4 Is the sea level changing?

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SEA LEVELS AND TIDES

The sea level is defined as the height difference between the level of the ocean's surface (most commonly the level halfway between mean high and low tide) and the level of a fixed point on the adjacent land. Sea levels are used as a standard in reckoning land elevation or sea depths. Sea levels are measured by tide gauges and determine the relative position of land and sea at the coastline.

The mean sea level is the average level of the sea calculated from long series of observations. It is a convenient datum from which all terrestrial elevations and submarine depths can be referred. Any instantaneous measurement of sea level in a series may be considered as the sum of three components parts:

Observed sea level = mean sea level + tides + meteorological residuals

Tides are the alternate rise and fall of the sea caused by periodic astronomic factors (relative motions of earth, moon, sun and other stellar bodies). These tide generating factors can be predicted with reasonable accuracy. The sea level data from tide gauge records also contain meteorological and oceanographic signals as well as vertical movements of the earth associated with glacial and other tectonic processes.

Some of the oceanographic signals that can be deduced from tide gauge data include:

- Static inverted barometer effects
- Geotrophic currents
- Coastal upwelling
- Coastal trapped waves
- Seasonal variability
- Low frequency atmospheric forcing
- El-Nino effects
- Secular variability

HISTORICAL EVOLUTION OF SEA LEVEL

The present climatic and continental positions were established in the Cenozoic era. About 35 000 years ago, the level of the sea surface was the same as it is now. This level then reduced, reaching a minimum of about 130m below the current levels about 15 000 years ago. From that point there was a relatively rapid rise in the sea level, gradually slowing down 8 000 years ago when the levels were about 15m below the present levels. The present levels were reached more gradually some 4 000 years ago. Since then the changes in the level of the sea surface have not been as dramatic.

In recent years there has been increasing concern about the projected rise in the level of the sea surface, due to global climate change. Industrialization has led to increased emission of green house gases (carbon dioxide, methane, etc) resulting in a rise in the global temperatures. Global sea level has risen by the order of 15cm over the past 100 years. Current models predict an increase in atmospheric temperatures of between 1.5 - 4.5°C in the next 50 years, accompanied by a consequent rise in the levels of the sea surface in the region of 35 - 60cm.

However many other factors also contribute to the relative sea level change (e.g. precipitation, evaporation, river run-off, changes in land elevation, deformation of ocean basins, changing wind systems, changes of ocean circulation etc). In fact in some areas of the world the sea level is actually falling due to some of these factors.

The change in sea level due to crustal movements (land elevation) can be monitored by installing Global Navigation Satellite System (GNSS) receivers at tide gauge locations. The combination of both tide gauge and GNSS measurements allows one to discern whether the tide gauge is sinking into the harbour, or the sea is rising.

MEASUREMENT OF SEA LEVEL

Sea level and tides can be measured by several types of instruments that are available. The choice of equipment will depend on the requirements of the user and resources. The simplest method of measuring the level of the sea surface is using a graduated pole or string immersed in the water. The stilling well float gauge is the most common type of gauge used worldwide. This type of gauge consists of stilling well and a float counterbalanced by some weight. The well filters out high frequency variability. The sea level is determined from the length of the float wire relative to a level fixed to the benchmark. Other methods of measuring sea level include acoustic tide gauges which measure the travel time of acoustic pulses reflected vertically from the air-sea interface, and pressure sensors which measure the hydrostatic pressure of the water column at a fixed point and convert this to sea level. The sea level can also be determined using satellite altimetry.

PRACTICAL APPLICATIONS OF SEA LEVEL DATA

Sea level data and information have a wide range of scientific, research and practical applications that include coastal engineering (in which sea level data are needed as instantaneous levels), as well as statistics of extreme levels over long periods. Short-term measurements, often with real-time data transmission, are needed for ship movements in harbours and ports, for issuing storm surge, tropical cyclone and tsunami warnings, and for the operation of sluices and barrages.

Over a longer period, sea level data are needed for tidal analysis and prediction, for control of siltation and erosion, for the protection of coral reefs, for inputs to models to estimate the paths of pollutants, to forecast water quality, and for the design of reclamation schemes and the construction of disposal sites. In addition, they have application in studies of upwelling and fisheries throughout tropical areas.

