5. Tide Gauges

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5.1 Introduction

Tide gauge measurements provide data for routine tidal predictions in ports as well as for extreme events such as storm surges and tsunamis. Along with satellite altimeter measurements, tide gauges also provide measurements used for sea-level rise estimates. This is particularly important for impact assessment in low-lying coastlines of south Asia as well as islands such as the Maldives in the Indian Ocean.

5.1.1 Current status of the network

Figure 5.1 shows a map of active tide gauge stations in the Indian Ocean, including those that supply quality-controlled monthly-mean sea level data to the Permanent Service for Mean Sea Level (PSMSL, http://www.psmsl.org) and those that supply real-time data to the Intergovernmental Oceanographic Commission's Sea Level Station Monitoring Facility(http://www.ioc-sealevelmonitoring.org), operated by the Flanders Marine Institute (VLIZ, Belgium). The stations shown as 'PSMSL only' include records without complete datum control, known as non-Revised Local Reference (non-RLR) stations, and many records of only short duration. Real-time stations have increased in number since the 2004 tsunami. There are 20 stations that have datum-controlled records (RLR) longer than 40 years that can be used for estimating long-term changes in sea level (shown in green). Unfortunately, most of them are in the northern hemisphere. Only two stations, namely Mumbai on the west coast of India and Fremantle on the west coast of Australia, have more than 100 years of data.

The spatial coverage of the Indian Ocean tide-gauge network is not as good as in the Atlantic and Pacific. Due to inadequacies in coverage, particularly in the southern Indian Ocean, long-term trends and variability at decadal and longer time scales are less well resolved.

Figure 5.2 shows the network of Global Navigation Satellite System (GNSS) stations co-located with tide gauges in the Indian Ocean, as stored at the SONEL (Service d'Observation du Niveau des Eaux Littorales) data center (http://www.sonel.org). GNSS measurements monitor changes in the level of the land on which the gauges are located and are necessary to place sea level measurements from tide gauges in an absolute, geocentric reference frame. Hence, there is a requirement for GNSS equipment to be co-located at GLOSS core network tide gauge stations (IOC, 2012). The Indian Ocean is particularly deficient in this respect. King et al.,(2014) has highlighted several sites as priorities for GNSS stations near to Indian Ocean tide gauges. Priority stations include Karachi, Aden, and stations along the Thailand coast, such as Ko Taphao Noi, where the tide gauge records are longer than 40 years but there is no GNSS station in the vicinity. In parallel to new installations, an effort should be made in making the data of the existing GNSS stations publicly available (the stations in red in Figure 5.2 are co-located GNSS stations for which no data are available on SONEL, mainly along the Indian, Indonesian and Australian coasts). There is also a particular need for long-term datum control within the tide

