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Tidal effects on bio-optical variability in Gulf of Khambhat using ocean colour monitor on-board Oceansat-2

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Abstract: Every moment, Gulf of Khambhat witnesses a huge load of sediments as well as tremendous amounts of domestic and industrial discharge. Simultaneously, its typical tunnel-like structure leads to one of the highest tidal ranges thereby causing unique churning of the estuarine environment. To understand the complex waters here, bio-optical variability per se, a study was carried out using OCM-2 data. The data was interpreted for two months with simultaneous observations of tidal amplitude and tidal range. Routine observations from OCM-2 data was found to be helpful in monitoring the area covered under sediments thereby affecting the bio-optical signatures. Identification of the permanent turbidity zone as well as the maximum turbidity extent within this time frame was carried out which revealed ~ 110km of the gulf as permanently turbid while the maximum extent reaches ~300 km.

Keywords: Gulf of Khambhat, OCM-2, low and high tide, bathymetry, bio-optical

1. Introduction

India has a coastline of about 7,500 km, with nearly 560 million people living in the coastal districts and union territories (iomenvis.nic.in). According to the naval hydrographic charts, the Indian mainland consists nearly of 43% sandy beaches, 11% rocky coast with cliffs and 46% mudflats and marshy coast. The coastal area accounts for a very significant share of India's economic infrastructure. On the other hand, they are also subjected to recurrent natural disasters such as cyclones and floods which often lead to substantial changes in physical and biological characteristics. The west coast of India is a region of high wave activity during the southwest monsoon (Sanil Kumar et. al., 2006). At about 1600 km, Gujarat on the west coast has the longest coastline amongst the Indian states (iomenvis.nic.in). It has two Gulfs viz. the Gulf of Kutch and the Gulf of Khambhat. Gulf of Khambhat is a shallow and complex natural basin formed by south to north penetration of Arabian Sea. The entire gulf is relatively shallow, compared to Arabian Sea, with the maximum water depth of about 30m (Giardino et. al., 2014). The gulf is intercepted by many inlets of sea and creeks formed by confluence of many rivers like Sabarmati, Narmada, Mahi, Tapi and Shetrunji. These rivers form estuaries and download huge volume of sediments into the sea (Deshkar et al., 2012). The concentration of sediments in the surface water of Gulf of Khambhat is greater than 4mg/l and at the bottom more than 8mg/l (Vora et al, 1980). The typical funnel structure of the gulf experiences high tidal variations due to the combined effect of geometry and bottom friction. Tidal range varies from 10 m at Bhavnagar, Gulf of Khambhat to 0.5 m along the peninsular tip of India (Giardino et al., 2014; Kumar and Kumar, 2010). The measured current speed is roughly more than 3 m/s in the Gulf (Kumar et al, 2010). The high tidal energy along with a large number of fine sediments brought by the rivers makes the water always turbid with high suspended load (Sinha et al, 2010). High turbidity influences the oxygen content of the water and light penetration, thereby directly affecting the aquatic life (www.snh.org.uk), corals (https://scholarspace.manoa.hawaii.edu) etc. Moreover, the rivers also drain tremendous loads of domestic and industrial wastes into the gulf. Together, these have resulted in the degradation of the environment and decline in biodiversity of the otherwise significantly rich gulf.

Therefore, regular monitoring of estuaries is important for conserving aquatic life. So, in this direction data from Ocean Color Monitor, on-board Oceansat-2 was investigated for studying the optical variability of watercolour due to tidal influence.

2. Methodology

2.1 Study Area

The Gulf of Khambhat, Gujarat, lies in the west coast of India and north of the Arabian Sea between 20"00N−22"30N, and longitude 71"00E−73"00E (Figure 1). The longitudinal stretch of the Gulf is about 115 km. It is a home of many major rivers like Mahi, Narmada, Sabarmati and Tapti and many other rivulets.

