

# 1:2 Land-Ocean Interactions in the Coastal Zone

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The consolidated project proposal on Land-Ocean Interactions in the Coastal Zone (LOICZ) submitted to the Department of Ocean Development (DOD) in 1995 has been approved by DOD for funding at a total projected cost of Rs. 1,39,35,000/-. The organizations involved are National Institute of Oceanography (NIO), Goa, Physical Research Laboratory (PRL), Ahmedabad, Andhra University, Visakhapatnam, Jawaharlal Nehru University (JNU), New Delhi, and Anna University, Chennai. The project is being coordinated by Dr S W A Naqvi of NIO.

The approved work planned under LOICZ (India) is covered by seven sub-projects. Two of these, grouped under the Eastern Arabian Sea Marginal Exchange (EASMEX) Study, focus on coastal processes off the central west coast of India with NIO being the nodal agency. These are:

1. Time series water-column measurements and benthic fluxes across the continental margin off the central west coast of India (NIO).

2. Study of sinking particulate matter and its dispersal on the central western continental margin of India by time-series sediment traps (NIO).

The other five sub-projects focus on biogeochemical cycling in the Godavari delta including the coastal zone of the Bay of Bengal that receives discharges from this river.

These investigations, being coordinated by PRL, are:

- 1&2. Biogeochemistry of carbon and related elements in the Godavari River and the adjoining coastal zone (PRL and Andhra University).
- 3&4. Nature and flux of organic matter in the Godavari River Basin (JNU and Anna University).
5. Remote sensing studies on coastal biogeomorphological environments in the Godavari delta region (Andhra University).

The overall objectives of the projects are:

- ♦ To determine fluxes of various elements such as carbon, nitrogen, trace metals and major elements across the western continental margin of India.
- ♦ Development of budget, process and system models for the west coast of India.
- ♦ Benthic fluxes and trap derived fluxes of particulate and dissolved carbon from the sediments of the west coast of India.
- ♦ Time series fluxes of carbon and associated elements in the Godavari estuary.
- ♦ Budget models for carbon and nutrients in the coastal zone near the Godavari estuary
- ♦ Fluxes of various trace metals and radioactive isotopes and major elements in the Godavari estuary.

- ♦ Fluxes of various trace metals and radioactive isotopes and major elements in the Godavari estuary.
- ♦ Quantitative assessment of coastal morphodynamics in terms of erosion and deposition during the present century and generation of prospective maps.
- ♦ Quantitative assessment of the nature of biogeomorphological changes in terms of reduction in mangrove and other wetland environments (lagoons, marshes, tidal flats, etc.), resulting from direct human activities such as changing land use, population, settlements, etc. in the deltaic coasts.
- ♦ Assessment of the changing microclimates of the region as a consequence of the effect of human activities and biogeomorphological response.
- ♦ To understand the nature of organic matter such as amino acids, peptides and carbohydrates and quantify the fluxes of organic matter both labile and non labile in the Godavari River Basin.
- ♦ To determine the concentration of toxic metals associated with organic phases in the Godavari Basin.

Although the project is of four-year duration (1997-2001), the work could be initiated only in 1998 as the final sanction letter was received in January 1998. However, in anticipation of funding, time series observations were initiated in August 1997 off Goa. A brief summary of the work and highlights of the results are given below:

### **Eastern Arabian Sea Marginal Exchange**

*Project A: Time series water-column measurements and benthic fluxes across the continental margin off the central west coast of India*

Seven cruises have been undertaken so far: two on board FORV Sagar Sampada during August-September 1997 (SS158) and January 1998 (SS161), and five on board ORV

Sagar Kanya during July-August 1998 (SK137), October 1998 (SK138A), December 1998 (SK140A), September-October 1998 (SK148) and December 1999 (SK 149D). During all these cruises observations were made along the EASMEX section off Goa sampling the very same sites. In addition, the five shallowest stations of the section were sampled using hired fishing boats on 16 occasions. On four of these cruises (SS158, SK137, SK148 and SK149D) several other sections traversing the shelf between Quilon and Mumbai were also worked to investigate the effect of upwelling on biogeochemical cycling.

