Sea Level Rise detected in the Atlantic and Caribbean Coast of Puerto Rico

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Abstract

Empirical Mode Decomposition of monthly sea level data (1962-2016;1955-2016) in the north and south coast of Puerto Rico reveals a positive sea level trend with a Sea Level Rise (SLR) of 4.51 mm/year at San Juan Harbor and of 3.65 mm/year at Magueyes Island. The SLR accelerated between 2012 and 2016 and before 2012 the SLR values were around 2 mm/year.

Introduction

Sea level rise is a concern for coastal communities around the globe. Their productivity and its way of life is already being affected by an accelerated sea level rise. There is a necessity for reliable analysis methods to detect the sea level trend signal in tide-gauge data and altimetry data. Empirical Mode Decomposition (EMD) is one method capable of removing long-period mean sea level oscillations from the monthly water elevation data. This way is possible to obtain a sea level trend allowing us to detect Sea Level Rise (SLR) and accelerations. EMD has been applied successfully in SLR studies of the East Coast (Kenigson and Han, 2014, Ezer and Corlett, 2012).

Methodology

Data Collection

For this study we selected monthly means of water level elevations above MLLW (NTDE 1983-2001) from NOS/CO-OPS stations 9759110 at Magueyes Island and 975531 at La Puntilla, San Juan Bay. For the specific stations locations and data please visit the following pages.

https://tidesandcurrents.noaa.gov/stationhome.html?id=9759110

https://tidesandcurrents.noaa.gov/stationhome.html?id=9755371

Below we display the time span of each original time series:

Station Identification	Start Series	End Series	Number of Years
CO-OPS Station 9759110	JAN-1955	SEP-2012	57.67
CO-OPS Station 9755371	APR-1962	SEP-2012	50.5

New available data allowed us to extend both time series for an additional 42 months, up to March 2016. We will refer to it as the extended time series. We applied EMD analysis to the original and extended time series.

Empirical Mode Decomposition (EMD)

Empirical Mode Decomposition (EMD) and Hilbert Spectrum Analysis (HSA) are the two main components of Hilbert Huang Transform (HHT) analysis. HHT performs time-frequency analysis of nonstationary signals, as do other techniques such as wavelets. However, HHT is better suited than wavelets for analyzing signals resulting from nonlinear processes (Huang et al. 1998). A detailed explanation can be found in Huang et al. (1998, 1999). EMD can separate the signal into orthogonal components with different time scales. The successful application of EMD for decomposing nonstationary and nonlinear oceanic physical phenomena in Puerto Rico has been reported in a number of papers (Huang et al. 2000, Alfonso-Sosa, 2010; 2009). That previous experience motivated us to analyze the CO-OPS water level data using EMD. This technique decomposes time series data into a finite number of **intrinsic mode functions (IMFs)** with time variable amplitudes and frequencies. The decomposition is orthogonal and adaptive. By adaptive we mean that the EMD decomposition adapts to the local variations of the data. Adaptive basis is indispensable for nonstationary and nonlinear data analysis. Any function is an IMF if (1) in the whole data set, the number of extrema and the number of zero-crossings is either equal of differ at most by one, and (2) at any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima are zero. The second criterion means that the function has symmetric envelopes defined by local maxima and minima respectively. The process to achieve this decomposition is called “extrema sifting”. Maximum sift time was 10. The original water elevation time series was subjected to the Empirical Mode Decomposition (EMD). The original time series was decomposed into six IMFs (C1-C6) and one nonlinear residual (C7). Each IMF represents a oscillating component that might represent a physical mode of oscillation at a particular time scale and the trend represents the sea level trend. After a linear least-square fit of the sea level trend we determined the sea level rise (SLR).

The analysis was repeated on the extended time series of Magueyes (1955-2016) and San Juan Harbor (1962-2016) but this time the maximum sift times value was changed until we obtain a residual monotonic function and no interior maximum. This approach allowed us to obtain eight IMFs (C1-C8) and an almost linear residual (C9).