Historically, many national datum levels for land surveys are based on measurements of mean sea level over some defined period. These levels are often used to define state and national boundaries, as specified in the United Nations Convention on the Law of the Sea. Low water levels are used as the datum for tidal predictions and for the datum level in hydrographic charts.

Scientific and practical applications interact in many ways. For example, knowledge of long term sea level rise will need to be input into the engineering design of coastal structures, many of which will have a lifetime of many decades or centuries. Insight into the rate of sea level rise may also help in the understanding of complex coastal processes, such as sedimentation and erosion, which may result in high costs. A second example concerns sea level data assimilation into numerical models (e.g. storm surge, water quality, etc).

Sea level data is also used for studies on ocean circulation, long-term sea level changes as well as calibration and validation of satellite altimeter data.

SEA LEVEL VARIATIONS IN AFRICA

There is increasing consensus in the earth science community on the rate of sea level change globally. The Intergovernmental Panel Climate Change (IPCC) reported an increasing overall global rate of change; from 1.7mm per year for the 20th Century to 1.8mm year for the period 1961-2003 (Bindoff et al., 2007). Analysis of sea level rise is based on tide gauge data taken since the 19th century, as well as historical land records, archaeological data, geological evidence from the Holocene period, and more recently, altimeter data. To estimate present and future global and regional rates of change using tide gauges, records must be long (more than 50 years), and be free of crustal movements due to plate tectonics. Continuous sea level records from Africa are very short (generally less than 20 years).

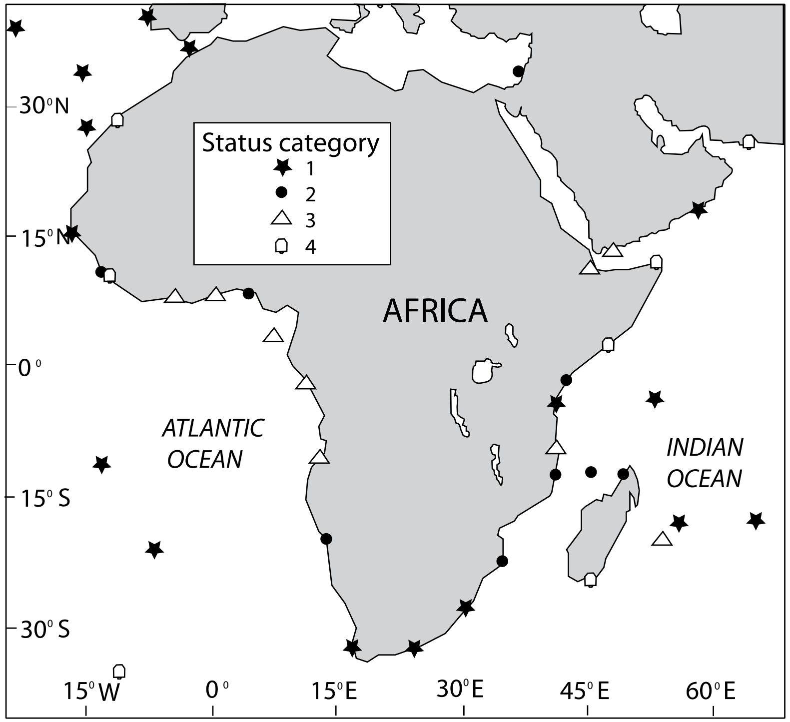

Figure 1. Map of GLOSS Core Network stations in Africa. Those marked by stars are category 1 (relatively recent data having been received by the PSMSL). Categories 2 and 3 indicate that historic but no recent data exist, whereas Category 4 stations have no historic or recent data at all. Categories are defined as of October 2006 (Woodworth et al. 2007).

Figure 1 shows the status of monthly and annual sea level data received by the Permanent Service for Mean Sea Level -PSMSL- (Woodworth and Player, 2003) from locations in the core network of the Global Sea Level Observing System (GLOSS). It can be seen that major sites identified by the GLOSS working groups, are spaced approximately 500km between them and with locations of oceanographic interest (e.g. Straits of Gibraltar) included. This set of stations is clearly not enough to satisfy the complete set of scientific and practical requirements. This figure shows that with the major exception of stations in South Africa and ocean islands, there are few relatively stations which provide recent data to PSMSL in Africa.