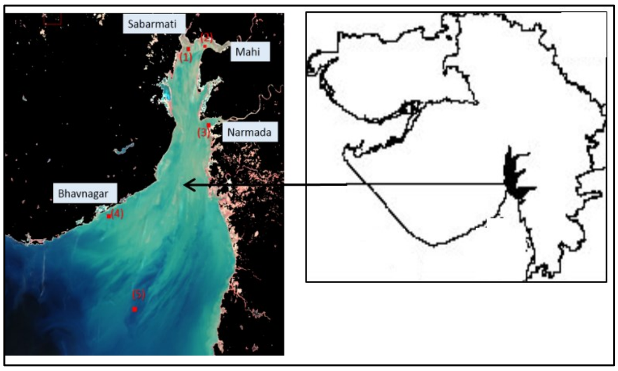

Figure 1: Study area-Gulf of Khambhat

2.2 Methods

Radiance data from Ocean Colour Monitor (OCM) onboard Oceansat-2 was used for this study. Oceansat-2 was launched in September 2009. It carried three payloads-OCM, ROSA and Ku band pencil-beam scatterometer. OCM-2 is almost similar to OCM-1 except the fact that band 6, located at 670nm is shifted to 620nm and band 7 is shifted from 765nm to 740nm. The broad specifications of OCM are as tabulated in Table 1 below.

Table 1: Specification of Ocean Colour Monitor on-board Oceansat-2

No. of bands	8 (402-885nm)
Bands	B1=404-424nm B2=431-451nm B3=476-496 nm B4=500-520 nm B5=546-566 nm B6=610-630 nm B7=725-755 nm B8=845-885 nm
IGFOV (at nominal altitude)	360x250 m
Quantization	12 bit
LAC at 360m and GAC at 4km	

The geocoded data was available every alternate day for the study site. In this study, OCM data was studied for a period of two months, starting from January 1, 2017, until February 28, 2017. Land areas were masked using the data values in band 8.

Gulf of Khambhat was routinely observed vis-a-vis tidal table of Bhavnagar at Oceansat passing time of 12.00 noon. Tidal tables were generated using model WXtide32 version 4.7 (http://wxtide32.com). The low, as well as high tide, were matched with the extent of turbid area in the gulf. Also, as tidal range is directly related to turbidity (Uncles et al, 2002), this parameter is also evaluated over the test time frame of two months. Turbid water extent was also studied vis-à-vis bathymetry of the gulf. Shallow water bathymetry map was generated using gridded data from General Bathymetric Chart of Oceans (GEBCO) of British Oceanic Data Centre (www.gebco.net).

3. Results

Starting from January 1, 2017, till February 28, 2017, data from OCM-2 was obtained every alternate day. A total of five control points were taken to observe the variation in turbidity and changes in radiance pattern with time and tidal effects. The points were taken at each of the confluence regions of rivers Sabarmati, Narmada and Mahi, near Bhavnagar and at the far end of the funnel (shown in figure 1).

The true colour image is shown in figures 2a and 2b give an overview of the ocean colour over a period of two months. At the onset, it can be said that the waters within the Gulf of Khambhat are highly turbid. This indicates huge sediment deposition from three major rivers- Sabarmati, Narmada and Mahi. At the mouth of the gulf, a sudden change of watercolour is seen which indicates shallow regions of phytoplankton presence and finally leading to deep water. High turbidity is observed at most of the times. It may be attributed to high tidal range during the day or the occurrence of low tide, thereby revealing the underwater surface

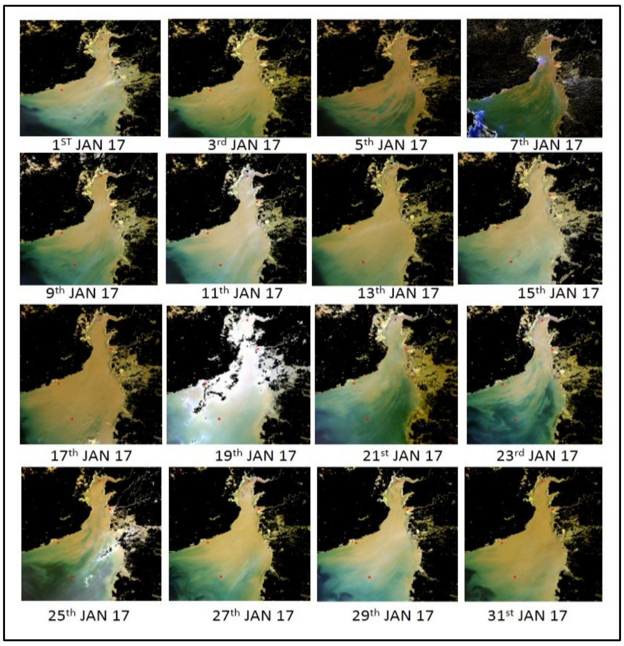

Figure 2a: OCM data focusing gulf of Khambhat along with five control points for the month of Jan-2017

