Long term variability in the tide gauge records along the coasts of the north Indian Ocean

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Introduction

Global sea-level rise has been relatively well studied by making use of the coastal tide gauge data that are available (Woodworth and Player, 2003) through the Permanent Service for Mean Sea Level (PSMSL). However, studies on regional sea level rise have not gathered momentum, similar to those on a global scale. As far as the north Indian Ocean is concerned, studies on sea-level rise are a few. This is because, not many tide gauge records in this region are long enough for a reliable estimate of sea-level-rise trends. However, the record at Mumbai (earlier known as Bombay), has a duration of more than 100 years.

Earlier attempts to study the sea-level-rise along the Indian coasts were made by Emery and Aubrey (1989) and Douglas (1991). Though studies on sea-level rise in this region are not many, studies on low frequency variability in the tide gauge records of the north Indian Ocean gathered momentum in the 90 ‘s. Clarke and Liu (1994) studied inter-annual variability of sea level along the coasts of north Indian Ocean. In a series of papers, for instance, Shankar (1998), Shankar and Shetye (2001) etc., studied the low frequency variability in the tide gauge records along the Indian coasts in relation to the dynamics of the north Indian Ocean.

Inter-consistency among tide gauge records

In a recent study, Unnikrishnan and Shankar (2007) made an analysis of all the records (see Fig.1 for location of tide gauge stations) having duration of more than 20 years to check for inter-consistency. The stations considered in the Arabian Sea were Aden (Yemen), Karachi (Pakistan), Kandla, Okha, Mumbai, and Kochi (India); the stations considered in the Bay of Bengal were Chennai (earlier known as Madras), Vishakhapatnam, Paradip, Sagar, Gangra, Diamond Harbour (Kolkata) (all in India), Hiron Point, Cox's Bazaar (both in Bangladesh), Rangoon (Yangon) (Myanmar), and Ko Taphao Noi (Thailand). Annual-mean relative sea level data for the above stations upto the year 2004, downloaded from the website of PSMSL, were used for the analysis.

Fig.2 shows a comparison of each individual record with that of Mumbai for stations in the Arabian Sea coasts, while in Fig.3, each individual record is compared with that of Vishakhapatnam for stations in the Bay of Bengal coasts. Only records longer than 40 years are presented. A linear correlation was performed for each Arabian-Sea record with that of Mumbai and for each Bay-of-Bengal record with that of Vishakhapatnam (Table 1); this includes stations with records longer than 20 years. All records on the Arabian-Sea coast, except those at Kandla and Kochi, are well correlated with that at Mumbai, and all records on the Bay-of-Bengal coast, except that at Sagar, are well correlated with that at Vishakhapatnam. Unlike the Mumbai, Karachi, and Aden records, the record at Kochi is well correlated with that at Vishakhapatnam (Table 1). Kandla and Kochi, whose correlations are not significant even at the 90% confidence level. The former station is situated in a region known as Kachch (Kutch), which experienced a massive earthquake in 2001 (see for instance, Jade et al., 2003), while the record at the latter (Kochi), nevertheless, is well correlated with that of Vishakhapatnam and has a statistically significant trend. The reason for the sea level at Kochi being correlated better with the sea level at Vishakhapatnam than with that at Mumbai is complex and can be explained in terms of the large-scale dynamics and salinity changes along the Indian coast. Low-salinity waters advected from the Bay of Bengal have a large influence on the salinity at Kochi and farther north along the Indian west coast (Shankar and Shetye, 1999; Han et al., 2001). A large fraction of the low-salinity waters are, however, trapped in the Lakshadweep High (Shenoi et al., 1999; Han and McCreary, 2001; Rao and Sivakumar, 2003), which forms off southwest India during winter, when the low-salinity waters are advected into the southeastern Arabian Sea; as a consequence, only a fraction of the low-salinity waters are advected farther poleward along the west coast to Mumbai. This results in the high correlation between Kochi and Vishakhapatnam, but in a lower correlation between Kochi and Mumbai. The record at Diamond Harbour (Kolkata) shows a steep rise, when compared to other long records in the region. This station lies in the delta of the River Ganga, whose subsidence rates known to be up to 4 mm yr^{-1} (Goodbred and Kuel, 200). Similarly, high rates of sea-level rise are found for the records at the Bangladesh coast (SMRC Report, 2000). The changes occurring in this region are partly associated with sea-level rise and partly due to the land subsidence.

