

7.4 - Time Series Observations in the northern Indian Ocean

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Being surrounded by land masses on three sides, the oceanography of the North Indian Ocean exhibits several features not observed in other oceans. Peninsular India divides the region into two major basins - the Arabian Sea and the Bay of Bengal. Although these basins lie within the same latitudinal belt, they experience contrasting hydrographical and biogeochemical conditions. The dominance of the monsoons that are known to respond to climate changes in controlling oceanographic processes make the region vulnerable to global warming. There are additional reasons to believe that the region will be among the first to respond to human-induced changes. These include fragility of ecosystems, a very delicate biogeochemical balance and a very high population density in the littoral countries, many of which are experiencing rapid economic/industrial growth. For instance, the North Indian Ocean houses one of the ocean's most severe oxygen minimum zones (OMZs). The continental margin area that comes in contact with water containing dissolved oxygen less than 0.2 mL L^{-1} is about 2/3 of such area globally. Moreover, a large volume of water within the region, especially in the Bay of Bengal, is just above the threshold of becoming suboxic (i.e. where dissolved oxygen becomes so limiting that respiration largely occurs through anaerobic pathways, greatly impacting cycling of redox-sensitive elements, especially nitrogen). With stronger stratification due to a warmer climate, altered subsurface circulation, lower seawater pH, and elevated anthropogenic nutrient loading, which is expected to be particularly high in this region, large changes in biogeochemical cycling and ecosystem functioning are expected.

The highly interesting oceanography of the North Indian Ocean has led to several international projects focusing on this region, particularly the Arabian Sea. The Joint Global Ocean Flux Study (JGOFS) has been the most notable of such efforts after the International Indian Ocean Expedition (IIOE). However, almost all of these programmes were implemented in the expedition mode with much lesser emphasis, relative to other oceanic areas, on sustained observations that are essential to differentiate natural variability from long-term human-induced changes. Thus, there is no equivalent in the Indian Ocean of HOT (Hawaii Ocean Time-Series) in the Pacific Ocean and BATS (Bermuda Atlantic Time-Series) in the Atlantic Ocean. In the open ocean the only long-term time series observations that have been carried out in the past were under an Indo-German collaborative project. This study, initiated in 1986, involved monitoring of particle flux to the deep sea through deployment of sediment traps at several sites in the North Indian Ocean. Limited ancillary measurements in the water column were also made as a part of this programme. The results of this project, published in scores of peer reviewed journals, showed, amongst other things, that particle fluxes to the deep sea are forced mainly by monsoon-related processes, with prominent seasonal as well as inter-annual changes.

Unfortunately, this programme had to be discontinued in 2001 due to limited ship time, and even though it was resumed in 2007, albeit on a smaller scale, by redeploying the western Arabian Sea trap (WAST), it continues to be plagued by problems arising mostly from piracy. There has been greater success in establishment of time series sites in coastal areas. The National Institute of Oceanography (NIO) initiated time series observations in 1997 at a coastal site off Goa (called the Candolim Time Series (CaTS)). Sampled at least once a month, except during rough weather, this observational programme has provided valuable insights into carbon, nitrogen and sulphur cycles, especially the processes related to seasonal occurrence of anoxia over the shelf (see Cowie and Naqvi, this issue). A similar observational programme is being run off Visakhapatnam along the east coast of India by the Regional Centre of NIO. This in-house project involves monthly observations at a station located 30km off the coast since 2007. A sediment trap mooring has also been deployed at Lat. 16.41°N , Long. 82.52°E . In addition to scientists from India, researchers from Sultan Qaboos University, Oman have also been collecting data since 2004 at four monitoring sites, two of which are located in the Gulf of Oman and two in the Arabian Sea near Masirah Island. Samples are collected twice a month in the Gulf of Oman and once monthly in the Arabian Sea. The data being collected include plankton diversity and hydrographic parameters such as temperature, salinity, oxygen, nutrients and dissolved organic carbon (DOC). These data will serve as baseline to assess human impacts on coastal ecosystems and improve understanding of seasonal and inter-annual changes associated with the monsoonal forcing.