This analysis was performed in Matlab, using the m-files provided by: 中央大學數據分析中 Research Center for Adaptive Data Analysis. Chungli,Taiwan http://rcada.ncu.edu.tw/intro.html

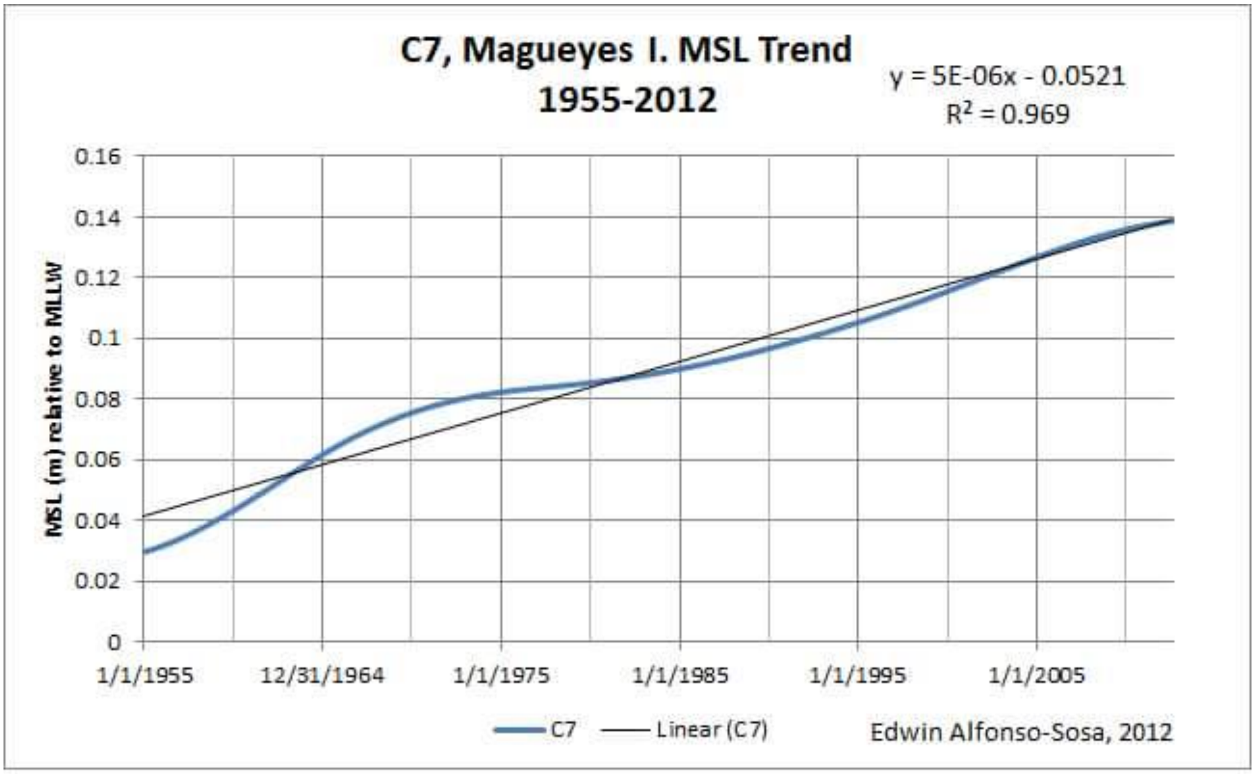
The same procedure was applied to the water level records (2010-2015) obtained from the San Juan Harbor tide gauge station (NOAA/NOS/CO-OPS/Station 9755371).

Results

In this section we present only the residual of the original time series that ended on 2012 and the residual of the extended time series that ended on 2016, named C7 and C9, respectively. The IMFs (C1-C6) of the original time series are shown in the following document and includes a brief explanation of the diverse physical phenomena responsible in forcing most of the oscillating components. The Solar Annual Tides and Rossby waves with time scales between 90 and 120 days were the largest amplitude signals in the Caribbean Coast.
https://www.academia.edu/30329908/LongPeriod_Mean_Sea_Level_Oscillations_in_Magueyes_Island_1955-2012_