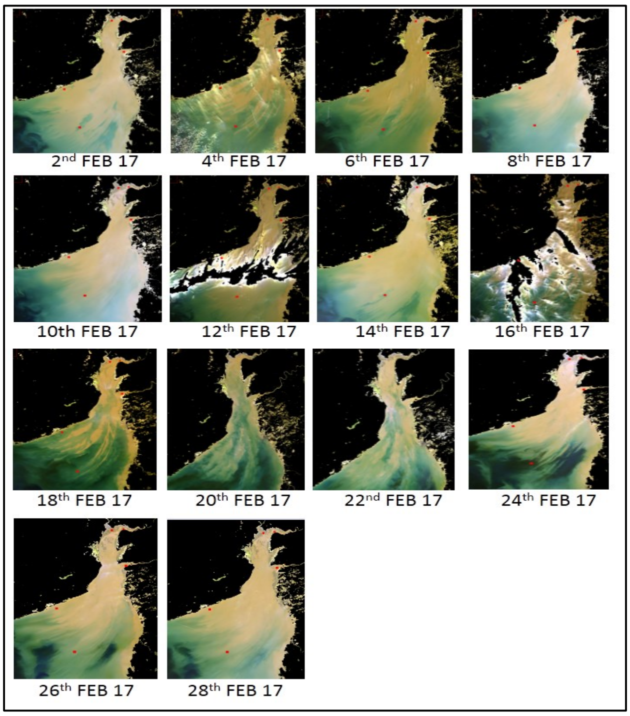

Figure 2b: OCM data of gulf of Khambhat along with five control points for the month of Feb-2017

To add to the visual clarity, density slicing of the study area was done, shown in figures 3a-b. Band 6 was used for density slicing and a total of five classes were made. It helps in identifying the boundary of sediment sweep under the tidal influences. Deep blue sea falls under 0-2 mW/sqcm/nm/str (blue) while highly turbid waterfalls under 4-5 mW/sqcm/nm/str (brown) class.

It may be seen from the figures that clear demarcation can be made for highly turbid and clean waters. Consequently, class distribution analysis was carried out as shown in figure 4.

