Sea Level Variability in Sri Lanka Waters

Wijeratne. E.M.S[1] and Charitha B Pattiaratchi[2]

[1] National Aquatic Resources Research and Development Agency, Colombo-15, Sri Lanka

[2] School of Environmental Systems Engineering, The University of Western Australia, Australia

Introduction

The sea level variation is associated with variety of motions in the oceans due to by astronomical forcing, meteorological and hydrological forcing. In addition to short-term diurnal, seasonal and inter-annual changes, the sea level also responds to changes in freshwater inflow, heat flux and other factors that are linked to climate change processes.

Tidal effects can be clearly noticed in a sea level record as a regular rise and fall of sea level and occurs virtually everywhere throughout the ocean. Wind stress and air pressure variations force sea level variations on time scales ranging from hours, to diurnal and seasonal scales. In the open sea, a change of air pressure by 1 mb causes about a 1 cm change in sea level. Usually, sea level changes related to density (i.e. variation of specific volume due to change of temperature and salinity) are seasonal and caused by seasonal changes in precipitation, evaporation and heat fluxes. Such variations are referred to steric height variability (Tomczak and Godfrey, 1994). In addition, the El-Niño Southern Oscillation (ENSO) which occurs on a 2-5 cycle, causes climate changes around the world, which often have a large impact on the sea level..

Description of study area

Sri Lanka is an island situated in the northern part of the Indian Ocean between 6-10 ºN and between 80-82 ºE (Fig. 1). It covers 65,610 km^2, lies off the southern tip of the India and is separated by a shallow and narrow Palk Strait. Higher salinity Arabian Sea is located on its western side and the low salinity Bay of Bengal on its eastern side (Fig. 1). The continental shelf in Sri Lanka is narrow (2.5-25 km) and is shallower (30-90 m) than the average depth of the shelves around the world (75-125 m). The shelf is narrowest around the southern part of Sri Lanka, but it broadens to merge with the Indian continental shelf towards north and northeast. The outer edge of this shelf (continental slope), is comparatively steep falling to between 2000-4000 m (Fig.2). A large number of submarine canyons appear both on the shelf and the slope.

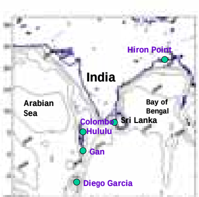


Fig.1: Map of northern Indian Ocean Region showing bathymetry, stations of some selected sea level monitoring stations

During the Southwest Monsoon, SWM (May-September) winds are from the southwest and during the Northeast Monsoon, NEM (December-February) winds reverse to the northeast. The waters around the Island are subjected to seasonal reversals of currents forced by the monsoons. The mean sea level pressure (SLP) in the North Indian region is maximum during December-January and minimum in June-July with seasonal range of about 5-10 mb (Wijeratne, 2003).

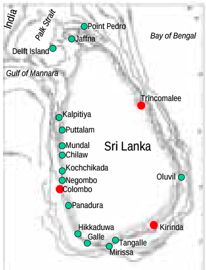


Fig. 2: Map showing temporary tide gauge stations (•)and present permanent sea level monitoring stations (•)

In the Arabian Sea, the net freshwater supply (precipitation + river runoff- evaporation) is strongly negative (about 1 m yr^{-1}), whereas it is strongly positive (about 0.4 m yr^{-1}) in the Bay of Bengal (Delaygue et al., 2001). The salinities of the Bay of Bengal are generally lower than the oceanic mean salinity (35), while the salinities of the Arabian Sea is high up to 36.5, which is due to high evaporation and hardly no freshwater input. The seasonal difference of sea surface salinity (>2) around Sri Lanka is highly significant compared to other regions (Levitus et al, 1994).

Aim of the study

This study examines the tidal, shelf oscillations, sub-tidal, seasonal and inter-annual sea level variability around Sri Lanka waters based on historical and recent sea level data measurements. Sea level data from selected stations from the northern Indian Ocean region, mainly derived from GLOSS databank are also analysed for comparison.

Time series analysis techniques

Methods of analysing these data have consisted of harmonic analysis, spectral analysis (SPA), and time filtering. Harmonic analysis uses a least squares method to fit amplitudes and phases of known cosine functions (constituents) to a measured time series of sea level. Method for spectral analysis used in this study was based on the application of a Fast Fourier Transform (FFT).

Results

Tidal sea level variations

Daily sea level changes in the region are dominated by tides. The semi diurnal tides (mainly M_2) account for most of the variations. The spring tidal range at inner Bengal Bay is about 2.4 m, the spring tidal range in Colombo Sri Lanka is only 0.6 m.

M_2 is the main tidal constituent in Sri Lanka waters with amplitude of 0.10 – 0.18 m depending on site. The tide is mixed semi-diurnal and spring tidal range, $2(M_2+S_2)$ is between 0.40 - 0.60 m. A smaller range appears in the northern region. The tidal phases on the east coast of Sri Lanka features different phases from the west coast with a rapid phase change along southern coast (Fig 3 and Table 1).

