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Research papers

Meteorological aspects of mud bank formation along south west coast of India

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ABSTRACT

The study mainly intends to investigate the meteorological aspects associated with the formation of mud banks along southwest coast of India. During the formation of mud bank, the prominent monsoon organized convection is located in the equatorial region and relatively low clouding over Indian mainland. The wind core of the low level jet stream passes through the monsoon organized convection. When the monsoon organized convection is in the equatorial region, the low level wind over the southwest coast of India is parallel to the coastline and toward south. This wind along the coast gives rise to Ekman mass transport away from the coastline and subsequently formation of mud bank, if the high wind stress persists continuously for three or more days. As a result of the increased alongshore wind stress, the coastal upwelling increases. An increase in chlorophyll-a concentration and total chlorophyll can also be seen associated with mudbank formation.

1. Introduction

Mud banks are calm regions of near shore sea water devoid of any significant wave action due to very high concentrations of sediments in suspension. They are unique and occur at only few places in the nearshore waters of the world oceans. They are generally associated with the dispersal pathways of rivers that discharge large quantities of fine grained sediments. Abundant supply of fine grade sediments is the most important factor in facilitating the formation of muddy coastal deposits of various types. Rivers with high concentrations of fine suspended sediment loads are a prime source of sediment to form muddy deposits in the coastal zone. Longshore redistribution of sediments from high discharge rivers may lead to the formation of significant stretches of muddy coasts downdrift of sediment sources (Wright and Nittrouer, 1995). Secondary factors favoring the development of muddy coastal deposits are a broad gently sloping coastal plain and adjacent shelf topography, macrotidal conditions and the absence of energetic oceanic wind waves.

Extensive well formed, broad muddy coasts are present around the Yellow River delta in the Bohai Sea of China, along the east coast of the Americas, with the Amazon River mouth and the northern coasts of Guiana. Muddy coast is widely evident in åthe tropical and monsoonal countries of Asia, including much of the coasts of India, Bangladesh, Thailand, Malaysia, Indonesia, the Gulf of Papua and Vietnam. The northern coasts of Australia, as well as the islands of the Pacific including New Zealand, New Guinea and even the coral reef islands, contain areas of muddy coast. For the African continent muddy coast occurs mainly within the tropical belt of both the east and west coasts. However, muddy coasts tend to be particularly conspicuous in tropical zones, especially in the Asia region and the muddy coastal deposits of largest extent are associated with major continental river discharges (Terry et al., 2002).

The 1600 km coastline downdrift of the Amazon River is the longest mud shoreline on Earth. The Amazon water is advected northwestward along the Guianas coast as a buoyant surface plume by interaction between the North Brazil current, easterly trade winds, and the cross shore, semi-diurnal tidal currents (Curtin, 1986; Lentz, 1995). As a generalization, the greater the freshwater discharge, the higher the delivery rate of fine-grained sediment and the more extensive the muddy coastal deposits, but with allowance for geological and climatic conditions of the drainage basin (Terry et al., 2002). The rate of sediment delivery alone is not the only factor responsible for the formation of a muddy coast, although it is a necessary requirement. Coastal processes, in particular a high tidal range and a low wave energy environment, promote the formation of extensive mud deposits along low gradient coasts in the presence of high riverine sediment delivery. Besides sediment supply, a primary oceanographic

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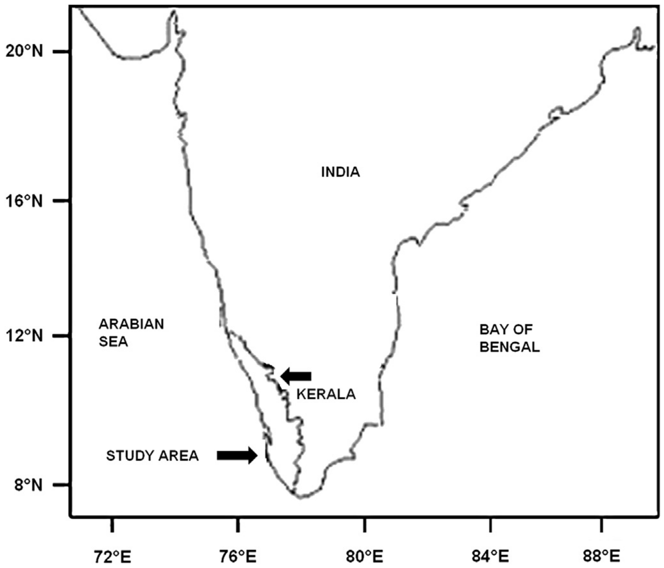

Fig. 1. The study area along the south west coast of India.

factor favoring the formation of muddy coasts is a macro tidal range, i.e. a tidal range greater than 4 m. A high tidal range and the associated strong tidal currents provide mechanisms where by silts and clays are trapped along the shoreline and form a muddy coast. The main reason for the development of muddy coasts in macro-tidal environments is a shore directed dispersive sediment transport explained by the correlation between current and sediment (and salt) concentration variability. The magnitude of this dispersive shoreward flux increases with the intensity of tidal currents flats (Kjerfve, 1986).