Figure 2 provides a histogram of the length of records, demonstrating that few are longer than 20 years (Woodworth et al., 2007).

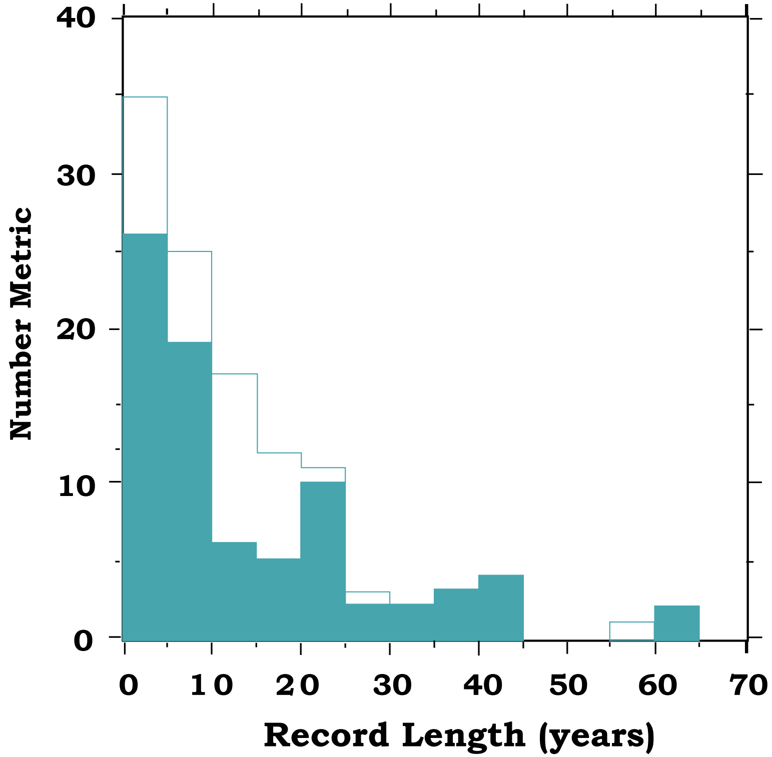

Figure 2. Histogram of the total number and record lengths of stations from continental Africa (Woodworth et al. 2007).

Even though the current sea level network in Africa is not as extensive as one would like, there is a considerable amount of existing information which can be used for research and education

RECENT TIDE GAUGES INSTALLATION

There is a great need to reinforce the ability of African states to acquire and use sea level measurements to support sustainable development and climate change studies. The urgency was demonstrated by the occurrence of the Indian Ocean Tsunami in December 2004, when few countries had functional tide gauges to provide the necessary data. In 2003, the Government of Flanders (Belgium) and Intergovernmental Oceanographic Commission (IOC) through the programme Ocean Data and Information Network for Africa (ODINAFRICA) installed 10 new sea level stations.

Stations planned and installed by ODINAFRICA include:
(i) Nouakchott (Mauritania) - December 2006
(ii) Takoradi (Ghana) - December 2006
(iii) Djibouti (Djibouti) - February 2007
(iv) Pointe Noire (Congo) - April 2007
(v) Limbe (Cameroon) - June 2008
(vi) Alexandria (Egypt) - 2009
(vii) Casablanca (Morocco) - 2009

Stations installed/upgraded by partners include:
(i) Port Louis and Rodrigues in Mauritius by UHSLC/IOTWS (2005)
(ii) Mombasa and Lamu in Kenya by UHSLC/IOTWS (2006)
(iii) Pointe La Rue in Seychelles by UHSLC/IOTWS (2006)
(iv) Zanzibar in Tanzania by UHSLC/IOTWS (2006)
(v) Dakar in Senegal by UHSLC (2007)
(vi) Inhambane and Pemba in Mozambique by GLOSS (2006)
(vii) Lamu, Kilifi and Shimoni in Kenya by Kenya Meteorological Department (2007)
(viii) Lagos in Nigeria by Nigerian Institute of Oceanography and Marine Science
(ix) Walis Bay in Namibia by BCLME (2008)
(x) Agadir and Tan Tan in Morocco by Service Hydrographique and Océanographique (Ministère de l'Equipement et du Transport, Direction des Ports et du Domaine Public Maritime)
(xi) Durban, Simonstown, and Port Elizabeth by GLOSS

The equipment employed at most sites consists of a radar tide gauge, which measures sea level from the time-of-flight of the radar pulses reflected back from the sea surface. Figure 3 presents a view of the radar sensors and aerials installation at Nouakchott. Figure 4 shows the status of the African sea level network (August 2008).