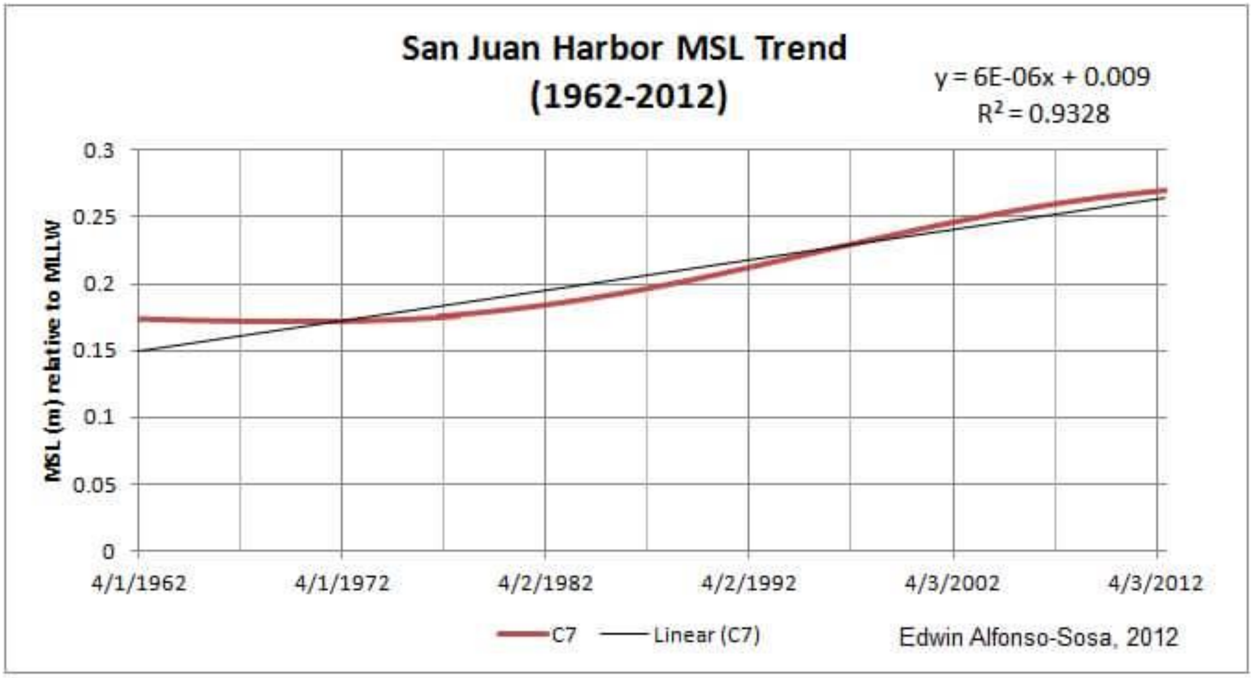
Figure 1 shows the residual, C7, that represents the mean sea level trend (blue line) after removing all the long period oscillatory phenomena. After applying a linear least-square fit (black line) on C7, its slope represents the sea level rise between 1955-2012. We obtained a SLR value of **1.83** mm/year for Magueyes Island. Figure 2 shows the sea level trend (red line) in San Juan Harbor between 1962-2012 and the corresponding sea level rise of **2.19** mm/year, larger than in Magueyes but the r-square value was reduced from 0.969 to 0.933. Figure 3 and 4 shows a linear sea level trend (C9, green line) for Magueyes and San Juan Harbor (C9, green line) extended series. The linear regression fits almost perfectly with r-square values of 0.999. Magueyes Island SLR value - up to March 2016 - is **3.65** mm/year. San Juan Harbor SLR value is **4.51** mm/year. Figure 5 and Figure 6 shows the extend time series (blue line) and an overlay of the 1955-2012 sea level trend (red line) and the 1955-2016 sea level trend (green line). The black lines are their corresponding linear fits. The figures clearly revealed that the last four years had an impact on the slope of the trend and the final sea level rise. This result suggests an acceleration in the SLR. Figure 7 shows the sea level trend in the last decade (2005-2015). The value of SLR was **6.3** mm/year.

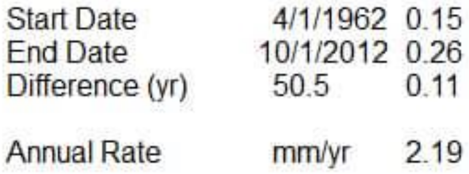
Figure 1. Sea Level Trend and SLR of the original time series at Magueyes Island.



