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Temporal Sea Level Variation in the West Coast of Sri Lanka

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***Abstract*— The temporal variation of sea level can be observed as hours, days, weeks, months, seasonal, annual, inter annual and as long term. Meanwhile, some extreme variations are governed by disturbed weather system such as storms, meteo-tsunami etc. A series of tide-gauge data were obtained from the Intergovernmental Oceanographic Commission (IOC) whereas from a global satellite based database, i.e. Achieving, Validation and Interpretation of Oceanographic Satellite (AVISO) data. Eight years of automated sea level gauge data in one minute frequency were used to analyze daily, weekly and seasonal variations while twenty years of satellite data were analyzed for long term variations. The outcomes of both data were super positioned to appraise the accuracy of the data sources. The T_TIDE harmonic analysis function of time series analysis in MATLAB' software was used to quantify the tidal constituents. According to the form factor (0.33), the type of tide was mixed semi diurnal. The spring tide range was 0.652m according to the statistical quantification of Hikes 2006. The average seasonal variation was 20-30 cm where the highest variation was identified during December and January while the minimum was identified during July and August. The observed long term sea level variation indicates a positive trend of 1.9 mm yr-1 in the west coast of Sri Lanka.**

***Index Terms*— Sea Level, Tide, Seasonal Change, Sea Level Rise.**

I. INTRODUCTION

This paper discusses the spatial variability of mean Sea level by different forces with time dimension. The mean water level, at which the oceans exist when, averaged between high and low tides which associated with many kinds of forcing agents such as astronomical forcing, meteorological and hydrological forcng [1]. The temporal sea level variations can be classified from hours to thousands of years with the frequency of variation such as days, weeks, months, seasonal, annual and inter annual and long term. [2]The sea level variability and changers are manifestations of climate variability and changers with recording to number of major coastal flood events in association with major storms such as Hurricane Kathrina in 2005 and the Cyclone Sidr and Nargis in 2007 and 2008 respectively [3]. The local regional oceanic variations are interconnected in order with meso scale, synoptic scale and global scale variations which initiated by different forces, phenomena in the oceanic and atmospheric system. According to the intergovernmental Panel on Climate Change (IPCC) the Global Mean Sea Level Rising (GMSLR) rate during 1901-1990 was 1.5 (1.3 to 1.7) mm yr -1 while during 1993-2010 was 3.2 (2.8-3.6) mm yr -1 with greater rate since the end of 19th century. Available evidence shows that the rate of sea level rise around the global coastline was significantly in excess of the global average over the period 1993–2002 [4]. The trend of sea level rise inferred from altimetry in the northern Indian Ocean (NIO) is 5 ± 0.4 mm yr -1 for the period of 1993–2012, which is significantly higher than the global sea level rise rate of 3.6 ± 0.4 mm yr -1 in the same period. There is significant difference in sea level trend in Bay of Bengal and Arabian Sea; trend is twice higher in Bay of Bengal than Arabian Sea within the Indian Ocean [5]. The long term sea level changes coursed by increase the volume of ocean by the effect of expansion, melting of glaciers, ice sheets and reduction of liquid water storage on land [6]. Extreme events of variations were recorded in specific location of the southern hemisphere with different process such as seiches, tsunamis, tides, storm surges, continental shelf waves, and annual and inter-annual variations inanition to the general sea level. Meanwhile some of extreme variations govern by sudden changed of atmospheric conditions in disturbed weather system such as Meteotsunami which are generated by meteorological events, particularly moving pressure disturbances due to squalls, thunderstorms, frontal passages and atmospheric gravity waves [7], [8]

Study area is central Western coast of the Sri Lanka; it is an Island state country in the Indian Ocean very closely situated southern tip of the Indian. With the situation of the equator the solar penetration is higher giving tropical properties to the country. The country is directly shows two main monsoon seasons giving the seasonal change of oceanic condition. Sri Lanka is directly faced the result of circulation in between BOB and Arabian sea with their specific properties of hydrostatic and meteorological; which high temperature and evaporation in the Arabian Sea and Cold water in the BOB with surrounded majour part in land preventing circulation in northward of the BOB. The excess of evaporation over the Arabian Sea and excess freshwater supply into the BOB leads 2 psu of salinity difference while 2C0 of temperature difference around Sri Lankan oceanic water [9]. With the different of salinity and temperature between the Arabian Sea and BOB originated water flow brings direct impact to the Island situated mid of the both seas.