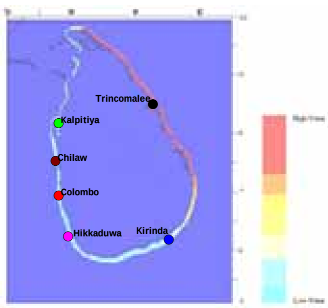


Fig. 3: Map showing some selected sea level measurements locations and tidal water levels at 09.00 am, 26 Dec 2004 constructed based on main tidal constituents phase distribution

Table 1: Tidal constants from different stations around Sri Lanka (where a is tidal amplitude and g is phase angle referred to local time). Sources: Admiralty Tide Tables, NARA measurements (Wijeratne, 2003)

Station	M_2		K_1	
	a(m)	*g°*	*a (m)*	*g°*
Point Pedro	0.16	242	0.05	328
Trincomalee	0.18	238	0.07	332
Batticaloa	0.14	235	0.05	330
Oluwil	0.07	230	0.05	332
Kirinda	0.07	92	0.03	29
Tangalle	0.10	061	0.03	009
Mirissa	0.14	089	0.04	028
Galle	0.16	056	0.05	029
Hikkaduwa	0.13	045	0.04	021
Kalutara	0.16	063	0.06	070
Panadura	0.16	030	0.08	002
Colombo	0.18	045	0.07	032
Dikkowita	0.18	028	0.10	018
Kochhikada	0.17	045	0.06	061
Chilaw	0.18	045	0.09	043
Kalpitiya	0.12	097	0.06	071
Jaffna	0.15	079	0.08	091
Kayts	0.03	063	0.12	061
Delft Island	0.11	038	0.11	076
Kachchaitvu	0.12	039	0.11	054

Sub-tidal and shelf oscillation

Spectral Analysis results on high frequency tide gauge records at selected stations around Sri Lanka are shown in Fig. 4. It clearly exhibits short-period (< 2hr) oscillations and ~5 day oscillations superimposed on the diurnal and semi-diurnal tides.

At Colombo 75 min and at Kirinda 70 min peaks are clearly visible (Fig. 4). Usually they have a smaller amplitude, compared with to the tide. The magnitudes and periods of these oscillations vary along the coast and occasionally they can attain heights that match or exceed the local tidal range. The region offshore Colombo, the mean depth is 40 m, shelf width is 20 km resulting in the natural period of oscillation period of about 70 min. Thus the sea levels with periods of around 70 min oscillations are related to continental shelf oscillations. In Trincomalee, a similar calculation yields a 40 min periodic oscillation (Fig. 4).

Oscillations of 80 and 120 hour periods are possibly due meteorological forcing, variation of atmospheric pressure.

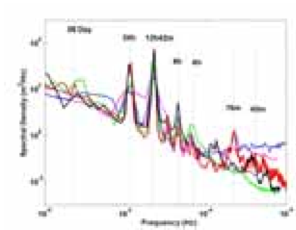


Fig. 4: Spectral analysis of sea level records from different part of the Island as indicated in Fig 3.

Spectral analysis results on sea level records at Colombo and Kirinda during (before and immediately after) Indian Ocean tsunamis of 26 Dec 2004 and 28 March 2005 are shown in Fig 5 & 6. Temporal variations of spectral density for dominant frequencies based on spectral analysis are shown Fig 6a-c.

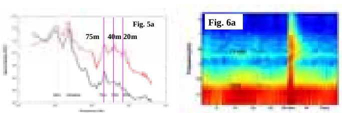
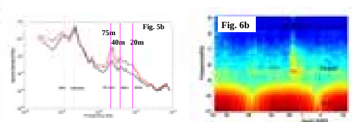


Fig. 5a: Water level spectra from Colombo showing the spectral energy before and after the action of the 26 Dec 2004 tsunami. Before Tsunami in black & after tsunami in red color

Fig 6a: Temporal variation of spectral densities in different frequencies before and after the action of the 26 Dec 2004 tsunami.



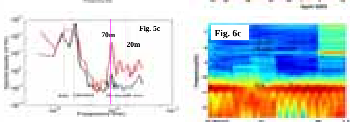


Fig. 5b-c: Water level spectra from Colombo (b) & Kirinda (c) showing the spectral energy before and after the action of the 28 March 2005 tsunami. Before Tsunami in black & after tsunami in red color

Fig 6b-c: Temporal variation of spectral densities in different frequencies in Colombo (b) & Kirinda (c) before and after the action of the 28 March 2005 tsunami.