Along the Indian Coast the coastal geomorphological processes are influenced by a number of environmental factors, primarily due to geological, meteorological and oceanographical factors that vary from one sector of the coast to another (Tatavarti et al., 1999). The coastal waters off the southwest coast of India (especially the Kerala coast, Fig. 1) draw special attention because of the formation of mud banks at certain locations mainly during the southwest monsoon period (June–September). The dimensions of these mud banks vary between 2 and5 km in the alongshore direction and 1.5–4 km in the offshore direction (Kurup, 1977). They have significant impact on the socioeconomic life of people, as this phenomenon is usually associated with very high biological productivity and increased fish catch.

Off the southwest coast of India, many studies dealing with hydrographic features and physical processes involving mud bank formation have been reported (Gopinathan and Qasim, 1974; åNair, 1976; Kurup, 1977; Balchand, 1981; Silas, 1984; Mathew et al., 1995; Mathew and Baba, 1995; Faas, 1995; Manojkumar et al., 1998; Li and Parchure, 1998; Tatavarti et al., 1999; Narayana et al., 2001; Balachandran, 2004). These studies proposed various theories for the formation of mud banks in this region. For example, Kurup and Varadachari (1975) suggested that the influx of freshwater from various rivers into the southeastern Arabian Sea during the southwest monsoon keeps the mud in suspension for longer duration and causes mud bank. Kurup (1977) attributed the mechanism of mud bank formation to the activity of higher period waves and their refractivity pattern. He observed that the fineness of the bottom sediments in the near shore regions favor the formation of mud banks. Mathew (1992) explained the formation, sustenance and dissipation of mud bank in terms of measured nearshore wave conditions. Tatavarti et al. (1999) suggested that far infra gravity waves play an important role in the dynamics of mud banks off Kerala. Balachandran (2004) proposed a new hypothesis of a subterranean flow, which is believed to be coupled with activated trending faults and originate from the adjacent watershed separated from the sea by a narrow strip of land where submerged porous lime shell beds are present, could be a possible mechanism to initiate the mud banks. Tatavarti and Narayana (2006) conducted exclusive field experiments in the mud bank regions during monsoon and non-monsoon seasons to understand their dynamics and concluded that the prevailing local meteorological conditions are also important in their formation. Later, Dinesh and Jayaprakash (2008) noticed that the presence of mineral zaherite in the required proportion, mud deposit and strong monsoon waves combined with suitable bathymetry are prerequisites for the formation of mud bank.

Even though meteorological parameters, especially, wind and wave, play a dominant role in the formation of mud banks, studies in this regard are quite fragmentary. This is mainly due to non-availability of meteorological parameters in the region of mud banks, as the mud bank along Kerala coast is migratory and usually do not occur at the same location on all years. With the advent of high-resolution satellite based scatterometer datasets like QuikSCAT, the limitations of wind data could be overcome to a certain extent. Even though these scatterometer data have technical limitations like land contamination, data analysis has shown that QuikSCAT vector wind measurements are accurate within approximately 25–30 km of the coast line (Tang et al., 2004). The main objective of the present study is to analyze the meteorological aspects that are associated with the formation of mud banks along Kerala Coast. This improves our understanding of the role of various atmospheric forcing in the formation of this unique phenomenon.

2. Data and methodology

To understand the evolution and propagation of monsoon organized convection, daily GOES Precipitation Index (GPI) data with resolution $1^\circ \times 1^\circ$ is utilized (Huffman et al., 2001). In order to understand the role played by the meteorological factors in the formation of mud bank, wind at 850 hPa (~1.5 km above sea level) and at surface level (10 m) derived from NCEP/NCAR reanalysis (Kalnay et al., 1996) at a spatial resolution of $2.5^\circ \times 2.5^\circ$ latitude–longitude grid is utilized. For a better understanding, high resolution ($0.25^\circ \times 0.25^\circ$) satellite derived surface wind data (available from 1999 onward) taken from QuikSCAT is also utilized.

Satellite derived outgoing long wave radiation (OLR) is considered as a proxy for rainfall in the tropics, because areas with low OLR are associated with high cloud tops and hence deep convection. It is therefore an important parameter to analyze the phase of monsoon, viz-active, weak or break. Daily OLR data derived from NCEP/NCAR reanalysis is utilized to examine the phase of monsoon during mudbank formation.