Figure 3. View of the radar sensor and aerials installation at Nouakchott station (Simon F., 2006).

Figure 4. African tide gauge status (August 2008).

TIDAL VARIATIONS ALONG AFRICAN COASTLINE

Time series data are often used to compute significant time-table tidal parameters, which describe the tidal regime at the place of observation. These parameters are called tidal constituents on the assumption that the responses of the ocean and seas to tidal forces do not change with time.

Figures 5a and 5b show different types of tides along the west African coastline. Table 1 represents the main constituents, amplitude and phase at Takoradi.

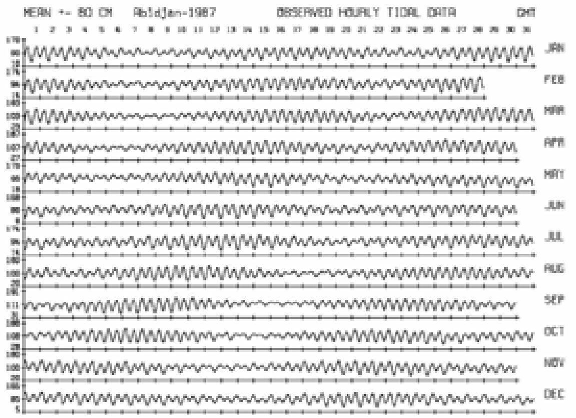

Figure 5a. Tides at Abidjan.

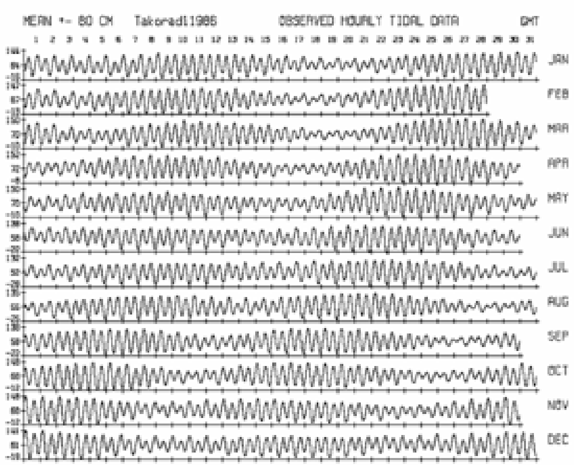

Figure 5b. Tides at Takoradi.

Table 1. Tide description for Takoradi based on TASK2000, T_TIDE and SLPR2 software.

	$F=\frac{K_1+O_1}{M_2+S_2}$	(M_2+S_2)	(M_2-S_2)	(M_2+S_2)
TASK -2000	0.2041	1.1842	0.2925	0.5921
T-TIDE	0.2253	1.2388	0.2964	0.6194
SLPR2	0.225	1.23882	0.296371	0.619441