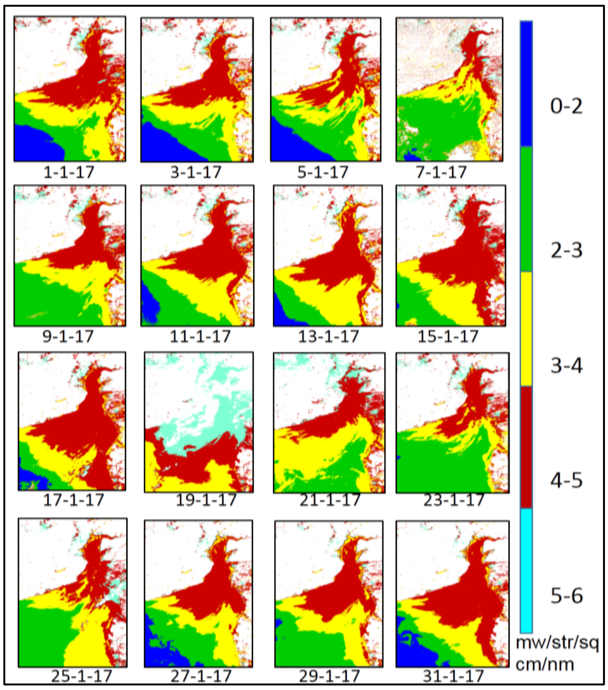

Figure 3a: Density sliced image for Gulf of Khambhat for the month of Jan-2017

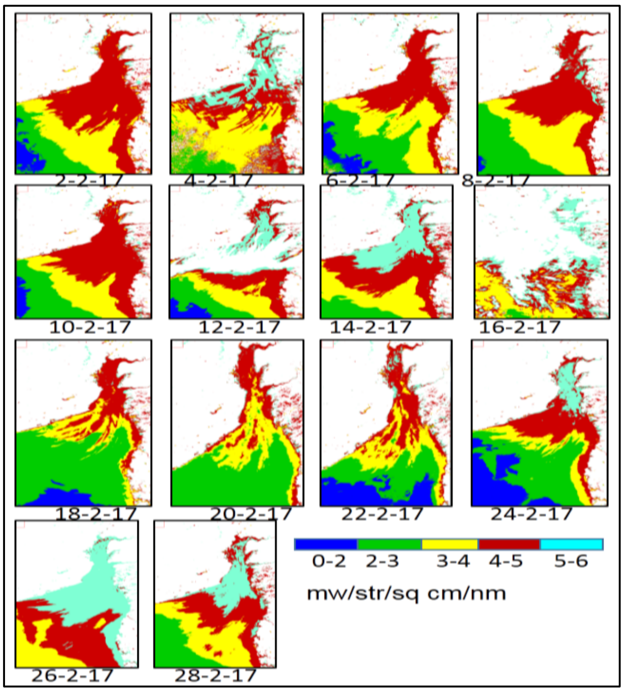

Figure 3b: Density sliced gulf of Khambhat image for the month of Feb-2017

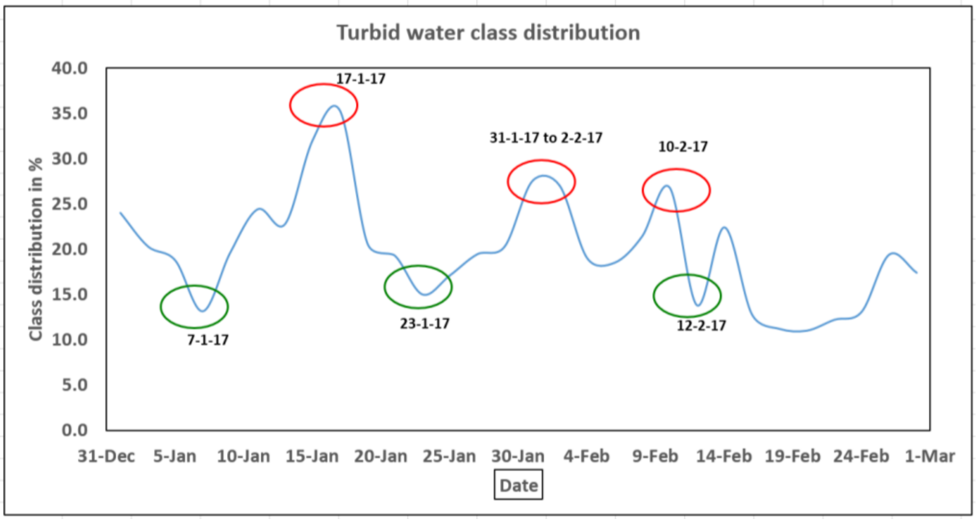

Figure 4: Turbid water plot for gulf of Khambhat during Jan-Feb 2017

For 17th January 2017, nearly one-third of the gulf was turbid while on 31-1-17 and 2-2-17, more than one-fourth of the gulf was turbid. This is shown in the three peaks of the graph, showing a high spread of sediments. On the contrary, three troughs are also noticed, where only around 10% of the gulf is turbid. This can be attributed to the occurrence of tidal cycle of significant amplitudes, shown in figure 6. For 17th Jan 2017, high tide of amplitude > 10m was encountered a couple of hours before the image capture. And when the water retreats, it takes away a lot of suspended soil with it. A similar pattern is seen for the other two dates. In case of the dates of low turbidity, high tidal amplitude is observed at the time of imaging. This exposes the massive tidal bars for the image on 7th January 2017. For the date of 12th Feb 2017, false trough is seen owing to a huge patch of cloud cover. This image is not considered for interpretation. From figure 5, it may be seen that the tidal bars correspond with the shallow regions of the gulf.

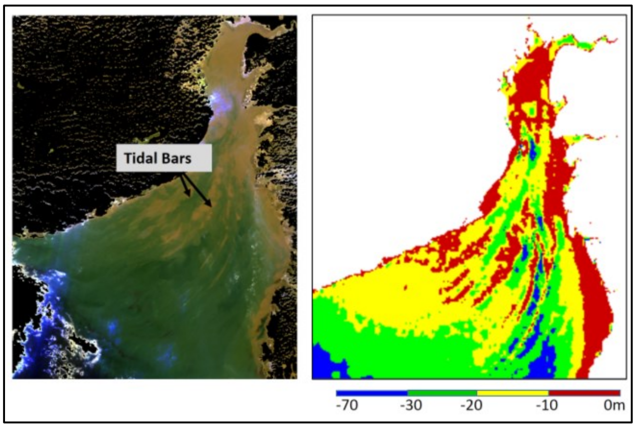

Figure 5: Tidal bars of image dated 7th Jan 17 (left) and bathymetry map (right)