Start Date	1/1/1955	0.048
End Date	9/1/2012	0.154
Diference (yr)	57.67	0.105
Annual rate	mm/yr	1.83

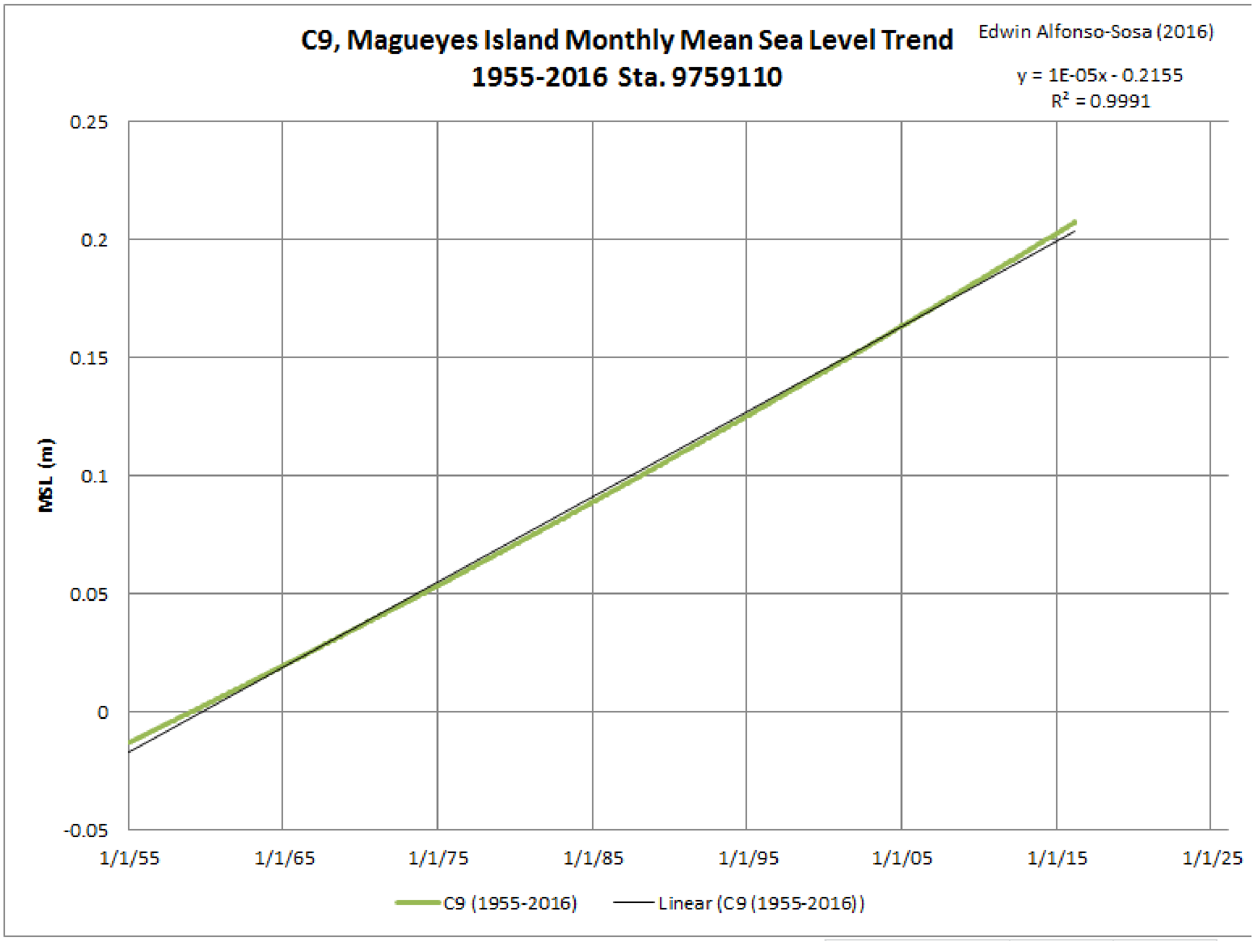
Figure 2. Sea Level Trend and SLR of the original time series at La Puntilla, San Juan Harbor.