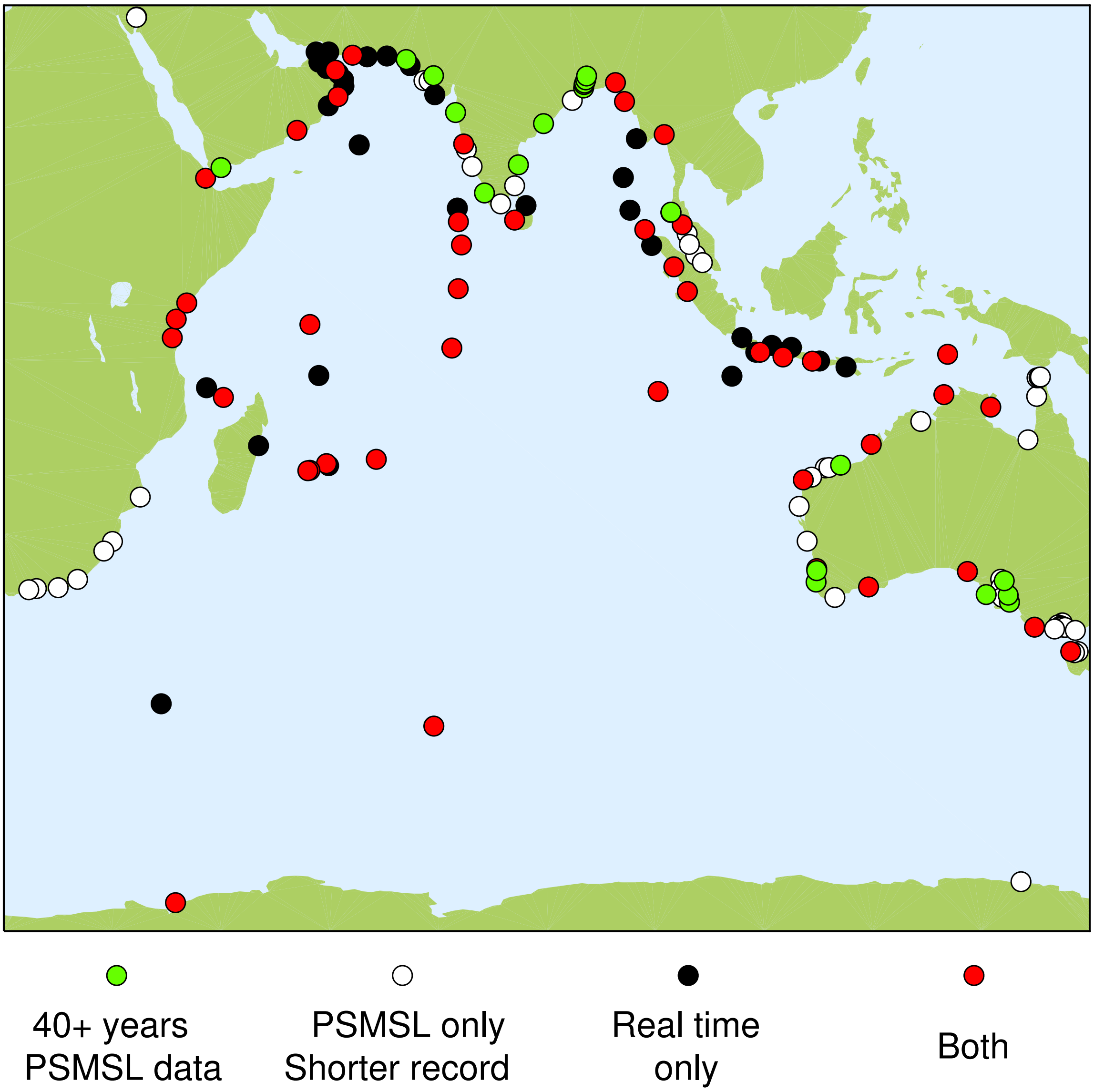

Figure 5.1 Active tide gauge stations in the Indian Ocean. PSMSL stations are considered active if data are available for 2011 or later. Real-time stations are considered active if they have supplied data in 2017.

gauge network and for ties between the tide gauges and GNSS equipment (Woodworth et al., 2017).

5.1.2 High-frequency data

The Indian Ocean tide-gauge network has been extended since the commencement of the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) following the 2004 Indian Ocean tsunami. This was achieved by upgrading some stations and with the installation of some new stations. There are now more than 100 tide gauges in the Indian Ocean (Global Sea Level Observing System (GLOSS) and non-GLOSS) that provide sea level data in real time (not quality controlled) via the IOC Sea Level Station Monitoring Facility. Higher-frequency, quality-controlled data (hourly values and similar) are available from the University of Hawaii Sea Level Center (http://uhslc.soest.hawaii.edu/). Tide gauge hardware with real time transmission has