In addition to collecting routine physico-chemical data salinity, temperature, dissolved oxygen and nutrients [nitrate ( $\text{NO}_3^-$ ), nitrite ( $\text{NO}_2^-$ ), ammonia ( $\text{NH}_4^+$ ), phosphate and silicate], analyses of climatically important gases (nitrous oxide, methane and dimethyl sulphide) were performed during most cruises. Primary productivity and/or chlorophyll measurements were made at selected sites during SS158, SK 137, SK148 and SK149D. Samples were collected and analysed for dissolved and particulate organic matter on SK137 and 140 and for stable isotopes in dissolved nitrogen species [ $^{15}\text{N}/^{14}\text{N}$  in molecular nitrogen ( $\text{N}_2$ ),  $\text{NO}_3^-$  and  $\text{N}_2\text{O}$  and  $^{18}\text{C}/^{16}\text{O}$  in  $\text{N}_2\text{O}$ ] during most cruises.

The data obtained have provided new insights into seasonal changes in the biogeochemical processes over the continental margin along the west coast of India. The most important process that affects the biogeochemical cycling in this region is upwelling. The results indicate that the extent and significance of this process had not been fully appreciated so far. The process seems to occur for over six months (from June to December), but since the upwelled water is overlain by a 5-10 m thick low-salinity layer formed as a consequence of land runoff and local precipitation during the southwest monsoon, the effect of

upwelling is not discernible at the sea surface and is missed by the satellite observations as well. But nutrient replete ( $\text{NO}_3^- \lesssim 20 \mu\text{M}$ ) waters are found well within the euphotic zone and consequently the rate of biological production is very high (several grams of carbon per square metre per day) during the early part of the southwest monsoon (June-July). This, in turn, enhances the oxygen demand at depth, which in conjunction with the low oxygen content of the upwelled waters and strong vertical stratification, causes the development of suboxia (denitrification) and occasional anoxia (sulphate reduction) in the inner shelf during the later part of the southwest monsoon (August-September). Thus, hydrogen sulphide ( $\text{H}_2\text{S}$ ) was detected in concentrations reaching up to  $20 \mu\text{M}$  in the inner-mid-shelf regions at several places between Mangalore and Mumbai during SK137, SK138A and SK148 and on a number of boat trips off Candolim (Goa) during the late southwest monsoon and post monsoon periods of 1998 and 1999. This is the first report of  $\text{H}_2\text{S}$  from the open coast from the Indian Ocean.

The reversal of monsoonal winds after the southwest monsoon facilitates the establishment of "normal", conditions sometime in December with deep (>50 m) mixed layer having low-nutrients and high oxygen. This pattern probably repeats every year albeit with considerable inter-annual variability.

An accumulation of ammonia was observed in the coastal suboxic zone especially after the onset of sulphate reduction. The highest ammonia concentrations measured was ~8 mM. However, the  $\text{H}_2\text{S}$  concentrations were about two orders of magnitude lower than expected from the observed ammonium levels. The possible causes of this anomaly are: (1) While periodic oxygenation caused by turbulence might lead to sulphide oxidation, oxidation of ammonium

(nitrification) would be inhibited by light at such shallow depths;

(2) A substantial fraction of ammonium might be supplied through diffusion from the sediments or produced during denitrification; (3) Sulphide might be lost at insoluble metal (mainly iron) sulphides: large accumulations of Fe and Mn in the dissolved forms were observed in denitrifying waters, but while Mn continued to accumulate within the sulphate reducing zone, Fe concentrations decreased in the dissolved phase and increased in the suspended phase; and (4) The presence of high ammonium levels within the well-lit anoxic layer might trigger anoxygenic photosynthesis.