Tide gauge station (duration of the record)	Number of years of data availability	Reference station for correlation	Linear correlation coefficient	Confidence limit (%)
Aden (1880-1969)	58	Mumbai (1878-1993)	0.68	99.9
Karachi (1937-1992)	39	Mumbai	0.31	95
Kandla (1954-1996)	40	Mumbai	-0.04	< 90
Okha (1975-2004)	22	Mumbai	0.67	99.9
Kochi (1939-2003)	54	Mumbai	-0.04	< 90
Kochi (1939-2003)	54	Vishakhaptanam	0.43	99.0
Chennai (1916-2003)	34	Vishakhapatnam (1937-2003)	0.62	99.9
Paradip (1967-2003)	20	Vishakhapatnam	0.91	99.9
Sagar (1937-1987)	48	Vishakhapatnam	0.22	< 90
Gangra (1974-2002)	25	Vishakhapatnam	0.88	99.9
Diamond Harbour (1948-2004)	55	Vishakhapatnam	0.46	99.9
Hiron Point (1983-2003)	21	Vishakhapatnam	0.75	99.9
Cox's Bazaar (1979-2000)	20	Vishakhapatnam	0.43	90.0
Rangoon (1916-1962)	25	Vishakhaptnam	0.34	90.0
Ko Taphao Noi (1940-2002)	58	Vishakhapatnam	0.29	95

Table 1: Linear correlation coefficient for the annual mean relative sea level for tide gauge records at stations in the Arabian Sea (Bay of Bengal) with that of Mumbai (Vishakhapatnam). The annual-mean sea level data upto 2004 are used. (From: Unnikrishnan and Shankar, 2007)

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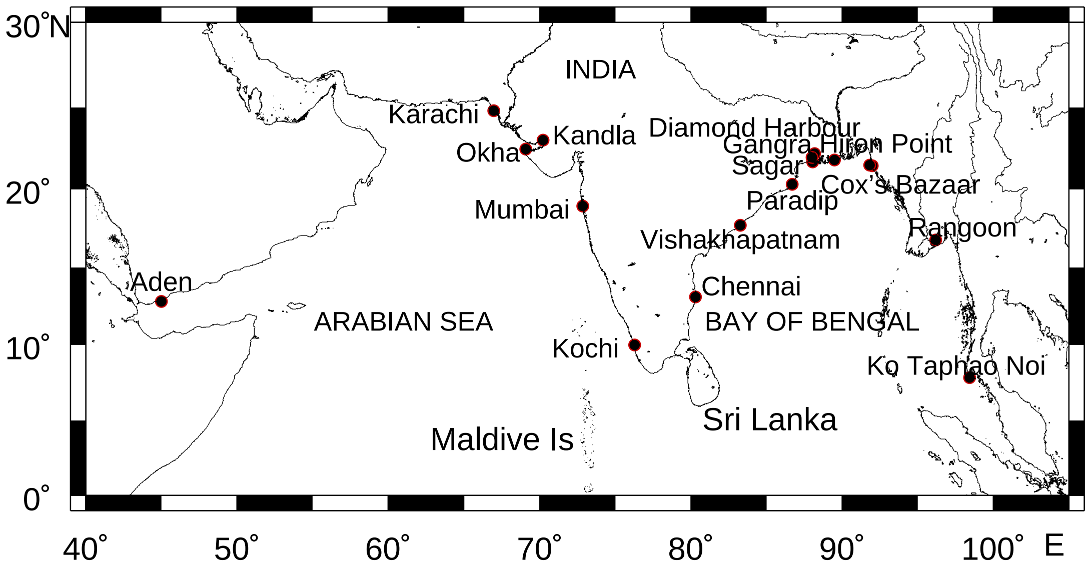

Fig.1: Location of tide gauges. Stations having at least 20 years of data are only shown.

