signatures of methane hydrates in both sI and sII structures.


Acknowledgements. We are indebted to Prof. H. K. Gupta, Raja Ramanna Fellow and Dr P. S. Goel, Secretary, Ministry of Earth Science Systems, Government of India for their keen interest and encouragement. We thank the Director, National Geophysical Research Institute, Hyderabad, for encouragement. We also thank Mr B. Satyanarayana for providing technical support in the fabrication of pressure vessels and the anonymous reviewer for stimulating suggestions on the manuscript.

Received 18 July 2007; revised accepted 24 April 2008.

Understanding the suspended sediment dynamics in the coastal waters of the Bay of Bengal using high resolution ocean colour data

P. N. Sridhar*, I. V. Ramana, M. M. Ali and B. Veeranarayana

National Remote Sensing Agency, Department of Space, Balanagar, Hyderabad 500 625, India

The suspended sediment concentration (SSC) in the coastal ocean of the Bay of Bengal (BOB) is retrieved with high-resolution ocean colour data of the Ocean Colour Monitor (OCM) on-board satellite Oceansat-I. The SSC distribution in the coastal waters of the BOB has a regional gradient from north to south that follows the general monsoon circulation of the east coast of India. However, factors like tidal, fluvial and longshore currents play a major role in the regional sediment dynamics with understandable source, sink and pathway. In addition, other influences like geostrophic currents in the coastal sediment transport and dynamics are evident from the ocean colour data.

Keywords: Coastal waters, geostrophic currents, ocean colour data, suspended sediment dynamics.

Suspended sediments play a major role in the coastal ocean turbidity, water quality, estuarine, tidal inlet, coral reef and mangrove ecosystem sedimentation excreta1,2. Therefore, coastal sediment transport and dynamics are central to the analysis and prediction of environmental quality, habitat stability, public-health risks, marine hazards such as ship-grounding, access to ports, seabed scouring, siltation of harbours and coastal protection3. The sediment dispersal system in the shelf of the Bay of Bengal (BOB) characterizes substantial temporal and spatial variability, as it is driven by major rivers4, namely the Ganges, Brahmaputra, Bramani, Baitaran, Mahanadi, Krishna, Godavari, Pennar and Cauvery from high-altitude mountains and hence has national and global significance.

Sediment distribution in the coastal ocean water column may occur either as a diffusive process, where the bed is flat and devoid of bed forms5 or as a convective process6. The sediment is also suspended and lifted upward in coherent pockets due to vortex shedding from ripples at the bed. The amount of sediment suspended depends on bed elevation, configuration, bed shear stress and wave breaker7. Winds drive water along the inner shelf and ocean circulation system forces the outer-shelf water movements. In the inner-shelf, the wave boundary layer thickness is smaller than current boundary layer

*For correspondence. (e-mail: sridhar_pn@nrsa.gov.in)
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thickness. Therefore, the oscillatory velocities are significantly larger than mean current velocity and involves relatively high turbid in the inner shelf waters than open ocean waters that moves shore to outer self\(^6\). In the nearshore waters, high suspended sediment concentration (SSC) within the surf zone can also result from river discharge and littoral drift\(^5\). The degree of interchange between the opposing water masses appeared to determine regional turbidity patterns. Temporal and spatial sediment dispersal patterns were probably due to ambient wind conditions, run-off volume from adjacent fluvial systems and the degree of incursion by open ocean waters\(^10\). Therefore, in the coast ocean, the bottom sediments are resuspended by the large shear stresses generated by wave motions, and currents play a subordinate role. Close to the bed, turbulence generated by breaking waves creates small turbulent eddies by bed friction that mobilize the sediment to higher elevations. Also, sediment concentration profile gradients are different under breaking and non-breaking waves. In the latter case, suspended sediment is confined to a relatively thin layer near the bed\(^11\).

Monitoring of suspended sediment dynamics over large spatial scales by conventional means has its own limitations. The Ocean Colour Monitor (OCM) on-board Oceansat-I, with 360 m ground resolution is capable of mapping coastal sediments. Thus, Indian Remote Sensing Satellite (IRS-P4), Oceansat-OCM data are useful for coastal studies. Their specifications\(^12\) are given in Tables 1 and 2. The main advantage of OCM data is that their extensive spatial and temporal coverage enables us to study basin-scale processes. The SSC is retrieved using the regional bio-optical algorithm\(^13\) and retrieved values are validated with in situ data. The SSC maps are corrected with ground control points to ensure geographic accuracies. The river discharge and tidal data are collected from the literature\(^15\) and Indian tide tables.