The anoxic-suboxic conditions greatly affected the cycling of methane and  $N_2O$  the concentrations of which were at times higher than observed anywhere else in the oceanic near-surface waters. Field observations backed by experimental studies seem to suggest that the large build-up of  $N_2O$  is mainly through denitrification. However, whether or not denitrification results in a net production of  $N_2O$  appears to depend upon the age of the suboxic system. The "young" denitrifying environments might be characterized by the accumulation of  $N_2O$  simply because the  $N_2O$  reductase, the enzyme which mediates the reduction of  $N_2O$  to  $N_2$ , may not be originally present in the facultative bacteria under oxic conditions, and they may require some time to synthesize it. Once it is synthesized, however,  $N_2O$  would be reduced to  $N_2$ . This was indeed observed in the "aged" denitrifying systems. However, due to shallow depths and wind-generated turbulence the water may alternately experience oxic and suboxic conditions. Moreover, for the same reason,  $N_2O$  would rapidly escape to the atmosphere. Thus, the rate of  $N_2O$  loss to the atmosphere is expected to be extremely high in the shallow, seasonally-suboxic coastal environments.

Although there have been reports of the occurrence of seasonal hypoxia/anoxia from several coastal areas, especially along the east coast of South America (in the Gulf of Mexico), and in the Black and Baltic Seas, the suboxia observed along the west coast of India is different in that it is forced by natural process rather than by anthropogenic perturbations (eutrophication) as happens elsewhere. It is possible, however, that eutrophication in this region may enhance the intensity of the process; whether or not this has already occurred to some extent cannot be established due to a paucity of previous data during the crucial periods of SW monsoon and post monsoon. Nevertheless, the results call for a regular monitoring of the health of our coast.

During SK148 and SK149D, sediment cores were collected with a spade corer at nine stations over the continental shelf/upper slope (one in the Bay of Bengal and eight from the Arabian Sea). These were sectioned at 1-cm intervals and the pore waters were extracted under inert atmosphere for nutrient profiling. Sub-sections of the same cores were incubated in PVC tubes at near-in situ temperatures after injecting acetylene-saturated, oxygen-free water through ports fitted with silicon rubber septa. Following incubations for 1-2 hours, the sub-cores were sectioned and the  $N_2O$  was extracted from each 1-cm segment and analysed by gas chromatography. These experiments have provided the first estimates of sedimentary denitrification in the Indian Ocean.

*Project B: Study of sinking particulate matter and its dispersal on the central western continental margin of India by time-series sediment traps*

Deployment of sediment traps under this investigation is yet to be made as the necessary equipment (such as

sediment trap, current meters, acoustic releases, floats and mooring line accessories) have just been procured. However, analysis of sediment cores collected from the western continental margin has been initiated.

Geochemical and mineralogical investigations have been undertaken on the sediment cores from the LOICZ area to understand elemental accumulation rates, their fluxes and associated paleo-processes especially during late Pleistocene and Holocene. The parameters investigated include total organic carbon (TOC),  $\text{CaCO}_3$  and bulk density; their variations in short cores (mostly covering the Holocene period) and  $\delta^{13}\text{C}$  of organic matter in surficial sediments were investigated. In addition, the concentration of TOC in near-bottom suspended particulate material was measured. Also organic carbon to mineral surface area ratios (OC:SA) were measured in fourteen sediments collected along the entire western margin of India. Based on these analysis the processes responsible for the preservation of organic carbon in the sediments and calculated burial efficiency of TOC in the study area were inferred.

The results of recent investigations clearly indicate that:

1. The concentration of TOC in near-bottom suspended materials ranged from 0.76 to 1.96. The  $\delta^{13}\text{C}$  values in sediments ranged between -19.6 to 20.9‰ suggesting that source of organic matter in these sediments is predominantly marine. Interestingly, concentration of TOC in suspended particulates did not show any relationship either with depth of the water column or the concentration of TOC in surficial sediments. The organic contents in sediments and their burial efficiencies are mainly determined by the environment of deposition and do not depend on the supply of organic material, which incidentally in the present case is the primary productivity.