The dates and location of mud bank formation are compiled from newspaper reports (Table 1). The mud bank formation is usually associated with increased biological productivity and increase in chlorophyll-a concentration (Nair et al., 1984). Chlorophyll-a, indicates the concentration of the photosynthetic pigment chlorophyll-a in the ocean, estuary and lake. Since the formation of mudbank is a highly localized phenomenon, high resolution ($0.083^\circ \times 0.083^\circ$) 8 day averaged Chlorophyll-a data from SeaWIFS sensor onboard Seastar satellite is utilized to verify the increase in phytoplankton growth associated with the occurrence of mudbank. NASA Ocean Biogeochemical Model (NOBM) assimilated daily total Chlorophyll data is utilized to study the daily evolution of total Chlorophyll during mudbank formation.

Alongshore wind stress is one of the most important atmospheric forcing for dynamic processes in the coastal environment.

Table1
Dates of mud bank formation along Kerala coast from 1990 to 2001 with alongshore wind stress (N/m^2).

Date of mud bank åformation	Place	Location	Alongshore wind åstress (τ_a) (N/m^2)	No. of consecutive ådays of increasing (τ_a)
22-06-2001	Kaipamangalam	10.31°N, 76.13°E	0.06	8
24-06-2001	Moonupeedika	10.31°N, 76.13°E	0.07	10
26-06-2001	Valappad	10.39°N, 76.09°E	0.09	13
	Perinjanam	10.31°N, 76.13°E		
18-08-2000	Palapetty	10.37°N, 76.12°E	0.03	3
19-08-2000	Azhikode	11.93°N, 75.31°E	0.03	3
31-08-2000	Vambaloor	10.26°N, 76.14°E	0.02	4
11-09-2000	Fort Kochi	09.97°N, 76.27°E	0.04	7
22-09-1999	Poonthura	08.44°N, 76.94°E	0.03	4
30-05-1999	Vizhinjam	08.36°N, 76.98°E	0.06	4
24-06-1998	Chennaveli	09.64°N, 76.28°E	0.02	4
09-07-1998	Puthiyappa	11.32°N, 75.74°E	0.02	5
03-08-1998	Beypore	11.18°N, 75.81°E	0.08	2
15-05-1997	Chavakkad	10.53°N, 76.05°E	0.03	3
28-07-1996	Purakkad	09.35°N, 76.36°E	0.02	3
19-06-1995	Ambalapuzha	09.38°N, 76.35°E	0.02	3
03-06-1994	Cherthala	09.70°N,76.31°E	0.01	5
12-07-1992	Chethy	09.62°N,76.29°E	0.03	5
07-06-1990	Vizhinjam	08.36°N,76.98°E	0.02	5

The along shore component of wind is calculated following Bakun (1973). The alongshore wind stress $\tau_a = \alpha\tau_y - \beta\tau_x$, where τ_y and τ_x are the respective northward and eastward stress components; $\alpha = \cos\phi$ and $\beta = \sin\phi$, where ϕ is the angle, counterclockwise from true north, of the large-scale coastline trend. τ_y and τ_x are given by, $\tau_x = \rho_a C d U_{10}|U_{10}|$ and $\tau_y = \rho_a C d V_{10}|V_{10}|$ here $\rho_a = 1.22$ kg/m^3 is the density of air; C_d is the drag coefficient, which is taken as a constant ($C_d = 0.0013$); and U_{10} is the zonal wind at 10 m and V_{10} is the meridional wind at 10 m. To study the time evolution of alongshore wind stress during mudbank formation, Hovmoller diagram is used. In this diagram, for representation purpose, only the magnitude of along shore wind stress is taken excluding the negative sign.

The daily mean coastal upwelling index (CUI) was downloaded from the Global upwelling index data group of NOAA's PFEG Live Access Server (http://las.pfeg.noaa.gov) for the Kerala coast å(8–12°N and 74–77°E), having 158° coast angle. CUI has been defined as the cross-shore Ekman transport per 100 m coastline, positive for offshore transport, i.e., upwelling conditions. The CUI is a measure of the volume of water that upwells along the coast.

3. Results and discussion

In this study we have analyzed 18 cases of mud bank formation along the coast of Kerala during the period 1990–2001. The dates and location of mud bank formation in this region obtained from the news paper reports are presented in Table1. It is observed that the mud banks occur mainly during the southwest monsoon season, consistent with the earlier studies (Nair, 1976; Kurup, 1977, Silas, 1984, Mathew and Baba, 1995 etc).

3.1. Chlorophyll distribution along mud banks

It is well established that the formation of mud bank is associated with an increase in phytoplankton growth and hence an increase in chlorophyll concentration (Kartha Krishna, 1984). Therefore, as a first step, the time evolution of chlorophyll-a concentration in this region in different years during the periods of mud bank formation is analyzed.