AFRICAN SEA LEVEL VARIATIONS

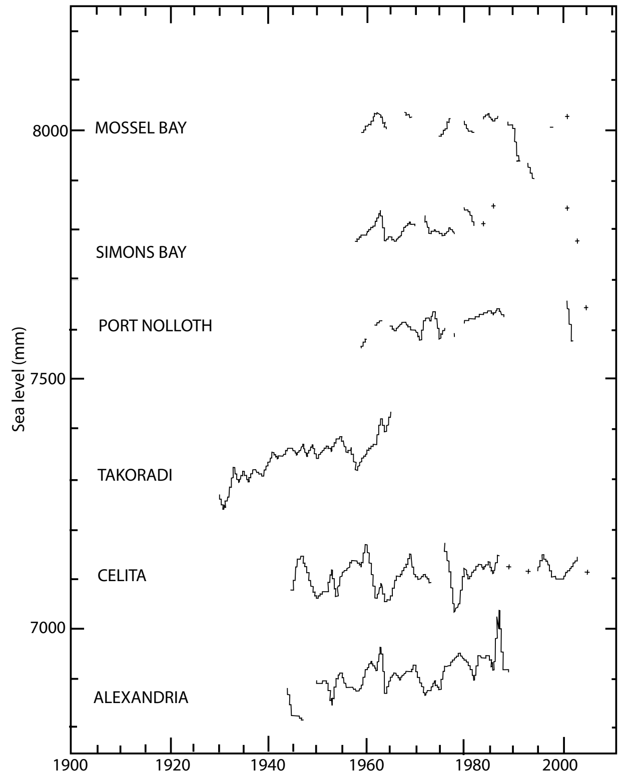

Figure 6. Annual Mean Sea Level for six stations in continental Africa with 40 or more years of data (Aarup et al., 2001).

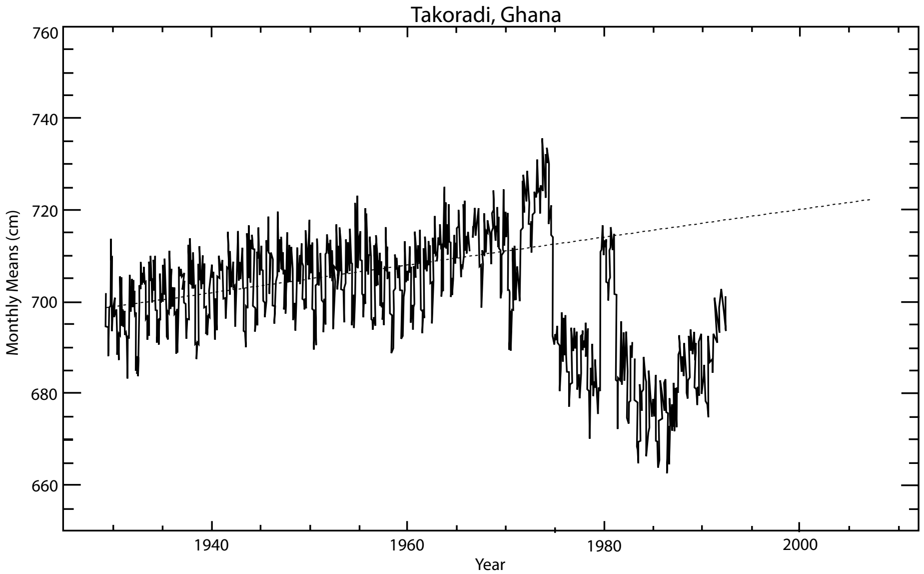

Figure 7. Monthly Mean Sea Levels reported from Takoradi. The dot represents Mean Sea Level for the first three months of 2007 from a newly installed ODINAFRICA tide gauge (Woodworth et al., 2007).

Figure 6 presents the annual mean sea level time-series for the six stations in continental Africa having record lengths over 40 years of data (Aarup et al., 2001). The secular trends for the six stations vary between -0.83 mm y-1 (for Mossel Bay) and 3.05 mm y-1 (for Takoradi). The many gaps observed in South Africa data reflected the problems with the acoustic gauges during the 1990s (Woodworth et al., 2007). The recent developments of African sea level network represent a good opportunity for studies of long term sea level change in recent years.

Figure 7 presents the historical monthly mean sea level values together with the first three months of 2007 from the newly installed ODINAFRICA tide gauge at Takoradi (Woodworth et al., 2007). This is a positive message for the future especially for ODINAFRICA. This finding is consistent with observations at other sites, which suggest little acceleration or deceleration in rate of sea level change during the past century (Woodworth et al., 2008). The linear trend of the extrapolation is 3.05mm per year. However, one should keep in mind that the recent data sets are short and the linear trend observed is the result of vertical land movements in addition to ocean changes.

In conclusion, the study of African sea level variations is not easy because the African sea level and the historical data sets are limited in size and quality. In Africa, sea level time series have only a short duration. Some times there is a gap of several years between data sets. In order to produce useful results for scientist and the broader community, it is important to maintain the new equipment at sites where historical data exist. As tide gauges can provide data to a large range of users in operational oceanography, African countries should develop a local skill-base to make maximum use of the data, and generate value added products.

