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A study on regional sea level variation along the Indian coast

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Abstract

Mean sea level variation is a global phenomenon with spatial variations in trends on regional levels. Among the key findings of IPCC, global mean sea level has increased and it will continue to increase in the coming century. The amount of sea level rise or fall and its effects at any given location is highly unpredictable. Increase in intense spells of precipitation, uneven spread of rainfall in space and time, damage due to storm surges and coastal flooding are increasing in frequency with increase in global warming trends and the changing sea level.
Increasing trend in mean sea level may cause inundation of low lying areas especially affecting small islands. In case of storm surges the scenario may be even worse. Bay of Bengal being an active breeding area of tropical storms, it might become devastating to cope up with the situation if the increasing trend in sea level continues. Mangroves, the natural barrier of coastal flooding and erosion, will be at high risk of submergence due to sea level rise. There is a need to understand the statistics of sea level changes and adapt to the situation in all possible ways.
This study focuses on changes in the mean sea level on a regional scale. The available tide gauge data (along the coasts of North Indian Ocean (NIO)) and satellite altimetry data are analysed to understand the changing trend of the sea level in the NIO. Though most of the tide gauges show a positive trend there exists a few which also shows a negative trend in the sea level. Also there lies a gap in the global estimates of sea level variation and the local average. For instance, based on the available long tide gauge data, it is found that the sea level at few stations showed a rise of nearly 1 to 8 mm/year whereas few stations experienced decrease in sea level by as much as 3 mm/year. It is therefore important to understand the increasing/decreasing trend of various tide gauge records individually before considering them in regional sea level variation studies. In this study only the tide gauges with longer periods of data with minimum gaps in data set are considered for analysis. Satellite altimetry data available since 1993 is used to investigate the changes in the sea level at locations where tide gauge data are not available.

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Keywords: *Sea level rise; climate change; Indian Ocean; Master Station Method*

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1. Introduction

Sea level changes is one of the many impacts of recent trend of changing climate (IPCC). Mean sea level (MSL) changes measured by coastal tide gauges contain contributions from real changes in ocean level and from vertical movements of the land upon which the gauges are situated (Woodworth, *et al.*, 1999).Changes in the ocean volume is observed in recent past which is mainly due to the increased sea surface temperature (SST). Rise in SST is a direct consequence of increased global temperature. This rise in SST has led to variations in the MSL differently in different regions. The MSL measured using tide gauges contain information on sea level which may be due to actual variations in ocean level or vertical land movements around the tide gauge stations. However, changes in MSL due to vertical movement of land are local phenomenon and are not considered in the present study. IPCC (2013) reported a global MSL of 1.7 mm/year for the period of 1901-2010, based on the analysis of available tide gauge data. It is possible that the global average might have suppressed the local variability. Variation in regional MSL may be different due to non-uniformity in the distribution of tide gauges which gives rise to the need of investigating sea level variations on regional scales. However, tide gauge distribution over smaller regions is sparse and many of the tide gauge records are not long enough for a reliable estimate of climate change impact on sea level (Unnikrishnan & Shankar, 2007). Literatures like that of Leuliette, *et al.* (2004), used tide gauge data from all over the globe to find spatial pattern of the MSL variability during 1950-2000. It showed a MSL rise of about 2 mm/year in the whole of North Indian Ocean (NIO), but a much higher value of 4 mm/year over Bay of Bengal region. This clearly indicates that there is a non-uniformity in sea level variation in the ocean basins which needs to be further investigated. Thus, a preliminary study is carried out to collate all the tide gauge records in the Indian region and obtain the local sea level variability in the Bay of Bengal and Arabian Sea. Local sea level status may be helpful in evaluating the coastal flooding scenario and in the design of coastal structures.