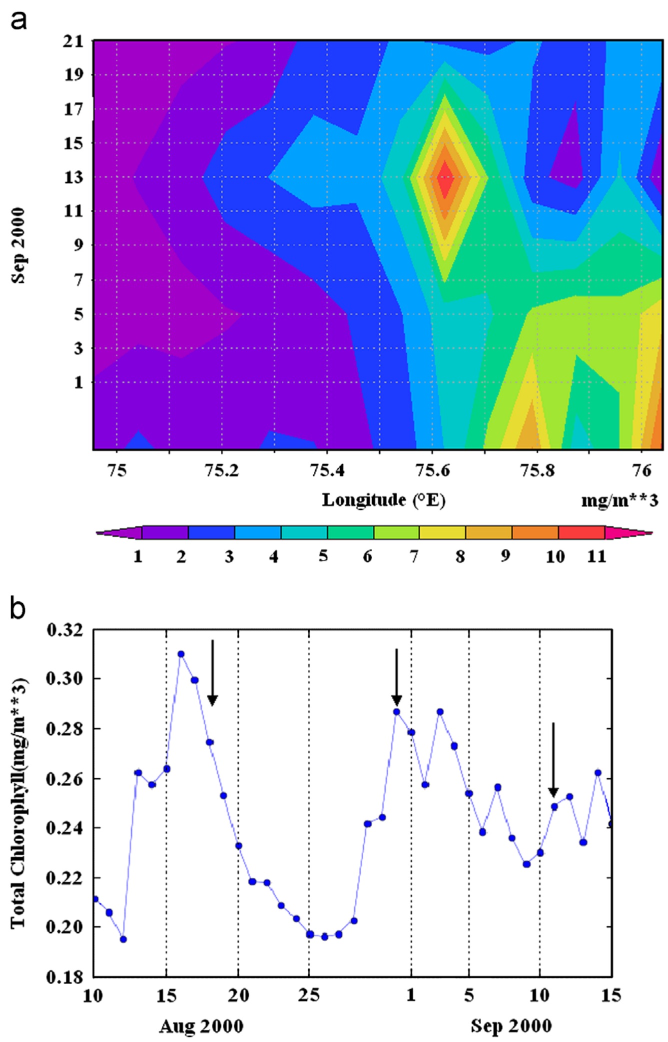

Fig. 2. (a) Hovmoller diagram of chlorophyll-a averaged over latitudes 9–11°N from 1 September to 21 September, 2000. (b) Area averaged time series of daily evolution of total chlorophyll obtained from NOBM for 10August–15 September, 2000. The arrows indicate the dates of mudbank formation.

The Hovmoller diagram of 8-day averaged chlorophyll-a data obtained from SeaWIFS sensor for the region 9–11°N during 1–21 September 2000 [Fig. 2(b)] clearly indicates an increase in the chlorophyll concentration between 9 and 18 September (>5 mg/m^3) with its maximum value of 9 mg/m^3 occurring on 12 September. The increase in chlorophyll concentration corresponds to the formation of mud bank on 11 September, 2000. Similar increase in chlorophyll concentration is observed in association with other mud bank formation days also. To confirm this and to analyze its daily evolution, area averaged time series of total chlorophyll obtained from NOBM for 1 August–15 September, 2000 is presented in Fig. 2(b). The total chlorophyll concentration continuously increases from 0.20 mg/m^3 on 10 August to 0.31 mg/m^3 on 16 August. This increase occurs just prior to mudbank formation reported on 18 and 19 August. Similar peaks in total chlorophyll concentration are observed on 31 August and 11 September coinciding with dates of mud bank formation. The increase in total chlorophyll remains high over the location for 2–3 days and decreases thereafter.

3.2. Propagation of monsoon surges

The mud bank formation mostly occurs during the southwest monsoon season (June–September). Therefore the prevailing åmonsoon situation will have an important role in the formation of mud banks. Fig. 3 represents the Hovmoller diagram of GPI precipitation data averaged over 65–80°E from 15 May to 30 September, 2001.

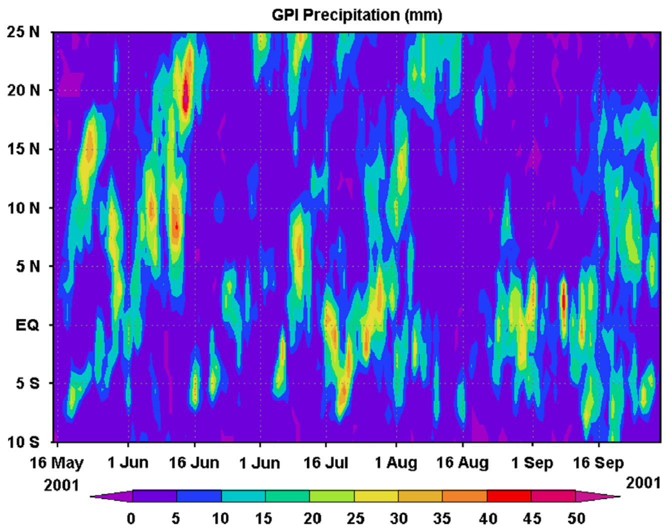

Fig. 3. Hovmoller diagram of GPI rainfall (mm) averaged over 65–80°E from 15 May to 30 September, 2001.