TSUNAMI SEA LEVEL STATI/RING FACILITY

ODINAFRICA, in collaboration with the Global Sea Level Observing System, the Indian Ocean Tsunami Early Warning and Mitigation System, and the Flemish Marine Institute have developed the Tsunami Sea level Data Facility (www.sealevelstation.net) with the following functions: (i) data capture via the Global Telecommunication System - GTS and archive in relational database as an ODINAFRICA backup to national and GLOSS data centres, (ii) web-display (including plots and raw data provision) and provision of tide-gauge operator alerts in case of equipment malfunction, and (iii) semi-automatic data quality control. The facility receives real time sea level data directly via GTS. The GTS link was made possible through the kind cooperation of the World Meteorological Organization. The sea level station status map provides information on which stations are operational.

Real time data display: the real time data display section of the Tsunami Sea Level Monitoring Facility provides a graph of the sea level variation over a given interval. Figure 9 shows the station plot for Lamu. You can also get data report, and the station metadata. The red shading for the stations indicates that no data were received for this station during 2 transmission intervals. The light-blue shading indicates no data available for the respective stations.

Database services: Specific site data can be retrieved from Tsunami Sea Level Monitoring Facility and users can plot, generate a report table, or download the data. The system has stored data received since 7 June 2006.

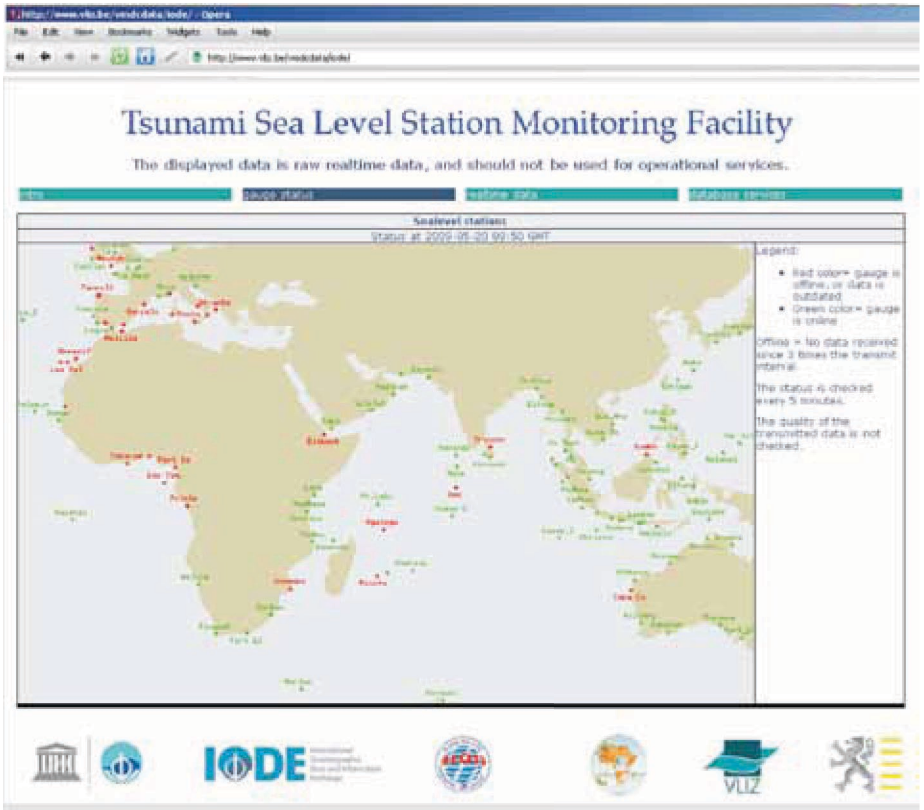

Figure 8. The sea level station status map provides information on which stations are operational.