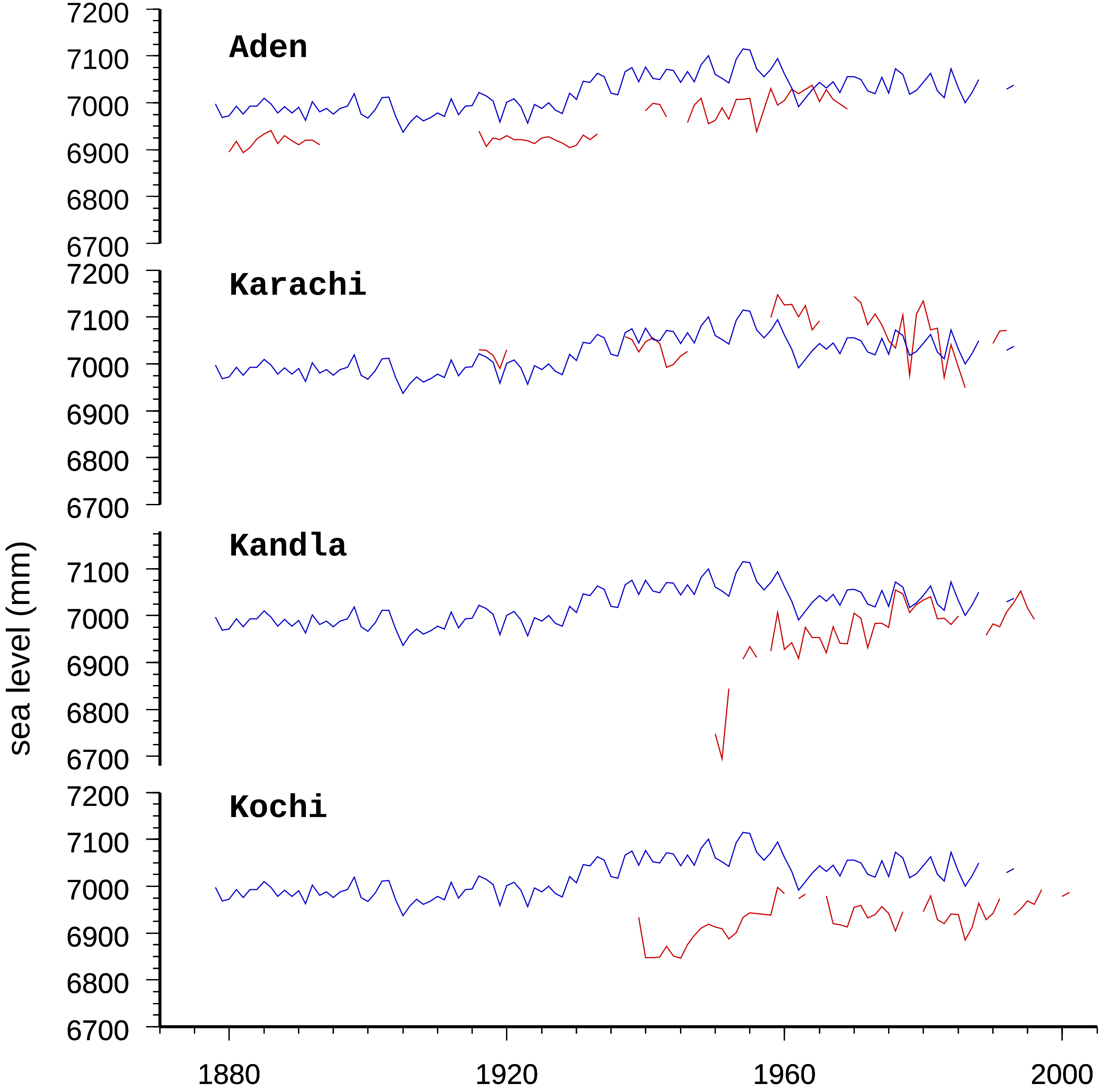

Fig.2: Tide gauge records (red) along the Arabian Sea coast compared with the Mumbai record (blue)