In this study, the tidal variation during spring and tides were assessed whereas the tidal range, seasonal, inter annual and long term variations are appraised using tide gauge data gathered by the National Aquatic Recourses Research & Development Agency (NARA), Sri Lanka

II. MATERIAL AND METHODS

Sea level data (in research quality) were obtained from Global Sea Level Observing System (GLOSS) conducted by the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) whereas from a global

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altimetry satellite database; Achieving Validation and Interpretation of Satellite Observations (AVISO).A Harmonic analysis was performed to obtain sea level variations and to quantify main tidal constituents by adjusting for astronomical impact residuals. Moreover, the pattern of tide was assessed quantitatively using the ratio of (K1+ O1) to (M2+S2), with regard to the Luni-solar Declinational diurnal constituent (K1), and the Principal Lunar Declinational diurnal constituent (O1). The astronomical effects produced by the Moon (M2); semidiurnal lunar and the Sun (S2); semidiurnal solar were calculated separately whereas the spring and neap tide variations in western coast of Sri Lanka were determined. M2 : Principal lunar, K1 : Luni-solar diurnal , S2 : Principal solar , O1 : Principal lunar diurnal , SA : Solar annul component. The seasonal and long term sea level variations were obtained using residual sea level. Furthermore, seasonal and long term variations were analyzed using the monthly mean values obtained from gauge data satellite data separately, together with the super positioned curves.

III. Results

The residual sea level variation obtained by the removal of tidal constituent through a harmonic analysis. Figure 1 illustrates the phases of obtaining of residual sea level variation. A shows the actual one minute's frequency reading whereas B and C show the predicted tidal and the residual sea level variation respectively.

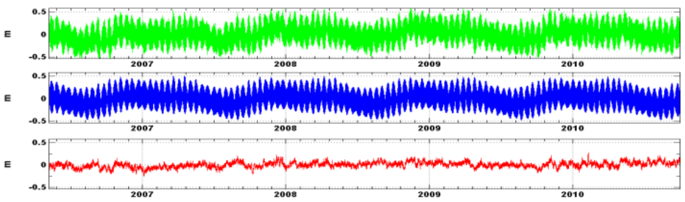

Figure1**:** Obtaining of residual sea level vation by separating tidal component

(A).The green line :Tide guage time series in one minutes frequency

(B).The blue line : the tidal component time series from the harmonic analysis

(C).Red line : The residual time series [observed record (A) - predicted tide (B)]

Table 1**:** The resulted tidal constituent by harmonic analysis

Station	ID	Colombo
M_2	A (m)	0.178
	g^o	243.369
S_2	A (m)	0.123
	g^o	285.932
K_1	A (m)	0.070
	g^o	307.555
O_1	A(m)	0.029
	g^o	340.173
SA	A (m)	0.083
	g^o	25.287
Spring Tide (m)	$2(M_2+S_2)$	0.650
Neap Tide (m)	$2(S_2-S_2)$	0.10

Table 1 shows the magnitude of M2, S2, K1, O1, SA; main tidal constituents and the extent of spring and neap tide resulted from the analysis. Moreover, two whole tidal cycles for each astronomic cycle were identified, where the Semi diurnal tidal variation falls under the category of micro tide with range of 70-75 cm per day in line the finding of wijerathne in 2006 of mixed semidiurnal with a spring tidal range of 0.40 - 0.60 [2] in Colombo, Sri Lnaka.

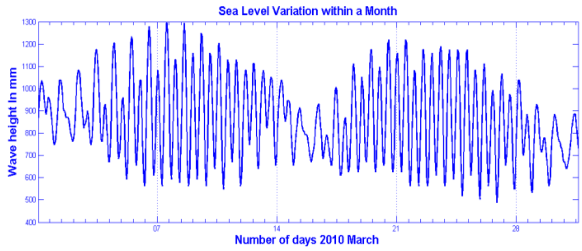

Figure 2: Tide variation within a month period in the west coast of Sri Lanka. Two spring tide within a month were observed.

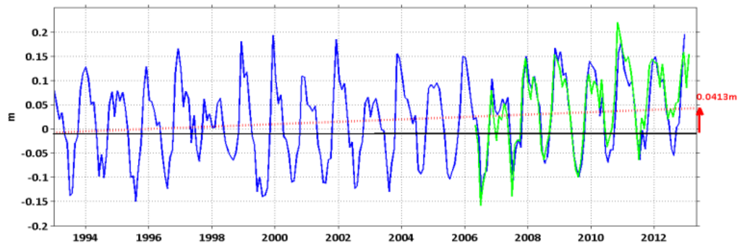

Figure 3: Shows comparison of sea level data derived from the satellite database for a period of 20 years and 10 months, from January 1993 to December 2012, and almost seven years of tide gauge data from May 2006 to March 2012.

(A) Blue -Long term variation plotted using satellite data in the West Coast of Sri Lanka.

(B) Green -Long term variation using tide gauge data in the West Coast of Sri Lanka.