The main thrust of the recently launched SIBER programme, as apparent from its title, is on sustained observations (see Hood et al., this issue). India has already launched a multi-institutional SIBER programme, supported by its Ministry of Earth Sciences (MoES). The programme consists of two project clusters, one focusing on the open ocean and the other on selected coastal areas. Under the open ocean cluster, repeat observations are being carried out at two fixed sites, one each in the Arabian Sea (Lat. 17°N , Long. 68°E) and the Bay of Bengal (Lat. 18°N , Long. $89^\circ 26'\text{E}$). Whenever possible, sampling is also carried out at several other stations forming transects extending to these sites from the coast. In the other cluster, which deals with estuaries and coastal areas, sustained observations are being conducted in four areas - off Goa and Kochi along the west coast and in the Vellar-Coleroon estuaries and Hooghly-Matla estuaries and adjoining coastal waters along the east coast of India. The programme has now adopted CaTS observations; in addition, a new coastal time series is being initiated off Kochi by the Centre for Marine Living Resources and Ecology (CMLRE), Kochi.

The two open ocean sites will gradually be developed into full-fledged time series that will be accessible to the international community. Deep moorings with sediment traps and current meters have already been deployed at both sites (since 2007 in the Arabian Sea and 2010 in the Bay of Bengal). The Arabian Sea Time Series (ASTS) has been visited twice whereas Bay of Bengal Time Series (BBTS) has been visited three times since the programme was launched in 2010. The core measurements currently being made include temperature, salinity, dissolved oxygen, nutrients, nitrous oxide, methane, dimethyl sulphide, dissolved inorganic carbon (DIC), alkalinity, DOC, particulate organic carbon (POC), chlorophyll *a*, phytoplankton composition including picoplankton, zooplankton biomass and composition, total bacterial counts (TBC) and primary production. In addition, several specialised measurements to investigate the biogeochemical and ecological processes under other funded projects are planned to be added in 2012. There are also plans to deploy moorings with several oceanographic and biogeochemical sensors at the two locations in collaboration with the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad.

So far the sampling frequency has been lower than originally planned (six times every year). The availability of ship time is a major constraint as most of the time of the MoES research fleet is already committed to other funded projects. Efforts are underway to get additional ship time by chartering research vessel(s). The situation is also expected to improve after the new vessel being constructed by NIO is commissioned in 2012. In the case of the Arabian Sea, however, there is an additional, more serious, impediment - the threat by Somali pirates that has brought oceanographic observations in the region almost to a standstill (see the article by Maddison *et al* in this issue). In the recent past, several planned cruises had to be either cancelled or their tracks altered as a result of this threat. This included a visit to the ASTS by us in 2011. Like all oceanographers keen to pursue their research in the Arabian Sea, we hope that this issue will be addressed through concerted international efforts in the near future.

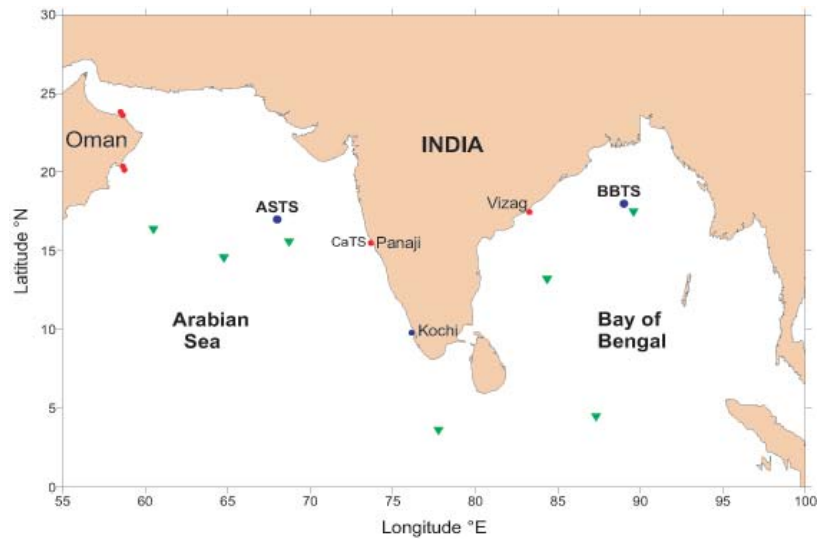


Figure 1: Time Series locations in the North Indian Ocean. Green triangles show positions of the Indo-German sediment traps (1986-2001). Red dots indicate presently operational coastal time series stations, and blue dots denote times series in the central Arabian Sea (ASTS), central Bay of Bengal (BBTS) and off Kochi initiated under the SIBER-India programme.