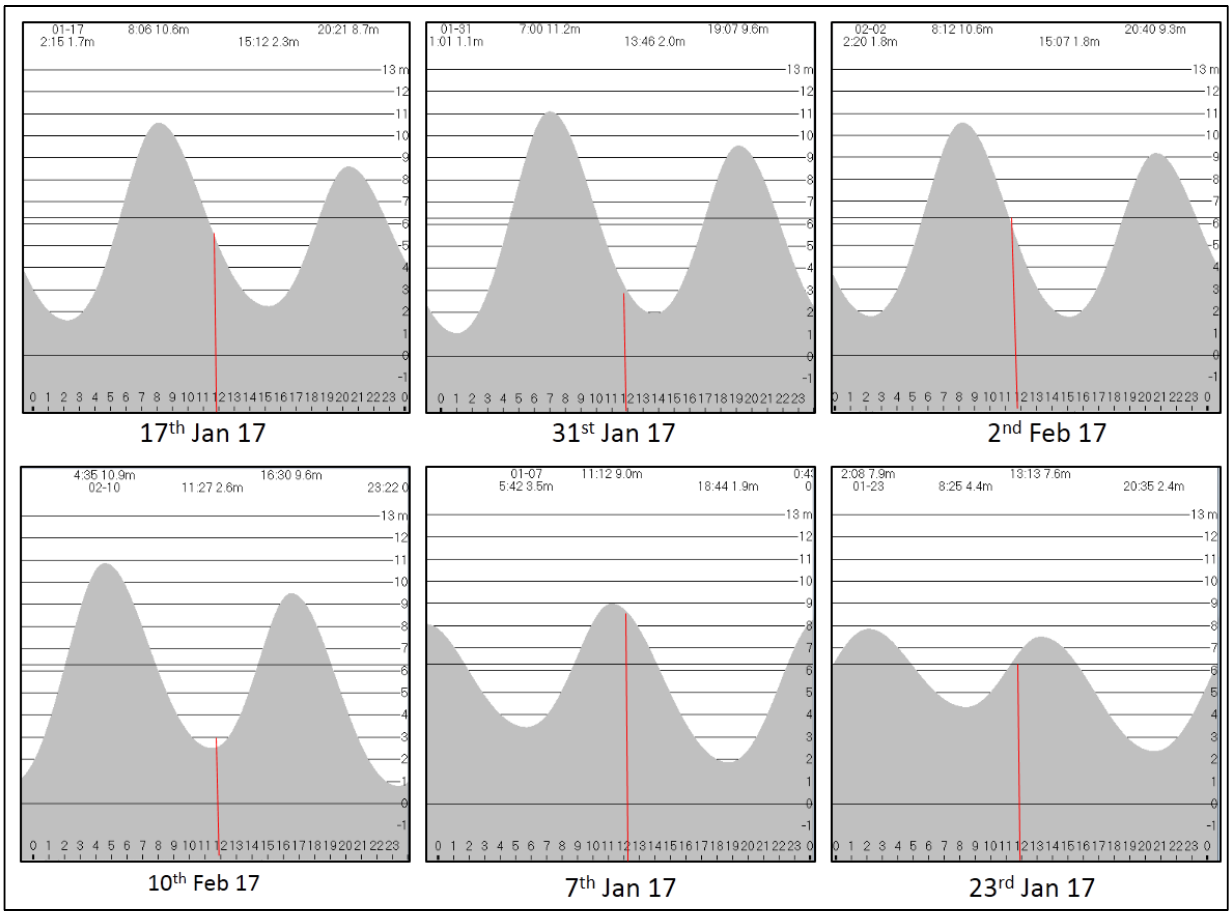

Figure 6: Tidal cycle for the dates of peaks and troughs

For the highest extent, > 300 km of the gulf is covered with turbid water while for the other case, ~150km of the gulf is turbid, for the tidal amplitude of <9m. It may be implied that in case of high tidal amplitude (>9m), the turbid extent of the gulf may further reduce. If one looks at the bathymetry map shown in figure 5, it becomes relevant to note that the turbidity dominates in the regions having bathymetry between 0 to -30m for the cases pertaining to case 1. In case 2, water remains highly turbid for bathymetry between 0 to -10m.