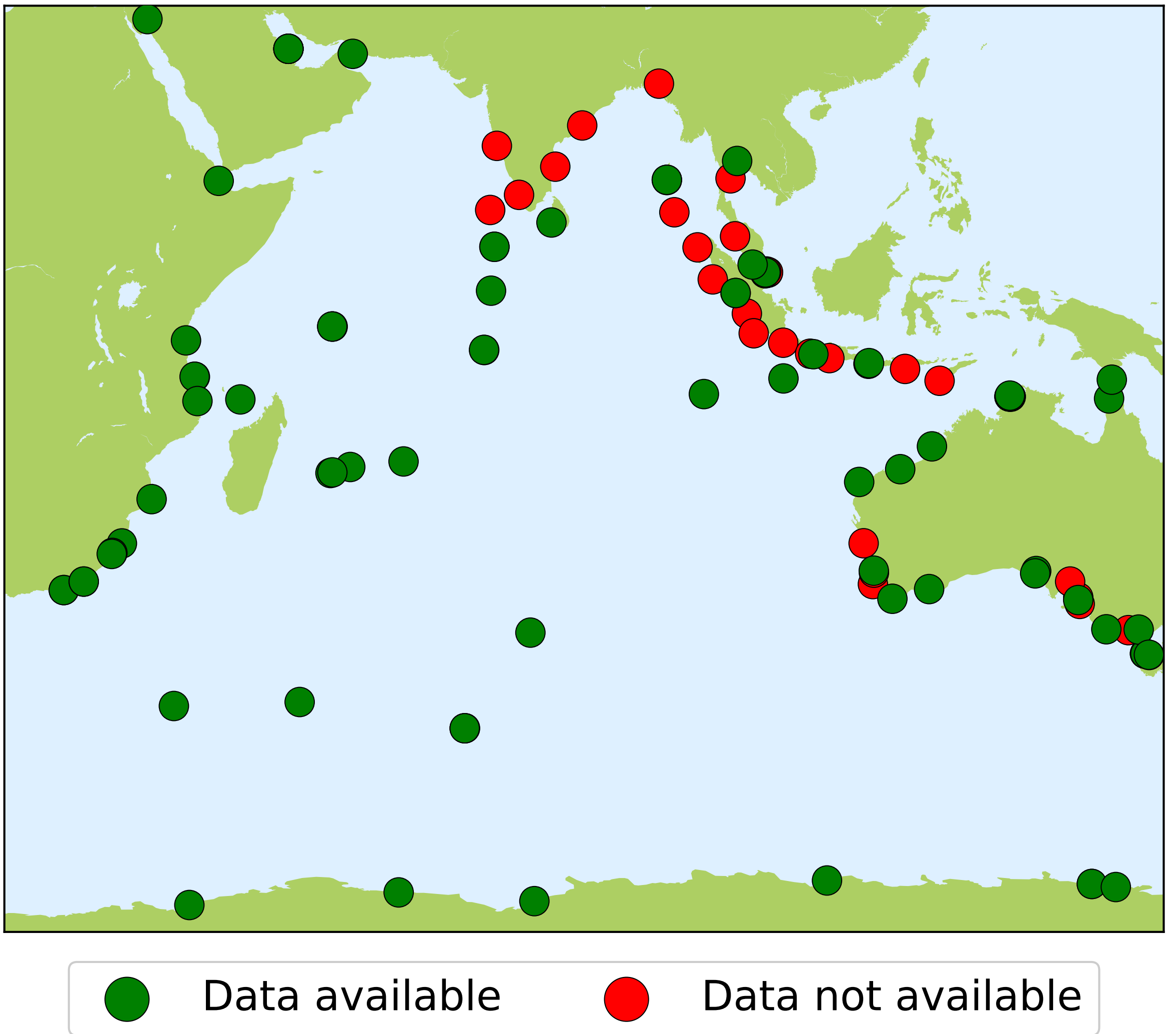

Figure 5.2 Current status (August, 2018) of the GNSS network co-located with tide gauges in the Indian Ocean.

declined in price and as a result we expect the density of the network can be increased over the coming years.

5.1.3 Data Usage and Comparison with Altimeter Data

Monthly and annual mean sea level data have been used for estimation of long-term trends in the northern Indian Ocean (e.g., Unnikrishnan and Shankar, 2007). The Indian Tsunami Early Warning Centre (ITEWC), at INCOIS, Hyderabad, India makes use of tide-gauge data as well as bottom pressure recorder data for detection of tsunamis in the Indian Ocean (Srinivasa Kumar et al., 2012, Ch. Patanjali Kumar et al., 2015). Church et al., (2006) found good correlations between tide gauge data and altimeter data at island stations in the Indian Ocean using approximately 10 years of altimeter data. Altimeter and tide gauge data comparison has also been undertaken using selected long records along the Indian coast (e.g., Kochi and Diamond Harbour, Unnikrishnan et al., 2015) and reasonable correlations reported. However, inconsistencies have been found across different sea-level reconstruction products used to determine regional decadal variability (Nidheesh et al., 2017) and more direct measurements are needed.

5.2 Actionable Recommendations

A. Enhance the tide-gauge network along the coasts of Thailand and Africa, in the equatorial Indian Ocean (Chapter 10.4) and Seychelles-Chagos thermocline ridge region (Chapter 14.3). Improve the network of island stations, which are highly effective for comparisons to satellite altimeter data and for combined 'reconstructions' of long-term regional sea level change.

B. Enhance and consolidate existing networks in the Southern Ocean and around Antarctica on a long-term basis through cooperation of their countries (namely Australia, France, Japan, Russia, South Africa and the UK).

C. Sustain the core tide gauge network for GLOSS and for tsunami monitoring (IOC, 2015). CLIVAR linkage and support in this respect is beneficial.

D. Digitize historical sea level data not already archived in several countries.

E. Increase number of tide gauge stations with colocated GNSS stations (land movement) and strengthen coordination between national operators of these stations.