Monsoon surges are organized convection that forms over equatorial region [10°S–0°] and moves northward to Indian mainland. The northward propagation of southwest monsoon organized convection is accomplished in surges, each surge taking the rainbelt further northward. A series of such northward propagations occur at intervals of 2–6 weeks throughout the summer monsoon season (Sikka and Gadgil, 1980; Ding and Sikka, 2006). From Fig. 3, nearly 8–10 monsoon surges of varying intensity can be identified during the entire southwest monsoon season. åTo illustrate the evolution of a monsoon surge, as an example, three dates are identified in the year 2001 when the monsoon surge is at three different positions viz. (a) over equatorial region (1 June), (b) between 8°N and 15°N (11 June) and (c) north of 25°N (14 Jun) The surface wind characteristics over Arabian Sea during these three dates are presented in Fig. 4.

The strong cross equatorial flow and the high intensity wind along the Somali coast can be observed in all the three cases. During the southwest monsoon season, the mean wind direction over the Indian region is from the southwest. But, considerable departure from this direction appears from place to place. åFor example, Babu and Hamza (2007) using radiosonde data, studied the changes in wind direction during active and weak phases of monsoon over two locations: Trivandrum and Mangalore, both situated along the west coast of India. They observed that, over Trivandrum (8°29′N and 76°59′E) the wind is directed northwesterly in the lower levels and westerly above 1.5 km but over Mangalore (12°52′N and 74°53′E) the wind direction is always westerly in the active monsoon phase. During weak situation, the wind shows an additional along shore component up to 3 km in both the stations due to the forcing by the organized convective cloud band, which formed over the equatorial Indian Ocean as part of formation of a new surge.

It can be observed that when the monsoon surge is at the equatorial region, the wind vector along Kerala coast is directed toward the equator. When the monsoon surge is between 8°N and 15°N, the wind vector along the southwest Indian Coast is directed perpendicular to Kerala coast and most of the wind passes through Indian mainland and this situation is termed as active monsoon situation. When the monsoon surge is located north of 25°N, the wind over the Kerala coast is directed slightly northward. The maximum rainfall during such situation will be along the foothill of Himalayas (Raghavan, 1973).

It is found that during the formation of mud bank along the Kerala Coast, the location of the monsoon surge is always at the equatorial region. The wind speed during the active monsoon situation usually exceeds 15 m/s along the Kerala coast. The wind strength along the Kerala coast during the mud bank formation usually ranges between 5 and7 ms^{-1}. However, at the mudbank locations winds greater than 10 m/s are noticed in certain occasions. Apart from the strength of the wind, it is the direction of the

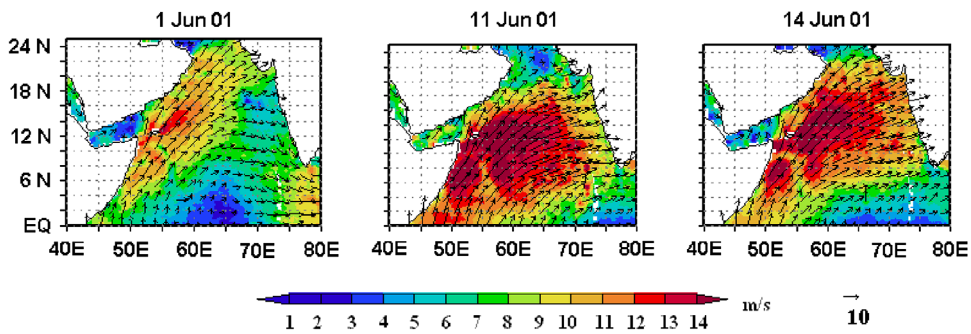

Fig. 4. Surface wind characteristics along southwest coast of India when the monsoon surge is over equatorial region (1 June), between 8° and 15°N (11 June) and north åof 25°N (14 June).