2. Data sets

Variation in MSL in few selected regions of NIO is analyzed using tide gauge and satellite altimetry data. The annual and monthly MSL tide gauge data used here are obtained from Permanent Service for Mean Sea Level (PSMSL) and the satellite altimetry data (available since 1993) is obtained from TOPEX/Poseidon, Jason 1 and Jason 2. According to Church *et al.*, (2006), the tide gauge data used for long term climate impact assessment should be RLR (Revised Local Reference) data and thus, all the tide gauge records used here are RLR data only. Out of the 28 available tide gauges along the Indian coast, 17 tide gauges are not functional currently and 5 tide gauges have severe data gaps (5-6 years of missing data) and hence are not included in the analysis. Only 6 tide gauges are useful as they show fairly good consistency in data. Tide gauge data used in this study are checked for consistency before inclusion in the analysis. Few stations have shown unusual increase/decrease in sea level (for example, Calcutta (Garden Reach), Sagar, Bhaunagar etc.). Garden Reach has a very long data record (1932-2010) but there exists a data gap of 10 years (not continuous). Therefore it could not be considered as a Master station in the present study (Master station method is employed). Though it is nearly 88% complete, it shows unusual and non-coherent increase in sea level trend. It shows a rise of 8 mm/year whereas the other tide gauges in the same region shows consistency with global trend with a rise of 2-4 mm/year. Similarly the station at Sagar (1937-1987) shows a negative trend of 3.8 mm/year. Neither this 94% complete dataset (currently nonfunctional) is useful as the trend is different from other tide gauges in the same region over the similar period of time. Tide gauge records are important in revealing the climate impact on trend in sea level as many of the tide gauges around the globe are available since many decades. It is unfortunate that the longer tide gauge data in the Indian region are few in number. Figure 1 shows how two of the longer records in the Bay of Bengal are no more useful in sea level measurement due to the absurdity in trends shown by them.

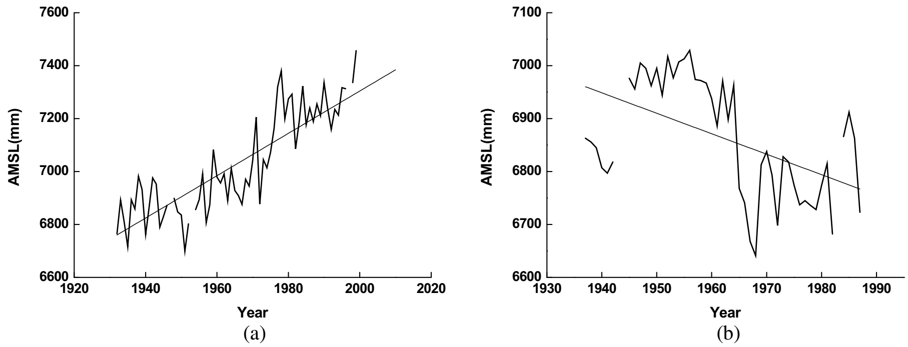


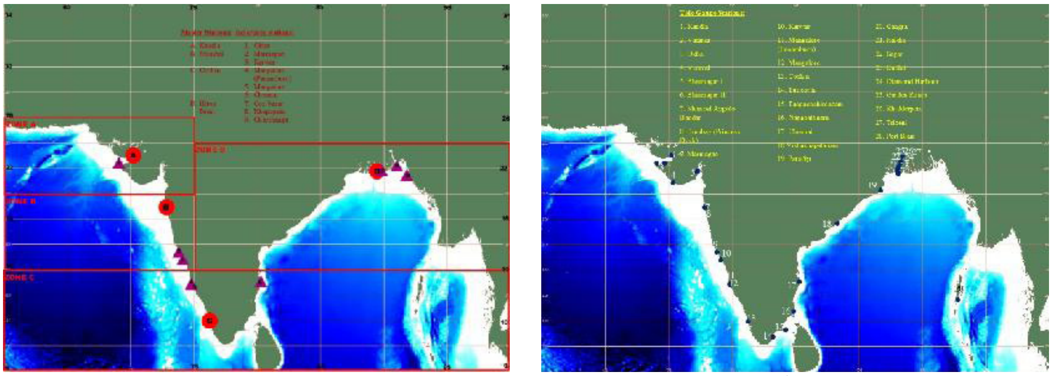
Fig 1 – AMSL at (a) Garden Reach (7.99 mm/year), (b) Sagar (-3.86 mm/year)