(C) Red -The trend of the sea level variation during considered period**.**

Satellite data is gathered for a period of red line is the linear fitting curve of sea level rise. Blue line shows the satellites data of twenty years from January 1993 to December 2012 and green line shows tide gauge record from 2006 May to 2012 March.

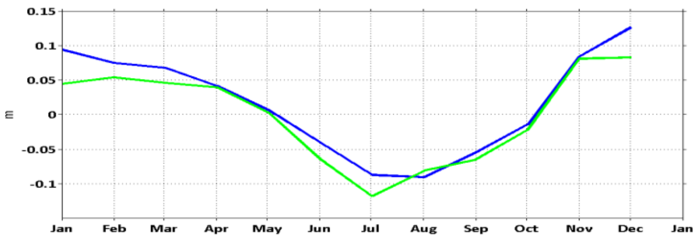

Figure 4: Comparison of seasonal sea level Variation in the west coast of Sri Lanka

(A) . The Blue - Monthly average AVISO Satellite data
(B) . The Green – Monthly average gauge data

Figure 4: Long term Sea level changes in west coast of Sri Lanka. Blue line shows satellites data from 1993 to 2013 and Green line shows tide gauge record from 2006 to 2013.

According to the statistical analysis he mean sea level (MSL) estimates obtained from tide gauge data showed root mean square differences (RMSDs) were approximately 80% of the variance of the MSL signal estimated from satellite altimetry data. Considering the individual time series, the results showed that coastal tide gauge and satellite sea level signals are comparable, with RMSDs less than 4cm and correlation coefficients up to the order of 0.9. Positive sea level linear trend for the analysis period were estimated for both the mean sea level and the coastal stations [10].

IV. DISCUSSION

The tidal effect originate and variant with consecutive movement and there attractive forces of Moon and Sun during the rotation of earth in the solar system. The form factor of tide was 0. 332 in Colombo while tide range during spring and neap are 0.65 m and 0.10 m respectively (10). According to the form factor tide type is mixed Semidiurnal with two highs and 2 lows per day with different strength. Maximum annual sea level variation shows 20-30 cm during the December to January while the minimum variation during July to August inline wijeratnne in 2002[11]. The inter annual variations shows as result of Niño effect. Ensemble empirical mode decomposition showed that inter-annual variability was related to the processes that have dominant periodicities of 4-6 years related to El Nino Southern Oscillation (ENSO) events [12].

Total sea level trend for the 20 years and ten month period is 41.3mm. Thus, the annual sea level rise is 1.98 mm. The seasonal and long term sea level changed by the effect of steric which the change of temperature and salinity. Further studies are required to determine the effect of fresh water discharge and the seasonal variation of sea level from Kalani River. Sea level changes related to density change of specific volume due to change of temperature and salinity is caused by seasonal changes in precipitation, evaporation and heat fluxes which referred to steric height variability [13].The seasonal sea level range around lower part of northern Indian Ocean waters is about 0.2-0.3 m responding to the fresh water inflow, heat flux and other factors that are linked to climate change processes [14].On the NE coast of Sri Lanka, the steric aptitude is a little lower, and peaks about one month later, than west coast of Sri Lanka. The northern boundary also hinders the otherwise characteristics boundary currents from developing thereby there is no possibility of warm surface water to escape northwards, Thus it is anticipated that the Indian ocean to be warmer than other ocean and also to obtain higher mean sea level. According to the previous study the temperature deference was recorded 2C0 around the Sri Lanka with the excess evaporation properties in the Arabian Sea and excess fresh water discharge through leads to the BOB. Further that phenomenon gives 2 psu salinity differences between two seas. As the result of combine effect of both salinity and temperature deference gives Steric height fluctuation by the expansion and contraction of the upper mixed layer amount to 21 cm, which is likely to cause a slope in the sea level between the two seas, consecutive flows from the bay of bangle to Arabian sea. [9].The estimation of IPCC 5th assessment report main courses and their individual contribution for long term sea level change are 42% of melting of land ice 35% of expansion of ocean water and 12% of adding land water.

V. CONCLUSION

Exploration of Sea level dynamic is important for future challengers induced with global change to sustainable use of the ocean resources for navigation, harvesting of ocean recourses and coastal development planning , Sri Lanka. According to tide classification of Hicks (2006)., tides in the east coast of west coast of Sri Lanka is in the category, Mixed Semidiurnal' with two highs tides and two lows tides per day with different strengths. The spring tidal range and the neap tidal range were 0.65m and 0.10m respectively under the category of 'Micro tide'. In line with the results of Wejerathne (2006), the monthly mean sea level ranged between 8-15cm. The maximum mean sea level change was recorded between December and January while the minimum level was recorded during September to October where those changes were significantly caused by the 'steric effect'. Long term sea level variation signifies a positive trend of about 1.9 mm per annum which is influenced by the effects of global climate change.

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