2. In fourteen surface sediments collected along the entire western margin of India, the organic matter contents range from 0.04 - 5.0 wt% OC, and mineral surface areas ranged from 0.6 - 31 m<sup>2</sup>/g. OC:SA ratios range from 0.2 to 5 mg OC/m<sup>2</sup>. The lowest OC:SA ratios are from shelf sediments (OC:SA <1), with high OC:SA ratios in upper slope sediments (OC:SA >2). Deep slope sediments again have low OC:SA ratios. When OC:SA is correlated with bottom water oxygen content, an inverse relationship is observed. This inverse relationship suggests that depositional conditions related to oxygen (Oxygenicity, oxygen exposure time) influence organic matter preservation. Since surface area-normalization removes biases in organic matter content related to grain size, the robust relationship between OC:SA and oxygenicity provides evidence that the organic matter content of sediments within the oxygen minimum zone of the Indian margin are at least indirectly influenced by bottom water oxygen content. These findings have direct implications on understanding the biogeochemical cycling of organic carbon, the main theme of LOICZ objectives.

## **Publications**

1. Jayakumar, D.A., S.W.A. Naqvi, P.V. Narvekar and M.D. George Methane in coastal and offshore waters of the Arabian Sea. *Mar. Chem.* (in press).
2. Naqvi, S.W.A., M.D. George, P.V. Narvekar, D.A. Jayakumar, M.S. Shailaja, S. Sardesai, V.V.S.S. Sarma, D.M. Shenoy, H. Naik, P.A. Maheswarana, K. Krishna Kumari, G.Rajesh, A.K. Sudhir and M.S. Binu (1998) Severe fish mortality associated with 'red tide' observed in the sea off Cochin. *Curr. Sci.* 75, 543-544.

## **Biogeochemistry of carbon and related elements in the Godavari river and the adjoining Coastal zone**

Since the rivers provide an important pathway for the transport of chemical constituents from land to ocean, there is a need to estimate the carbon and nutrient loads into the coastal zones. This has become more relevant in the context of ever-increasing use of synthetic fertilizers on land, a large fraction of which is carried to the sea by rivers. The transports of carbon and nutrients fluxes via the tropical rivers could be large enough to make the coastal ocean an effective net sink for anthropogenic CO<sub>2</sub>. In order to evaluate the significance of these processes in the Indian waters, extensive sampling has been undertaken under the LOICZ (India) programme, along the Godavari main stream (from its origin at Nashik to the river mouth at Rajamundry) and its major tributaries (Purna, Pravara, Wardha, Penganga, Wainganga, Pranhita, Indravati and Sabari). The observations were made on a seasonal basis in November 1998, and in March and September 1999, representing the moderate, lean and high discharge conditions.

Preliminary results on the transport of dissolved inorganic carbon (DIC) and the particulate organic carbon (POC) and nitrogen (PON) show that the POC and PON concentrations ranges in the main stream are 0.3-9.3 and 0.06-0.8 mg l<sup>-1</sup>, respectively, with consistently higher concentration occurring during the high flow (monsoon) season. The C:N ratio in the particulate phase also depicts large variation, ranging from 1.8 to 12.0. Among the tributaries, relatively high concentrations of particulate C and N are observed in the Pranhita and Indravati (POC : 20.3 mg l<sup>-1</sup>, PON: 2.7 mg l<sup>-1</sup>) that drain through extensive vegetation cover. The DIC concentration in the main stream

and tributaries varies between 7 and 46 mg l<sup>-1</sup>. The mass balance approach suggests that, of the total DIC load, 50% is from upriver transport with an equal contribution from the two tributaries (Pranhita and Indravati).

For preliminary budget calculations, discharge weighted concentrations of POC, PON and DIC have been calculated as 7.2, 0.6 and 24 mg l<sup>-1</sup> respectively. The total flux of DIC at river mouth (Rajahmundry) is estimated to be  $22 \times 10^{11}$  g yr<sup>-1</sup>, which is nearly four times higher than the POC flux ( $6 \times 10^{11}$  g yr<sup>-1</sup>). However the POC flux is ten times higher than the PON flux ( $0.6 \times 10^{11}$  g yr<sup>-1</sup>) to the Bay of Bengal. Though these data are preliminary, it is important to know how much of the observed DIC results from rock-weathering within the basin, from groundwater flow and from respiration within river? The mass balance approach in conjunction with the carbon isotope ratio (<sup>13</sup>C/<sup>12</sup>C) would provide more information on the processes occurring in the upriver and tributary inputs.