The spectral analysis results of sea levels for both tsunamis show that the energy of high frequency sea levels enhanced after the action of the tsunami. At Colombo, energy peaks of 20, 40 and 75 min were significantly enhanced after action of 26 Dec 2004 tsunami, which were present before the action of the tsunami (Fig.5a & 6a), but due to the 28 March 2005 event, only 75 min peak has enhanced (Fig 5b & 6b). At Kirinda, energy peak of 70 minutes was enhanced after 28 March 2005 tsunami (Fig. 5c &6c). These results clearly indicate that the tsunami enhanced the energy of existing oscillation, particularly at high frequencies. These large amplitude seiches are created when the frequency of the earthquake derived wave's match the frequency at which the water is oscillating naturally.

Seasonal sea level oscillations

Seasonal sea level variation at different locations in the Northern Indian Ocean region are Shown in Fig. 7a-d. In the inner Bay of Bengal at Hirno Point, the seasonal range of sea level variation is about 0.8 m. The seasonal range around Sri Lanka waters is about 0.2-0.3 m. The range decreases towards south; the seasonal range at Diego Garcia is less than 10 cm. The Fig. 8a shows that the sea level becomes maximum during August and becomes minimum in January in Hirno Point, Bangladesh. But variation is almost opposite for Colombo (Fig. 7b), where maximum sea level occurs in December-January and the minimum in August-September.

Approximately 50% of seasonal sea level range around Sri Lanka Waters could be explained by steric height variations, assuming a well-mixed surface layer of 100 m and salinity variations of 2 psu. Lowest salinities occur in November (Levitus et al., 1994), highest in July. However, these figures chosen are rather arbitrary because coastal hydrographic data are unavailable from the seas around Sri Lanka. The depth of the surface mixed layer is also not well known around Sri Lanka. On the other hand Patullo et al. (1955) found that the steric range in the inner regions of Bay of Bengal is 41 cm, though their calculations were also probably hampered due to insufficient data. They also meant that the steric departures in equatorial latitudes are largely thermal and relatively small. The rest is due to wind set up and air pressure. Anyhow, it is obvious that shifting winds and current systems off the coast (Schott et al., 1994) should contribute to the seasonal variability as well. However, it is obvious that the very large and strongly seasonal input of freshwater to the inner Bay of Bengal directly influences the waters of Sri Lanka.

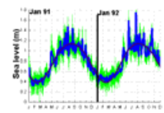


Fig. 7a: Hiron Point

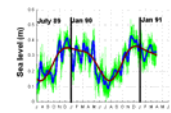


Fig. 7b: Colombo

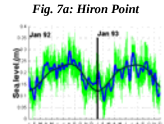


Fig. 7c: Gan

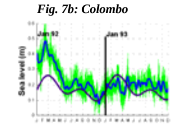


Fig. 7d: Diego Garcia

Fig. 7: Low passed filtered residual sea level data from Hirno Point (a), Colombo (b), Gan (c), Diego Garcia (d). Green line represents the actual residual and Blue line is the low pass filtered data (removed less than 7 days). Dark line shows the seasonal sea level variation.

Interannual sea level variability and trend

Figure 8a shows the inter-annual sea level variability from several stations in Northern Indian Ocean based on mean monthly sea level data. Figure shows significant correlation for sea levels of Cochin, Hulule and Colombo particularly later part of 80's. But there is no correlation with Madras sea levels. Spectral analysis results of mean annual sea levels from Cochin indicating relatively significant cyclic pattern with 3.5 years (Fig. 8b), probably forced by El-Nino.

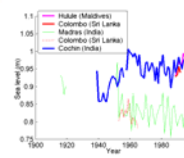


Fig. 8a: Interannual sea level variability at several stations in northern Indian Ocean region

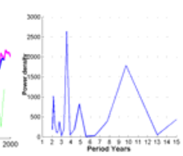


Fig. 8b: SPA results of mean annual sea level from Cochin

Conclusion

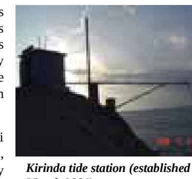
The tide around Sri Lanka is mixed semidiurnal with a spring tidal range of between 0.40 and 0.60 m. The range is less in the northern part of the island. The east coast features different phases from west coast with a rapid change in southeast. There are well-defined low frequency oscillations of 80 and 120 hrs period with a range of 2-3 cm. Sri Lanka coast also exhibits relatively high shelf oscillations with the period of 20 -120 m.

A seasonal range of sea level around Sri Lanka Waters is about 20 -30 cm. This variation seems to be dominated by a seasonally varying winds and freshwater input.

Acknowledgement

Historical sea level data were obtained from GLOSS data bank. Mutwal, Colombo GLOSS tide station is operating by NARA in collaboration with UHSLC, USA. Kirinda and Trincomalee sea level monitoring stations are operating by NARA in collaboration with BSH, Germany.

Mutwal, Colombo Tide Station (established Sep 2004)



Kirinda tide station (established March 2006)

Trincomalee tide station, established Nov 2005

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