For a better climate impact assessment, a continuous data set is advisable which can be obtained from the satellite data. This data has a global coverage with high spatial resolution of 0.25°×0.25° which is useful for detailed analysis of sea level variability. However, the satellite data is available only since 1993, which is not considered to be long enough to interpret climatic changes in long term MSL variations (Church *et al*., 2006). Therefore, both tide gauge and satellite data sets are considered in this study to assess the local MSL variability.

3. Methods

Various methods have been used to analyze tide gauge data (Woodworth *et. al.,* 1999, Church *et. al*., 2006, Unnikrishnan *et. al.,* 2007, Palanisamy et al., 2014). However, for a preliminary local level study 'Master station approach' (Woodworth, *et al.*, 1999) is found to be more appropriate. This method applies to regional assessment of sea level changes. It allows grouping of tide gauges in a homogenous region. The study region considered here extends from 60° E – 100° E and 6° N – 26° N. Availability of longer tide gauge data sets in the study area is meager, which leads to the need of such a method that holds good for analysis of scanty and sparse data sets. In the master station approach the larger study area is divided into smaller regions/zones. The master station approach assumes that the regions or zones, considered for sea level change analysis, are homogeneous in nature. Hence, any change recorded in the master station should ideally apply to the other tide gauges in the region. Whereas with increase in distance between the stations, differential oceanographic sea level variations have to be considered. In this analysis, tide gauge records within stations at short distances are differenced. This method yields a relative sea level trend (Woodworth, *et al.*, 1999). However, use of any other analysis method over small regions may result in different trends. Other methods used in sea level analysis studies gives a trend in sea level variation over the entire region considered for the analysis. They are suitable for large scale study regions but to analyze sea level changes in comparatively smaller regions, master station approach is suitable. It considers smaller zones to investigate the trend in sea level change and hence gives a detailed distribution of sea level change index over a much larger area.

The study area is divided into four zones; namely, zone A, B, C and D (shown in Figure 2 (a)) depending on the geology of the region and distribution of tide gauges in the region (Figure 2 (b)). Among all the tide gauge stations in a zone, the station with longest available tidal record is defined as the master station. The tide gauge stations at Kandla in zone A, Mumbai Apollo Bandar (hereafter refereed as Mumbai) in zone B, Cochin Wellington Island (hereafter refereed as Cochin) in zone C and Hiron Point (a station in Bangladesh) in zone D are defined as master stations A, B, C and D, respectively. The tide gauge station at Kandla is located in a gulf region, stations B and C experiences open ocean hydrodynamics whereas station D is situated in deltaic region. Out of all the tide gauges in each zones only the long and complete data records are selected for comparison. The tidal records of stations (stations 1 to 9 in Figure 2 (a)) are compared with their corresponding master stations to obtain the local variability. Data with common period are selected and differenced to find the relative sea level trend, assuming that the sea level variability due to the changing climate is coherent over small regions (Woodworth, *et al.*, 1999). This comparison makes it easy to identify the tide gauges that shows unusual increasing/decreasing trend. Annual MSL data for Arabian Sea and Bay of Bengal, obtained from satellite (TOPEX/Poseidon, Jason1 and Jason2) is compared with that of global trends reported by IPCC to find any existing gap in the estimates. Out of the different satellite altimetry data types available, the data with seasonal signals removed have been used in this study. It is important to use both the satellite data and tide gauge data because the former has evolved only since 1993 and the latter has data gaps and does not cover the open ocean sea level variability. In order to find out the climate change impact on sea level it is important to consider both the data sets as one gives global coverage on a much finer resolution and the other holds historical information.