Observations have also been made in the coastal and estuarine regions of the Gauthami-Godavari rivers during three seasonal surveys in February, May-June and September 1999. These consist of three coastal transects off Bhiravapalem, Vadalarevu and Antarvedi which cover the major coastal strip of the Godavari river. On each transect four stations were fixed at 10, 20, 30 and 50 m depth contours. Three estuarine regions were selected - one each on the Gauthami, Vasistha and Vainateyam rivers comprising a total of eight stations - to follow the salinity - nutrient relationships and tidal influence on these estuarine regions. In addition four riverine stations were fixed on the Gauthami, Vasistha and Godavari at Gannavaram, Jonmada, Siddantam and Dhawaleswaram.

Water samples from discrete depths were collected and processed/analysed for salinity, chlorophyll, pH, alkalinity, dissolved oxygen, dissolved and particulate nutrients, and selected major and minor elements (fluoride, calcium, magnesium and trace metals).

The results indicate a general decreasing trend in dissolved oxygen and nutrient concentrations from the head to the mouth of all the estuaries suggesting that these estuaries serve as nutrient traps. In general, higher values of nutrients were observed during the monsoon season indicating enhanced transports, especially of nitrate and silicate, during this season.

### **Remote sensing studies on coastal Biogeomorphological Environments in the Godavari Delta Region**

Satellite data pertaining to this area were obtained from the National Remote Sensing Agency (NRSA), Hyderabad, in digital form and were subjected to image processing. The image data were treated with various algorithms for enhancing the ground features for better interpretability and analysis. Initial understanding of the data was obtained by displaying the satellite data on the interactive display monitor, and by generating a three-band composite called the false colour composite. Various image processing techniques such as radiometric transformation, geometric rectification, image enhancement and classification were applied.

Based on the interpretation of the satellite imagery various landforms in the Godavari delta region (600 km<sup>2</sup>), such as paleo distributary courses on both sides of the present river and relict beach ridges which represent former shorelines even up to 30 km inland, have been identified.

The disposition of the former river courses vis-a-vis beach ridges indicated locations of former river mouths, the prograding nature of the delta and possible sea level changes.

The most important biogeomorphic environment that has been identified in the Godavari delta region is the mangrove swamp. This fragile coastal ecosystem is facing degradation as revealed by the analysis of multi-date maps and satellite imagery. The mangrove swamp that has occupied about 20,900 ha in 1976 has been reduced to 14,600 ha by 1999. The main reason for this large-scale mangrove degradation is the encroachment for aquaculture besides tree-felling for firewood.

Another significant inference made in the study is the coastal erosion more than deposition along the delta front. About 1340 ha of coastal area has been lost in about 21 years between 1976 and 1997, perhaps indicating possible sea level rise.

Drilling of boreholes has been done at nine locations in the delta region representing various biogeomorphological environments. A total of 115 subsurface sediments were collected for identifying the evolutionary chronological landform sequences. Fossil shells were recovered at four of these sites; these will be identified and dated. The grain size analysis of the sediment samples has been completed giving a rough idea of the various subsurface stratigraphic horizons and the possible depositional environments. However, a more definite interpretation awaits further analysis of sediments and radiocarbon dating of the carbonate material.

Temperature and rainfall data have been collected from the available twelve weather recording stations. The

analysis of these data has revealed that the rainfall has increased by about 200mm during 1990-1999 decade when compared to the 1980-1989 period. On the other hand, the temperature has decreased on an average by about  $0.3^{\circ}\text{C}$  during the same period. This is attributed to the increased vegetative canopy and the expansion of the wetland extent due to aquaculture ponds.