, E. and 21 co-authors, (1996), The NCEP/NCAR 40-year reanalysis project. *Bull. Am. Meteorol. Soc.*, 77, 437-471.

Masumoto, Y., H. Sasaki, T. Kagimoto, N. Komori, A. Ishida, Y. Sasai, T. Miyama, T. Motoi, H. Mitsudera, K. Takahashi, H. Sakuma, and T. Yamagata (2004), A Fifty-Year Eddy-Resolving Simulation of the World Ocean –Preliminary Outcomes of OFES (OGCM for the Earth Simulator)–, *J. Earth Sim.,* 1, 35-56.

Mergulhao, L. P., Rahul Mohan, V. S. N. Murty, M. V. S. Guptha, and D. K. Sinha (2006), Extant coccolithophores from the central Arabian Sea: Sediment trap results, *J. Earth Sys. Sci.* 115, 415-428.

Mergulhao, L.P., (2006), Seasonal variation of the flux of living coccolithophore communities in the Bay of Bengal and their implication on hydrography, Ph.D. Thesis, submitted to Goa University, India, 167 pp (Unpubl.).

Murty, V. S. N, Y. V. B. Sarma, D. P. Rao, and C. S. Murty (1992), Water characteristics, mixing and circulation in the Bay of Bengal during southwest monsoon, *J. Mar. Res., 50*, 207-228.

Nair, R. R., V. Ittekkot, S. J. Manganini, V. Ramaswamy, B. Haake, E. T. Degens, B. N. Desai, and S. Honjo (1989), Increased particle flux to the deep ocean related to monsoons, *Nature*, *338*, 749-751.

Pacanowski, R.C. and M. Griffies (2000), The MOM3 Mannual, GFDL Ocean Group Technical Report, 4, Princeton, NJ, NOAA/GFDL, 680pp.

Rao, R. R., M. S. Girish Kumar, M. Ravichandran, and B. K. Samala (2006), Observed mini-cool pool off the southern tip of India and its intrusion into the south central Bay of Bengal during summer monsoon season, *Geophys. Res. Lett., 33*, L06607, doi:10.1029/2005GL025382.

Reynolds, R. W., and T. M. Smith, (1994), Improved global sea surface temperature analyses using optimum interpolation, *J. Clim., 7*, 929-948.

Rixen, T., B. Haake, V. Ittekkot, M. V. S. Guptha, R. R. Nair, and P. Schlüssel (1996), Coupling between SW monsoon-related surface and deep ocean processes as discerned from continuous particle flux measurements and correlated satellite data, *J. Geophys. Res.*, *101*, 28,569 – 28,582.

Rosati, A. and K. Miyakoda (1988), A general circulation model for upper ocean circulation, *J. Phys. Oceanogr.*, 18, 1601-1626.

Saji, N. H., B. N. Goswami, P. N. Vinaychandran, and T. Yamagata (1999), A dipole mode in the tropical Indian Ocean, *Nature*, *401*, 360-363.

Sasaki, H., M. Nonaka, Y. Masumoto, Y. Sasai, H. Uehara, and H. Sakuma (2006), An eddy-resolving hindcast simulation of the quasi-global ocean from 1950 to 2003 on the Earth Simulator, in High Resolution numerical Modeling of the Atmosphere and Ocean, Ed. K. Hamilton and W. Ohfuchi, Springer, New York, (in press)

Shankar, D., P. N. Vinayachandran, and A. S. Unnikrishnan (2002), The monsoon currents in the Arabian Sea and Bay of Bengal, *Prog. Oceanogr.*, *52*, 63-120.

Smitha, B. R., V. N. Sanjeevan, K. G.Vimalkumar, and C. Revichandran (2006), An analysis of the upwelling process along the southwest coast of India with special reference to Kanyakumari. *Submitted to Cont. Shelf Res.*

Unger, D., V. Ittekkot, P. Schäfer, J. Tiemann, and S. Reschke (2003), Seasonality and interannual variability of particle fluxes to the deep Bay of Bengal: influence of riverine input and oceanographic processes, *Deep-Sea Res. II*, *50*, 897-923.

Vinayachandran, P. N, and S. R. Shetye (1991), The warm pool in the Indian Ocean. *Proc. Indian Acad. Sci.*, 100, 165-175.