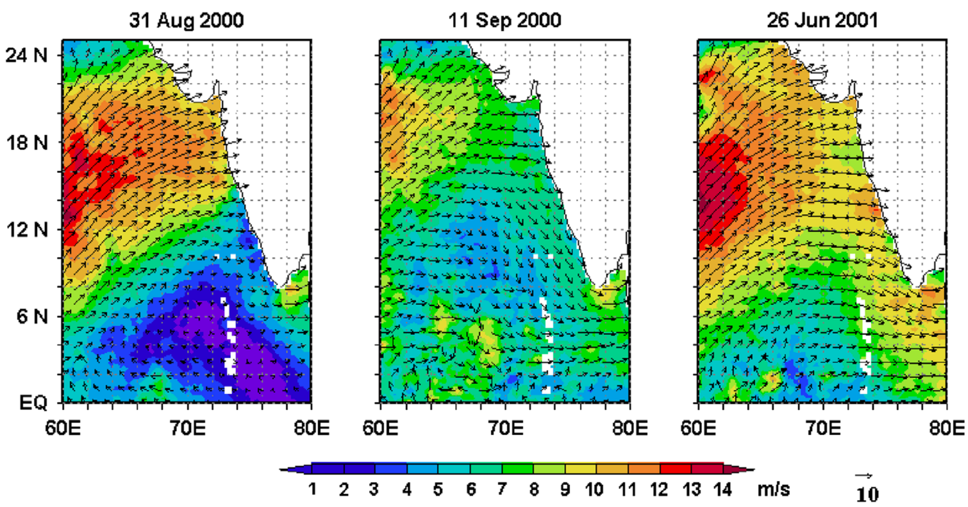

Fig. 5. Surface wind characteristics along southwest coast of India during three dates of occurrence of mud bank—31 August, 2000; 11 September, 2000; and 26 June 2001.

wind along the coast that really contributes to the formation of mud bank. As an example, the surface wind obtained from QuikSCAT during three dates of mud bank occurrence—31 August, 2000; 11 September, 2000; and 26 June, 2001 are presented in Fig. 5. The analysis of wind vector during mud bank formation shows that the direction of wind in most cases is parallel to the Kerala coast and directed to the south.

3.3. Outgoing long wave radiation

The outgoing long wave radiation (OLR) is an indicator of the cloudiness of the atmosphere overhead. It is therefore an important parameter to identify the phase of monsoon. The monsoon season typically consists of a sequence of active, weak/break phases. The active (break) phase is characterized by above-normal (below-normal) rainfall over the western and the central India and below-normal (above-normal) rainfall over the south-eastern and northern parts of India (Krishnamurthy and Shukla 2000, 2007, 2008). During an active phase, the southwesterly winds across the Arabian Sea and the Indian peninsula strengthen and the low-level cyclonic vorticity over the monsoon trough enhances, resulting in rainfall over central India and the Western Ghats. During a break period, the monsoon trough moves northward to the foothills of Himalaya producing rainfall over that region and in the southeastern part of India subsidence and dry conditions prevail over rest of India. Many Studies have considered different criteria for classifying the phases of monsoon (e.g. Webster et al., 1998; Goswami and Mohan, 2000; Krishnan et al., 2000; Annamalai and Slingo, 2001; Gadgil and Joseph, 2003). åOne such criterion based on OLR is used in the present study for the classification of active and break phases. The OLR values usually ranges between 150 and 270 W/m^2 during the southwest monsoon season. During the active phase of the monsoon, OLR value is less than 200 W/m^2 while during weak/break phases, it is higher than 240 W/m^2 over a large part of India (Prasad and Hayashi, 2007). Low values of OLR are typically due to deep clouds in the atmosphere and these regions indicate strong organized convection. Out of the 19 cases of mud bank formation considered in the study, the OLR analysis shows the presence of strong organized convection (OLR $<$ 140 W/m^2) over equatorial region and relatively low clouding (OLR>220 W/m^2) over Indian mainland in 15 cases. This indicates weak monsoon prevailed over Indian mainland during mud bank formation. During the remaining 4 cases, typically low OLR values ($<$ 140 W/m^2) were observed near the Kerala coast. This was associated with strong organized convection,

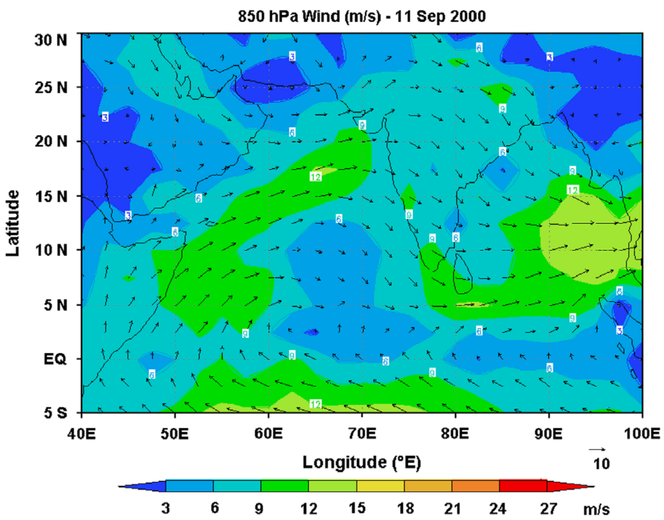

Fig. 6. Wind at 850 hPa (m/s) during mud bank formation on 11 September 2000.

which occurs during the formation of depressions and cyclones over Arabian Sea and Bay of Bengal. In both cases the low level wind flows through the maximum clouding zone where the latent heat release is maximum. The latent heat released causes the surrounding air to expand, resulting in increase of pressure gradient, which draws wind toward the equatorial region. This helps to have high alongshore wind component along the Kerala coast, which is a crucial factor for the development of mud banks.