(a) (b)

Fig 2 – (a) Selected zones and location of master stations (b) Location of existing tide gauges in India

4. Results

Ideally, a tide gauge should have more than 50-60 years of data to indicate any effect of climate change. However, it is difficult to obtain this type of long term data sets in the study region. Only tide gauge station at Mumbai has a record of more than 100 years (1878-2010) and hence it is considered as a major reference point of study in the Arabian Sea. A comparison of data with common period between master stations and their respective reference sites is given in Table 1. Most of the sites near master station A are incomplete and not operational currently, only one site is comparable and it shows a negative trend, whereas the master station shows positive trend. This difference indicates the MSL at Kandla is higher compared to Okha. The difference may be due to difference in bathymetry in these two stations as Kandla is located in the inner region of the gulf or this may be a record error. Zone B and C are consistent with the global estimate of 1-2 mm/year (IPCC, 2013), however, the individual tide gauges in this region behave differently with the master station. The behaviour at each site needs further investigation to confirm the actual causes of variability. As this zone is open to the ocean dynamics more information on the behaviour of ocean towards the changes in climate is required to conclude the response of the tide gauges. Stations in zone D shows very high positive values which are different from the global estimates. This is a highly flooded zone and the absurdly high tide gauge information makes it difficult to estimate the flood accurately. Due to the deltaic nature of this zone, it is necessary to understand the sedimentation processes that might have affected the tide gauge information. The already existing coastal flooding problem in this region has inundated acres of land and a slight rise in MSL will be devastating to the mangroves and human population living on the coasts of Sunderban (Karim & Mimura, 2008).

TABLE 1: Relative trends at different sites with their respective master stations

Tide gauge stations	Comparison period (years)	Relative variability (mm/year)	Standard Deviation (mm)
Master station A - Kandla			
Okha	1975-2007	-2.076 ±0.47	29.15
Master station B- Mumbai			
Marmagao	1969-2010	0.032 ± 0.01	23.70
Karwar	1971-2010	0.734 ± 0.16	21.89
Master station C- Cochin			
Mangalore (Panamburu)	1977-97	0.646 ± 0.03	21.43
Mangalore	1953-76	1.354 ± 0.06	38.90
Chennai	1953-2007	0.505 ± 0.06	33.88
Master station D- Hiron point			
Cox Bazar	1979-2000	4.30±0.04	99.60
Khepupara	1979-2000	15.50±0.90	90.03
Charchanga	1979-2000	5.84±0.15	84.72

Master station C shows a much different trend when compared with other master stations (Figure 3). This difference may be due to any instrument error or presence of some particular hydrodynamic property in that location. However, the rise in sea level is more or less consistent in other stations in Arabian Sea. Master station D shows a jump in value for few years but is otherwise consistent. The average rise in AMSL in Bay of Bengal based on available tide gauge data (stations with consistent records are considered) is 1.92 mm/year and in Arabian Sea it is 1.72 mm/year (which are well within the global estimate of 1-2 mm/year (IPCC)). The difference in AMSL in the Bay of Bengal and Arabian Sea may be attributed to the wind forced coastal circulation and salinity gradient along the coast (Shankar & Shetye, 2001). However, these values are different from the average AMSL derived from satellite data.