The OCM regional bio-optical algorithm is as follows.

\[
TSS (Total suspended sediment) = 25 \times \exp^{(2.36 + 0.931 \times X_s)}
\]

where \(X_s = (R_n555 - R_n670) \times (R_n555/R_n490)\), with \(R_n\) being the remote sensing reflectance in the corresponding channel.

The SSC map for the east coast of India is prepared by merging two Oceansat-I OCM scenes (13 and 14) covering the western boundary of the BOB. These time-series SSC data (1999–2005) cover the southwest and northeast monsoons and post-monsoon periods on a regional scale. The regional SSC distribution shows seasonal gradient during monsoon and inter-monsoon periods, following the general circulation pattern in the BOB\(^16\). However, there are localized variations in the SSC distribution at the river mouths, bays and tidal inlets controlled by tidal and fluvial currents. For convenience, the entire east coast of India is divided into three sectors: North, Central and South (Figure 1a).

The northern sector remains a high SSC region throughout the year. The Ganga, Brahmaputra, Baitaranii and Mahanadi are the four major rivers from the east coast India that discharge two-thirds of the sediments into the BOB during the southwest monsoon (June–September). The coastal circulation during the period is northward and the net sediment transport is from south to north. In this process, a large amount of sediment is transported towards sandy heads, that takes a turn clockwise and moves south (Figure 1b). Large-scale fluvial discharge also brings large amounts of sediment and contributes to the high SSC in this coast throughout the year. During the northeast monsoon, the coastal sediment drifts southward with an anticlockwise movement (Figure 1c) from sandy heads into the Gahirmata coast. Under mesotidal condition, this sediment is carried as far as 20°E lat. as seen in the satellite data (Figure 1d). This phenomenon moves the lithogenic plumes for kilometres into the deeper shelf region (Figure 1e). In the fair weather non-moon season, though the fluvial discharge is the least winds favour upwelling. This causes vertical density gradient in the nearbed region. It modifies the internal tide effects causing suspension of sediments oscillating back and forth by spring and neap tidal cycles (Figure 1f). In shallow depths, presence of along-shelf flow induced by the wind significantly increases the bed stress leading to enhanced sediment resuspension\(^18\).
In the central sector, Godavari and Krishna are the two major rivers discharging large quantities of sediment during the southwest monsoon. Most of the sediments are in the fluvial environment and are transported as suspended load in the micro tidal conditions. In the near-shore, littoral sediment transport and boundary currents propagate suspended load (Figure 2a). Though high sediment concentration is present all along the east coast of India, the offshoot of the plume is present at the Krishna coast, where the coastal orientation is E-W. Plumes of suspended sediment are jettisoned-off the coast up to 250 km into the deep shelf (Figure 2b) by the combined forcing of long shore, coastal and geostrophic current during February–May.

In the southern sector, high suspended sediments are found at the tidal inlets, namely Pulicat lagoon inlet, and Vellar and Coleroon estuaries during the northeast monsoon. The stretch of Palk Strait to Gulf of Mannar (GOM) shows high SSC throughout the year, in spite of meagre river discharge, as the sediments from the east and west coast drift into this region and are largely deposited permanently in the sand banks, numerous shoals, sand spits and islands. There are two circulations of water mass observed in the BOB: clockwise circulation during the southwest monsoon and the counter clockwise circulation during the northeast monsoon. Sediments from the east and west coast move into Palk Bay through the GOM during northeast and southwest monsoons respectively (Figure 3a–d). The sediment transported from the north to south mostly sinks in the Palk bay region. Low waves inside the bay carry the beach sediments by littoral drift and deposit them in the surf zone as sand bars that protect the beach from the southerly waves, thus favouring the beaching-building process.

In the GOM, wave action is low most of the time favouring formation of sand dune in this region. Under low
wave action, the coral banks and sandy shoals cause re-suspension of bottom material through transiting wind during summer. Between the reversals of monsoon circulation (SW to NE) during October, the low SSC may be due to lull wind conditions (Figure 3 e–h).

The coastal sediment dynamics along the east coast of India follows the general monsoon circulation. However, the surface sediment transport and distribution are controlled by local conditions like tidal currents, littoral currents (along shore and on/offshore) and fluvial currents. The coastal sediment dynamics is also influenced by open ocean phenomenon like geostrophic forcing.


Received 6 November 2007; revised accepted 2 April 2008