Vinayachandran, P. N., P. Chauhan, M. Mohan, and S. Nayak (2004), Biological response of the sea around Sri Lanka to summer monsoon, *Geophys. Res. Lett., 31*, L01302, doi: 10.1029/2003GL018533.

7. Figures Captions:

Figure 1. **(a)** Study area showing the sediment trap locations in the Bay of Bengal. The two rectangles (A & B) in (a) represent the boxes wherein the seasonal variation

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of the parameters are presented for 1991 -93 period, but surface chlorophyll-a is presented for 1998-2000, (b-c) seasonal variation of (b) biogenic fluxes at NBBT, CBBT and SBBT and (c) fluxes of G. oceanica and Gg. bulloides at SBBT only, and (d-h) seasonal variation of (d) OI SST and OFES temperature at 2.5 m depth, (e) surface chlorphyll, (f) Ekman pumping velocity (WE) in boxes A & B, (g) vertical velocity (W) at 100 m depth in boxes A & B, (h) OFES zonal currents at 2.5 m and 100 m depths in box B. The shaded band represents the SW monsoon period (June-September). Positive (negative) values of WE and W represent upwelling (sinking).

Figure 2. (a & b) SeaWiFs derived surface chlorophyll-a (mg m-3) during (a) July 1998 and (b) July 2000, (c & d) OFES simulated current vectors and temperature (color shading) during July 1992 at (c) 2.5 m depth and (d) 54 m depth. For clarity, alternate current vector in the adjacent grid (0.5° x 0.5°) is suppressed. The magnitude of the current vector is shown by arrow in the right top corner in (c & d).

Figure 3. Profiles of (a) nitrate, (b) silicate and (c) dissolved oxygen at the hydrographic stations close to SBBT in August 1993 and September 1984. [Source: Indian National Oceanographic Data Center, National Institute of Oceanography, Goa].

Figure 4. (a) Time series of total biogenic fluxes (black curve) and mean seasonal cycle (red curve) at SBBT (b) spatial correlations between the anomalies of biogenic flux at SSBT with OFES temperature anomalies at 100 m (correlation coefficients above 95% are bounded by curves) and (c) composite temperature anomaly (June - November) at 100 m depth during summer 1994 and 1997 IOD events. Location of SBBT is shown as star.

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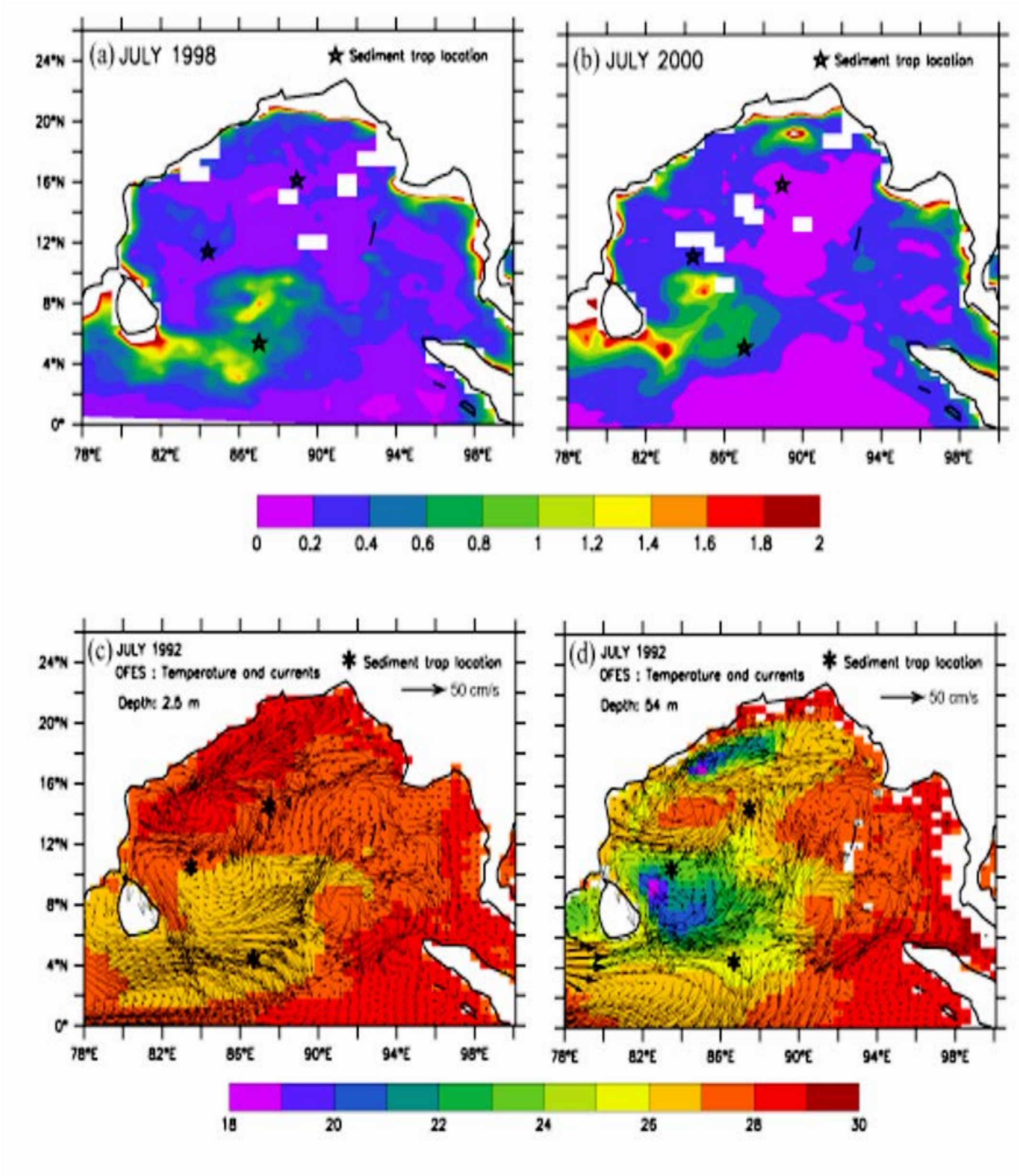