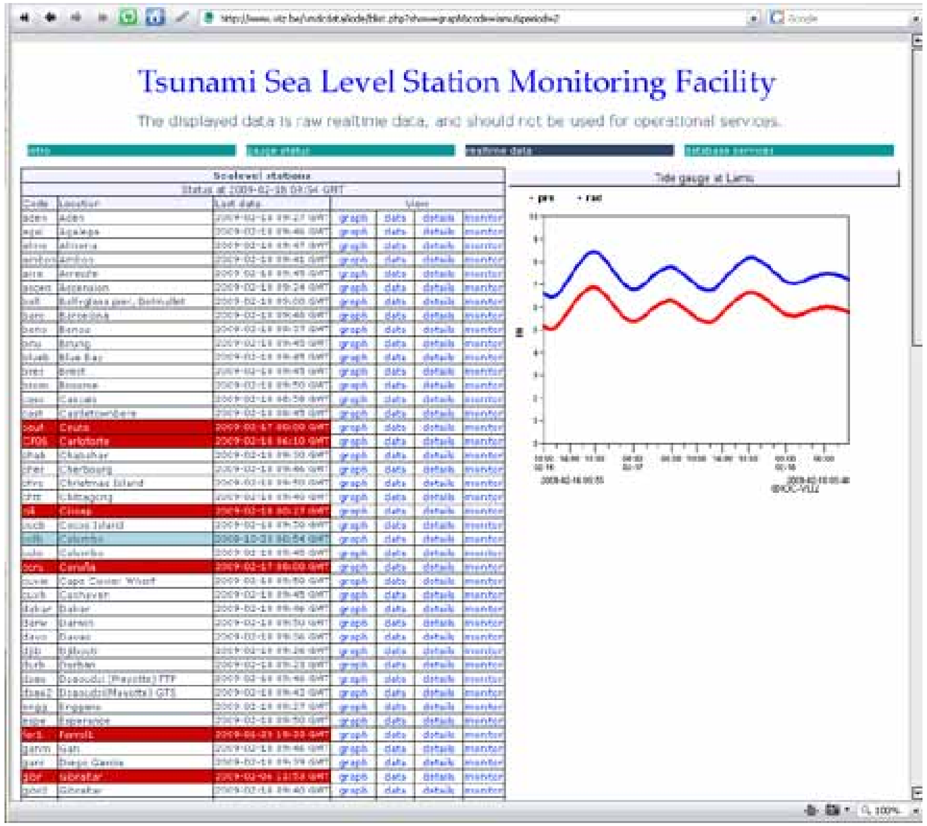

Figure 9. This screen capture shows the station plot for Lamu providing a real time graphic display of the sea level variation over a given interval.

Figure 10 shows a display of 30 days starting 7th June 2006 for the Zanzibar station. It is also possible to save the report for the same period, and spreadsheets generated, by using the “Download” function.

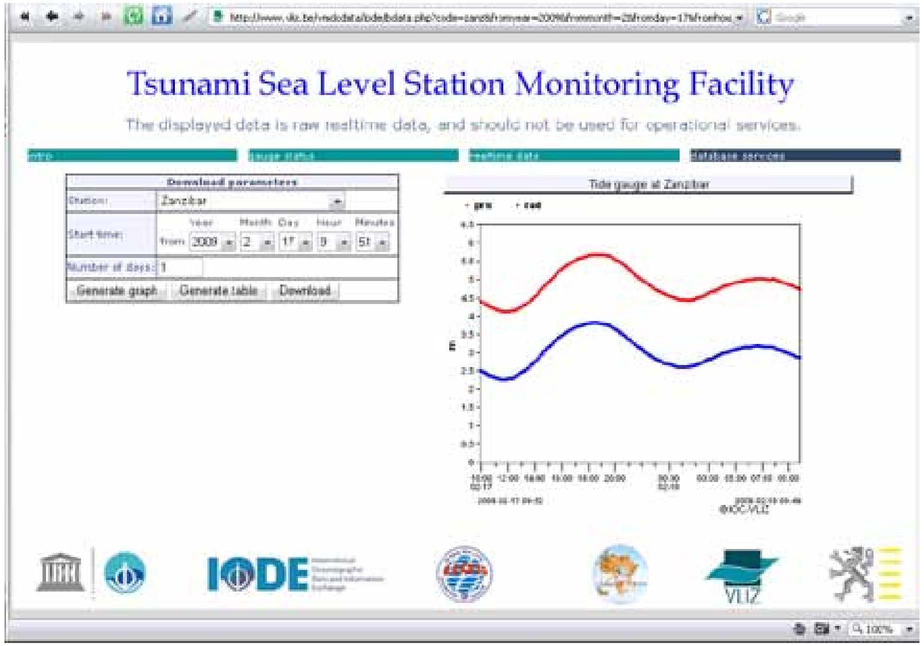

Figure 10. This screen capture shows 30 days of data plotted for the Zanzibar station.

ACKNOWLEDGMENT

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