Furthermore, control points were observed for turbidity level, tidal amplitude and range for different dates, shown in table 2 in order to achieve more clarity about the interpretation. Here, visual observation of turbidity was recorded. Only two classes were made for this category- turbid (H) and non-turbid (L). On relating figures 4,5 and table 2 for January 1,3, 11, 13, 15, 17, 27, 29, 31 & February 2, 10,12, 14, 26 and 28, it is observed that at all control points, the turbidity level was high. This may be attributed to low tidal amplitude but high tidal range, thereby washing away huge loads of sediments. In cases like January 5, 7 and 9, where high tide is encountered, points 4 and 5 continue in low turbidity condition, particularly unaffected by the high tidal range

Table 2: Observations of turbidity level (low/high) and tidal amplitude at 12.00 noon for the time frames of study

No. of Control Point	Date	Turbidity level (Low(L) /(High (H))	Tidal amplitude, Tidal Range (m) (Bhavnagar)	Date	Turbidity level (Low(L) /(High (H))	Tidal amplitude; Tidal Range (m) (Bhavnagar)
1	Jan 1, 2017	H	3.2; 9.7	Feb 2, 2017	H	4.6; 8.8
2		H			H	
3		H			H	
4		H			H	
5		H			H	
1	Jan 3, 2017	H	4.5; 9.1	Feb 4, 2017	H	6.8; 7.6
2		H			H	
3		H			H	
4		H			L	
5		H			L	
1		H			H	

2	Jan 5, 2017	H	6.9; 7.5	Feb 6, 2017	H	8.4; 6.8
3		H			H	
4		L			H	
5		L			L	
1	Jan 7, 2017	L	7.8; 7.1	Feb 8, 2017	L	5.2; 8.4
2		L			L	
3		L			H	
4		L			H	
5		L			L	
1	Jan 9, 2017	H	7.5;7.1	Feb 10, 2017	H	2.7; 10
2		H			H	
3		H			H	
4		L			H	
5		L			H	
1	Jan 11, 2017	H	3.7; 10.4	Feb 12, 2017	H	2.1; 10.5
2		H			H	
3		H			H	
4		H			-	
5		H			H	
1	Jan 13, 2017	H	2.3; 11.4	Feb 14, 2017	H	2.7; 9.6
2		H			H	
3		H			H	
4		H			H	
5		H			H	
1	Jan 15, 2017	H	2.9; 11	Feb 16, 2017	-	4; 7.9
2		H			-	
3		H			-	
4		H			-	
5		H			-	
1	Jan 17, 2017	H	4.8; 8.9	Feb 18, 2017	H	5.8; 6
2		H			H	
3		H			H	
4		H			L	
5		H			L	
1	Jan 19, 2017	-	6.8; 6.7	Feb 20, 2017	L	7.2; 4.6
2		-			L	
3		-			L	
4		-			L	
5		-			L	
1	Jan 21, 2017	L	7.8; 5.3	Feb 22, 2017	L	6.1; 5.5
2		L			L	
3		L			H	
4		L			H	
5		L			L	
1	Jan 23, 2017	H	7; 5.5	Feb 24, 2017	L	4.2; 7.8
2		H			L	
3		H			H	
4		L			H	
5		L			L	
1	Jan 25, 2017	L	4.8; 7.3	Feb 26, 2017	H	2.4; 9.4
2		L			H	
3		H			H	
4		H			H	
5		L			H	
1	Jan 27, 2017	L	3.2; 9	Feb 28, 2017	H	1.7; 10.2
2		L			H	
3		H			H	
4		H			H	
5		H			H	
1		H				

2	Jan 29, 2017	H	2.6; 8.5	
3		H		
4		H		
5		H		
1	Jan 31, 2017	H	2.9; 10.1	
2		H		
3		H		
4		H		
5		H		

4. Conclusion

This study was predominantly aimed at broadly investigating OCM data for deriving meaningful interpretation of the oceanic waters. Hence, the focus was planned at the Gulf of Khambhat, which, pertaining to its unique geography, encounters heavy sediment load from three major estuaries and then opens up into deep ocean with wide funnel-shaped mouth. The area also encounters high tidal range due to structure for most parts of the month. The data was interpreted for two months with simultaneous observations of tidal amplitude at Oceansat passing time of 12.00 noon as well as tidal range within the time frame of twenty-four hours. It was found that for majority part of the study time frame, the waters towards narrow region of the funnel remain highly turbid, while the other part, following mixing with open water, becomes heavily rich in sediments. In future, this kind of study in larger time frames shall help in understanding the time-dependent variability in marine productivity of this region. It was also found that the turbidity dominates in the regions having bathymetry between 0 to -30m for the cases pertaining to case 1. In case 2, water remains highly turbid for bathymetry between 0 to -10m. Additionally, in waters of low turbidity, high tidal amplitude exposes the massive tidal bars, verified through the bathymetry of the region. Furthermore, this study indicates the use of OCM data for shoreline erosion studies also.

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