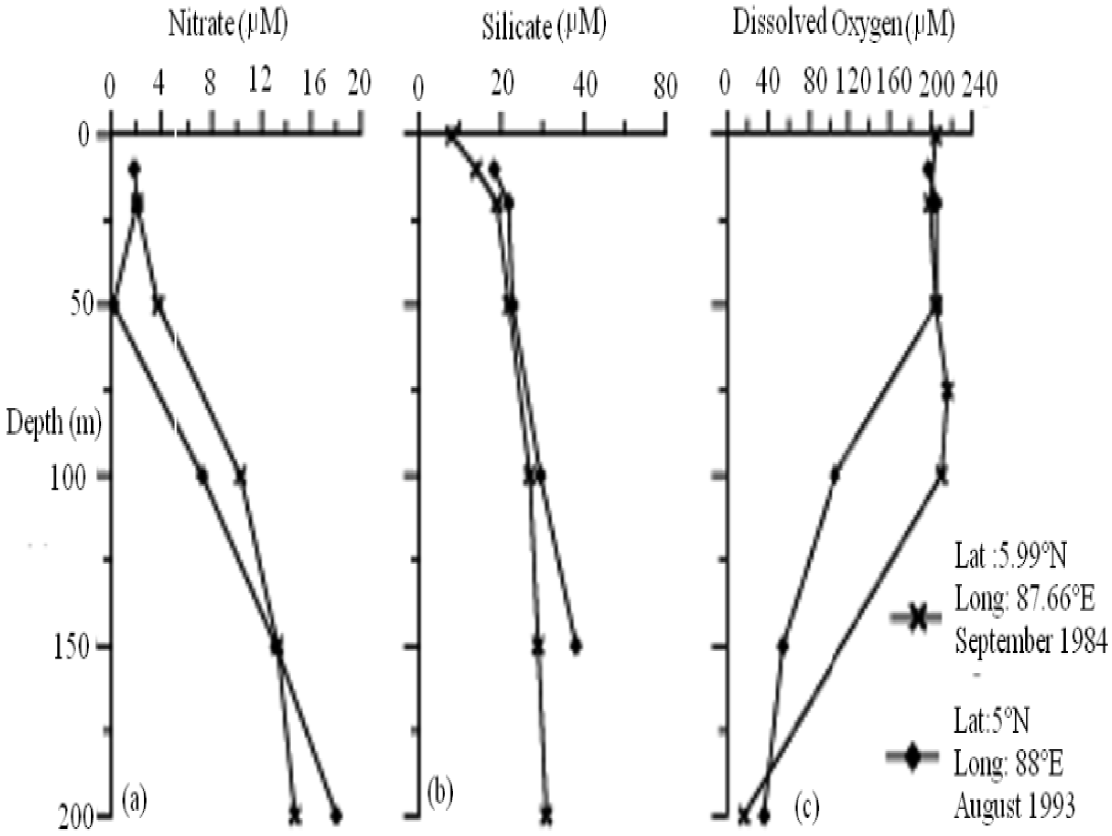
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Long: 87.66°E
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Long: 88°E