3.4. Wind at 850 hPa

The wind at 850 hPa (~1.5 km above the mean sea level) gives an indication of the strength of the monsoon current. During active monsoon, the core of the Low Level Jet stream (LLJ) from central Arabian Sea passes eastward through peninsular India between latitudes 12.5°N and 17.5°N while during break monsoon, LLJ from central Arabian Sea moves southeastward bypassing India and passes eastward south of India between latitudes 2.5°N and 7.5°N (Joseph and Sijikumar 2004). The wind at 850 hPa during mud bank formation on 11 September, 2000 is presented in Fig. 6. The 850 hPa wind analysis indicates that weak monsoon situation prevails over Indian mainland during most days of mudbank formation.

3.5. Alongshore wind stress

Alongshore wind stress is one of the most important forcing functions for dynamic processes in the coastal environment. The offshore Ekman transport which is driven by the wind is directly proportional to the equatorward alongshore wind stress, the constant of proportionality ($\sim 3.95 \times 10^4$ s for this particular latitude range) being the reciprocal of the Coriolis parameter. To the extent that the flow divergence at the coast due to offshore surface transport is not balanced by convergence of alongshore flow, the water transported offshore is replaced by upwelling of deeper waters to the surface. Thus, variability in alongshore stress is reflected in variability in intensity of locally wind-driven coastal upwelling (Bakun and Mendelssohn, 1989). Fig. 7(a) represents the alongshore wind stress along Kerala Coast during 11 September, 2000. The alongshore wind stress along Kerala Coast is negative showing that the wind is directed equatorward throughout the coast (Fig. 7(a)). Hovmoller diagram of alongshore wind stress at the location 10.125°N–76.125°E from 1 September to 17 September, 2000 is shown in Fig. 7(b). This latitude–longitude corresponds to the location of available wind data free from coastal contamination, nearest to the location of mudbank formation on 11 September, 2000. In this diagram, for representation purpose, only the magnitude of along shore wind stress is taken excluding the negative sign. The high alongshore wind stress associated with mudbank formation on 11 September, 2000 can be seen in the figure. This increase in the alongshore wind stress can be noticed in all cases of mudbank formation. In most cases it ranges from 0.02 to 0.09 Nm^{-2}. The dates, location, alongshore wind stress and the number of days of continuous increase in wind stress associated with mudbank formation is tabulated in Table 1 The high wind stress continuously persisted for 3 or more days in almost all cases as evident from the table. Very high wind stress (~0.08 N/m^2) for a short duration (~2 days) was noticed in one case.