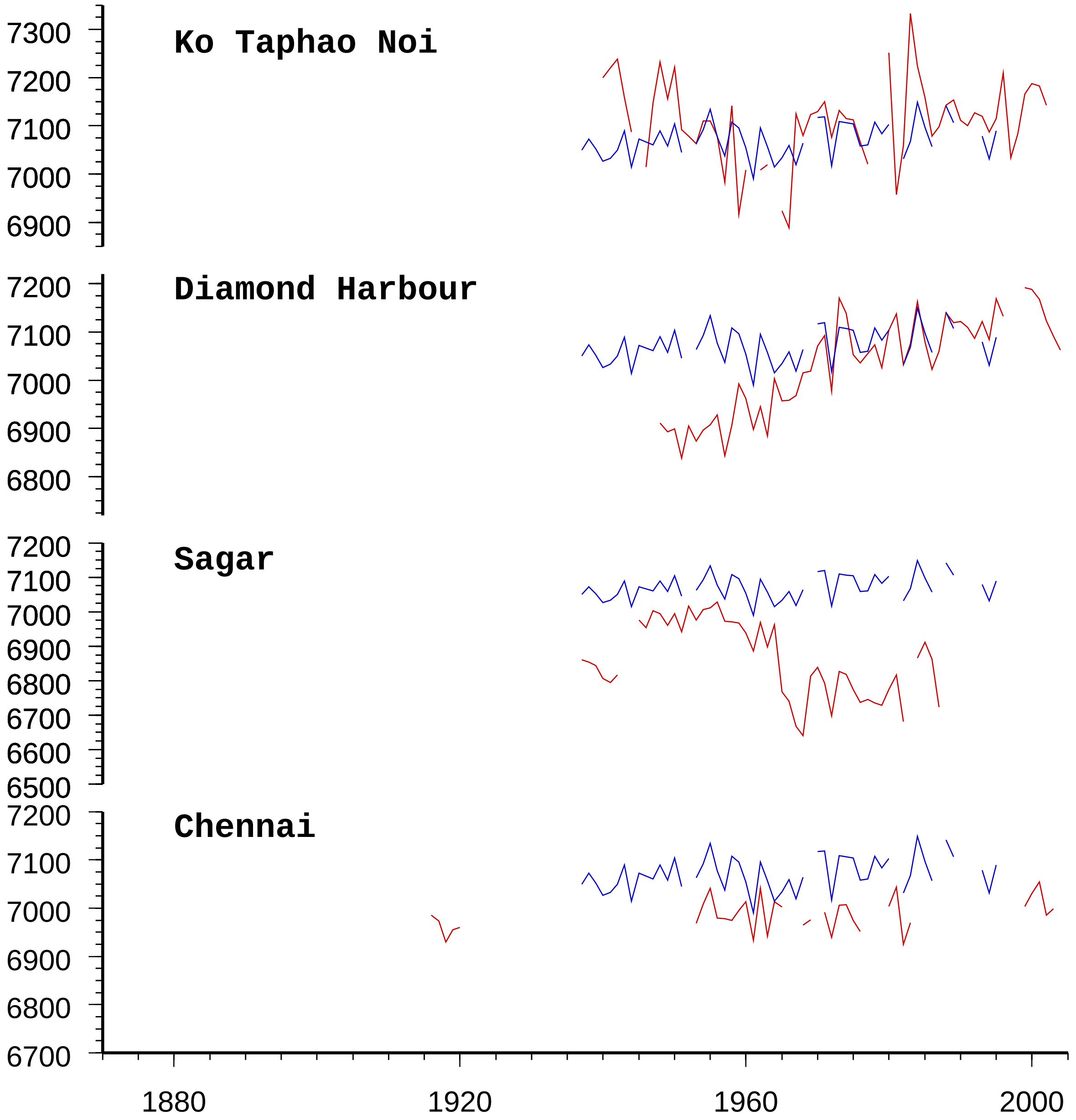

Fig.3: Tide gauge records (red) along the Bay of Bengal coast compared with the Vishakhapatnam record (blue)