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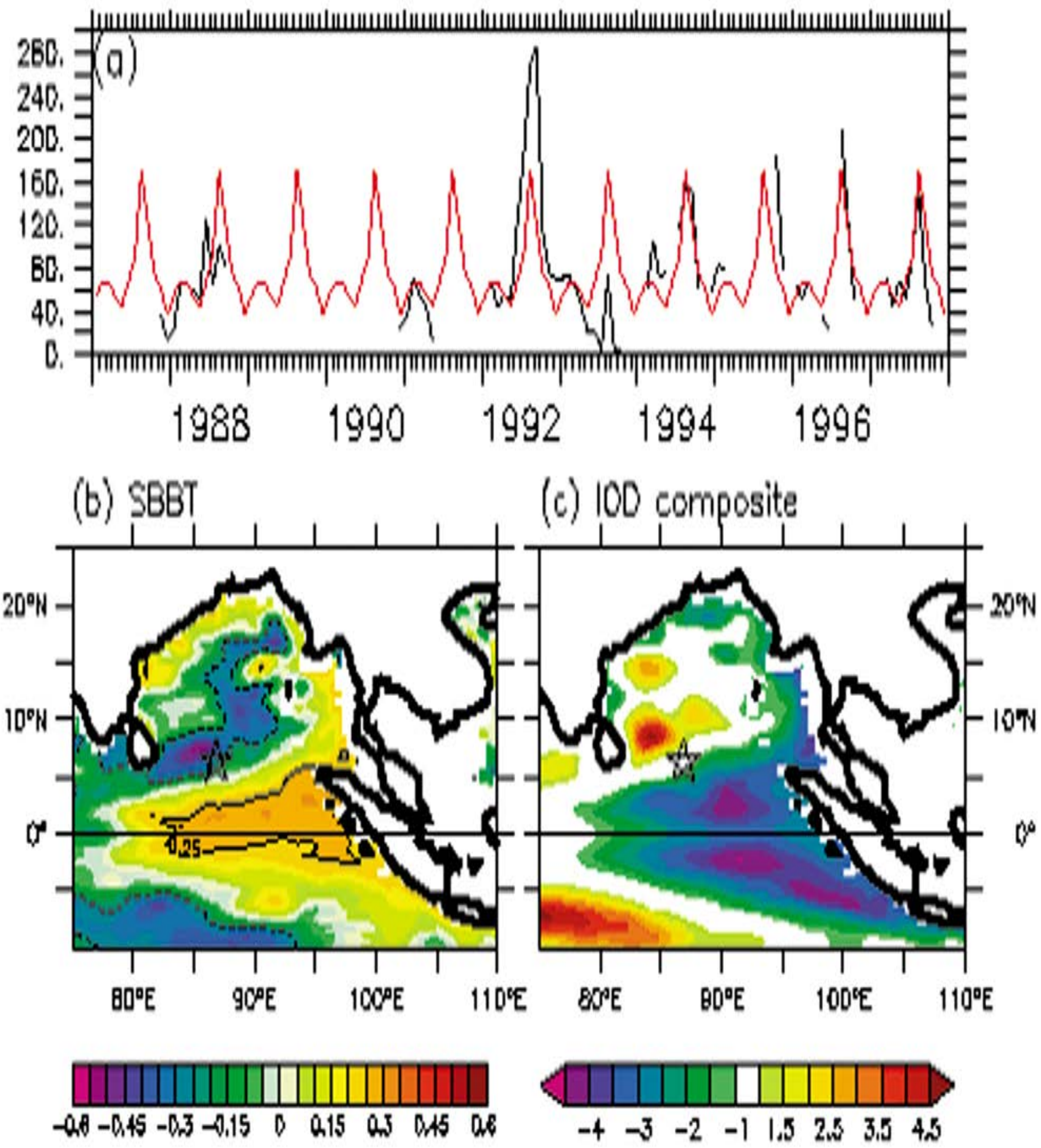
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90°E
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