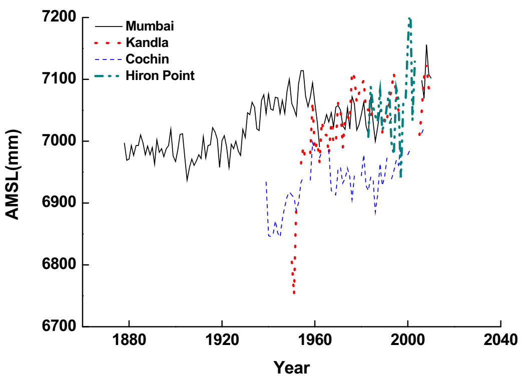
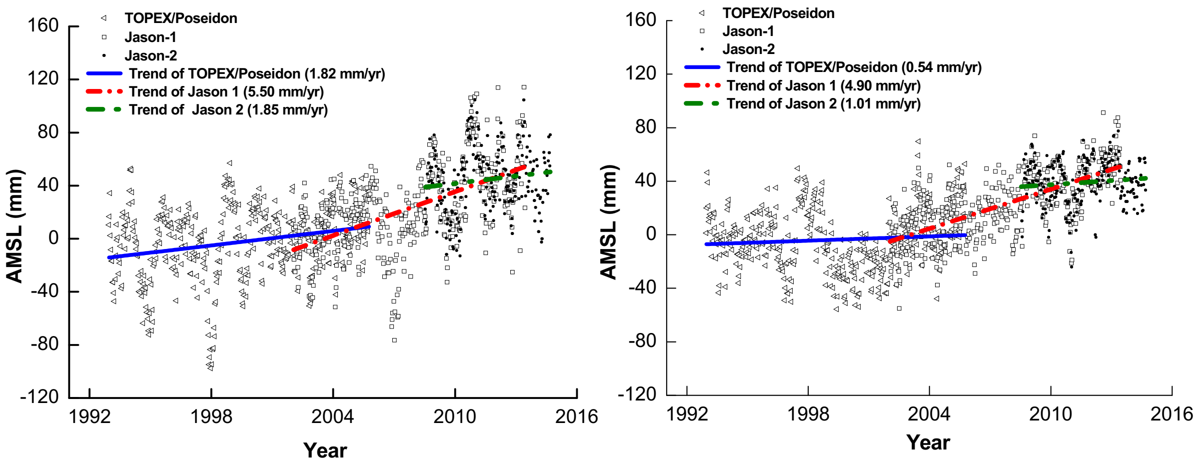


Fig 3 – AMSL (mm) at master stations Mumbai, Kandla, Cochin and Hiron Point

The satellite data used here includes TOPEX/Poseidon, Jason1 and Jason2 altimetry data. This data set is available since 1993 and has a global coverage with a resolution of 0.25°×0.25°. AMSL in Arabian Sea and Bay of Bengal is shown below (Figure 4). The trend in rise in sea level in Bay of Bengal is 3.05 mm/year and in Arabian Sea it is 2.15 mm/year, whereas, IPCC reported a global rise of 3.2 mm/year for 1993-2012. It is observed here that the satellite data over Bay of Bengal gives a more or less similar trend with that of the global estimate, whereas it is not the same for Arabian Sea. This calls for a detailed coastal hydrodynamic study in these local regions which show variations in trends from the global trend.



(a) (b)

Fig 4 – AMSL (mm) in (a) Bay of Bengal and (b) Arabian Sea

5. Conclusion

The tide gauge and satellite data in NIO region confirms a positive trend in the sea level. The trend in few places are comparable with the global estimates whereas some show unusual variations. Availability of only fewer long term tide gauge records in this region makes it difficult to compare the historical trends with other longer tide gauge records around the world. It is now evident from this analysis that in some locations the regional and global trends are not similar. Zone D shows a completely different trend compared to the other stations and the global estimate. The hydrodynamics of this zone is different from others as it is located in delta region. Similar difference is seen in tide gauge stations at Okha and Kandla, where each tide gauge behaves differently from the zonal trend. Also the satellite data gives different trends over regional and global scales. Thus, there is a need to investigate the local/regional MSL variability to understand the individual behaviour of each region towards climate change. A detailed regional MSL variability assessment will help in integrated coastal zone management and planning. However, only analysis of existing data is not sufficient to understand the reasons behind the regional variability in MSL. Proper hydrodynamic modelling on finer scales is required to understand the dynamics and regional variability of MSL due to climate change indices.

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