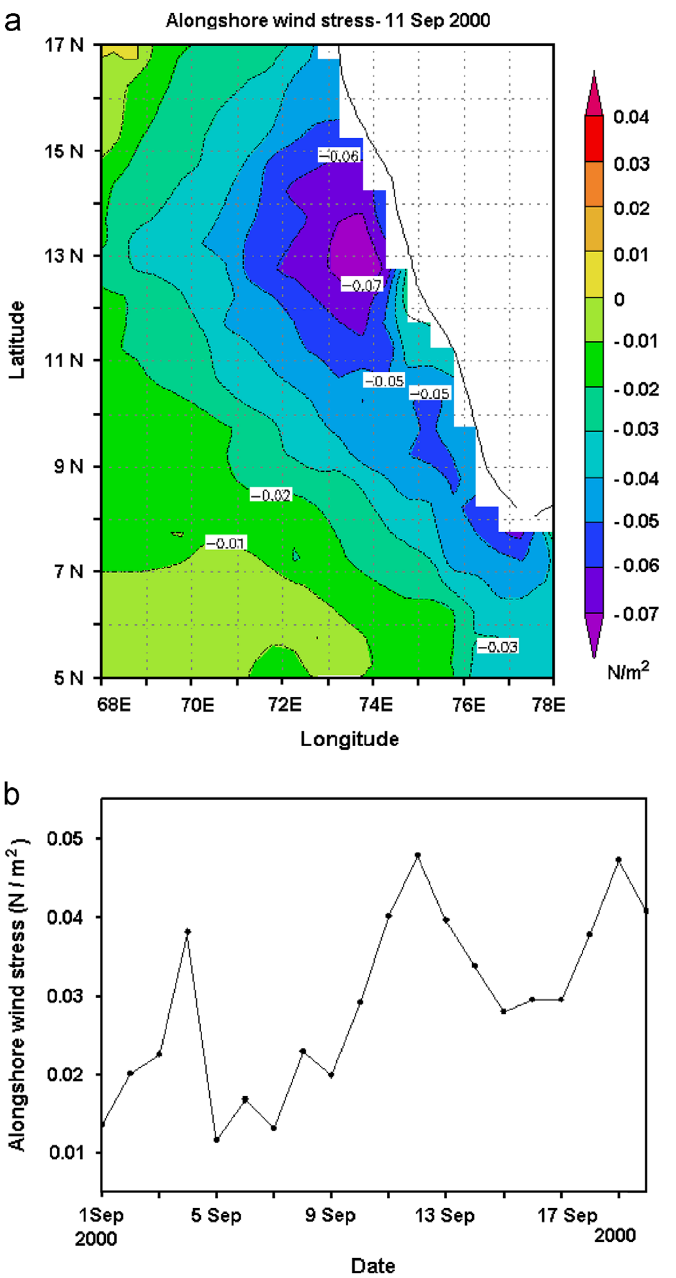

Fig. 7. (a) Alongshore wind stress along south west coast of India Coast on 11 September, 2000 and (b) Hovmoller diagram of alongshore wind stress at 10.125°N, 76.125°E during 1 September–20 September, 2000. The high alongshore wind associated with mudbank formation on 11 September, 2000 can be seen in the figure.

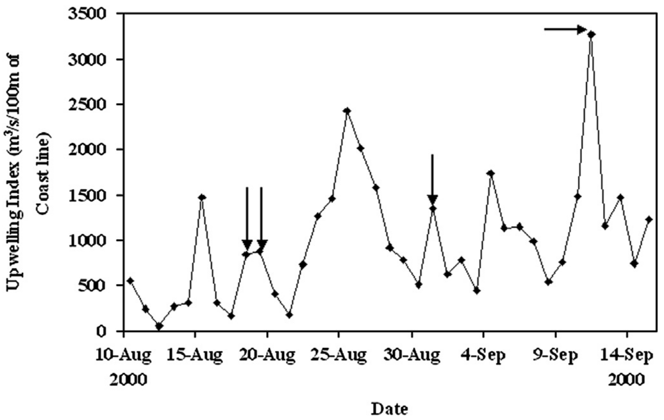

Fig. 8. PFEL derived coastal upwelling index during August–September, 2000. The occurrence of mudbanks on 18 August, 19 August, 31 August and 11 September, 2000 are indicated by the arrows.

3.6. Coastal upwelling index (CUI)

As a result of the increased alongshore wind stress, the coastal upwelling along the Kerala coast increases. The quantity of upwelled water along the coast is expressed in terms of coastal upwelling index. The positive values of CUI imply upwelling whereas negative values imply downwelling. Along the Kerala coast, CUI shows a clear annual pattern (figure is not included) with minimum during December–January (~−200 $m^3 s^{-1}$ per 100 m of coastline). It progressively increases from March (~0) to May (~600) and remains high till September (~400) with maximum during June–July (~1000) and from October onward it decreases. This high value during May–September is due to the high wind along this coast in the southwest monsoon season. Fig. 8. represents the PFEL derived coastal upwelling index during 10 August–15 September, 2000. The increase in upwelling index associated with the occurrence of mud banks on 18 August, 19 August, 31 August and 11 September, 2000 are indicated by the arrows. CUI is observed to increase during mud bank formation (Fig. 8). This is because the mud bank formation is associated with increased upwelling along the coast.

4. Conclusion

The study reveals that meteorological factors play vital role in the formation of mud banks along the Kerala Coast in addition to other dynamic forcing. An increase in chlorophyll-a concentration and total chlorophyll can be seen associated with mudbank formation. The maximum clouding zone during mudbank formation is located along the equatorial region coinciding with the location of monsoon surge. This increases the along shore wind component. This high wind stress continuously persists for 3 or more days in most cases. But very high intensity alongshore wind stress persisting for 2 days also caused mud banks in rare cases. OLR analysis shows that during the formation of mud bank, the maximum cloudiness zone is situated near the equatorial region. The low level wind flows through this zone. This helps to have alongshore wind component when the surge forms over the equatorial region. The surface wind has a component parallel to the coast. Apart from the strength of the wind, it is the direction of the wind along the coast that really contributes to the formation of mud bank. The wind is tangential to the coast on days of mud bank formation. The analysis of wind vector during mud bank formation shows that the direction of wind in most cases is parallel to the coast. It is noticed that the strength of the along shore component of wind is high during the formation of mud banks The analysis of 850 hPa wind shows that the wind core does not pass through the Indian mainland; this together with the OLR analysis suggest that the prevailing monsoon condition is weak on all cases considered. The coastal upwelling index increases during days of mudbank formation. This is because the mud bank formation is associated with increased upwelling along the coast.

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