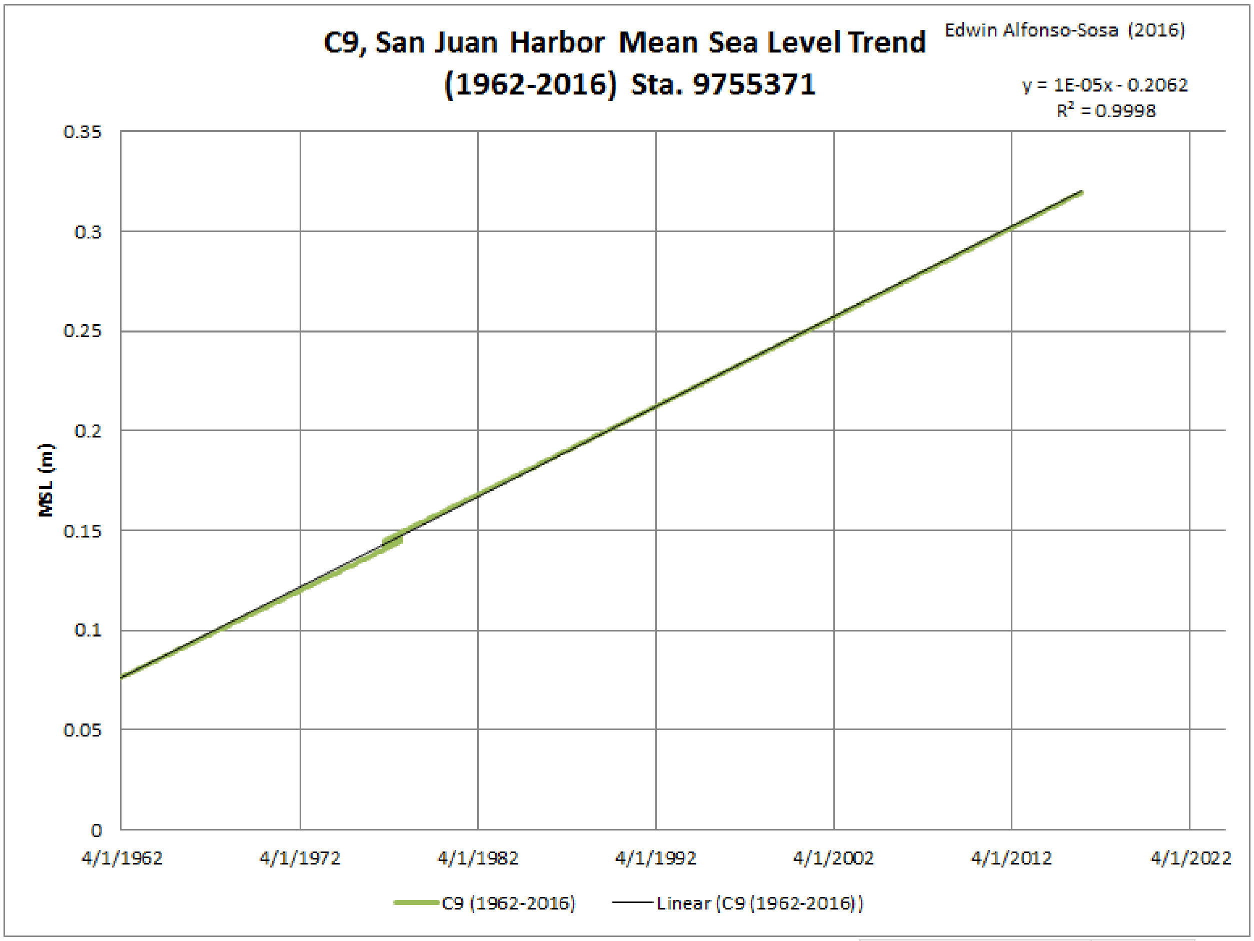
Start Date	4/1/1962	0.15
End Date	10/1/2012	0.26
Difference (yr)	50.5	0.11
Annual Rate	mm/yr	2.19

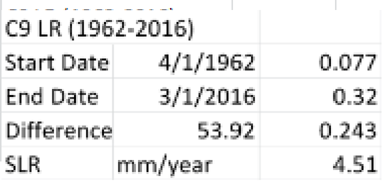
Figure 3. Sea Level Trend and SLR of the extended time series at Magueyes Island.



C9 LR (1955-2016)		
Start Date	1/1/1955	-0.015
End Date	3/1/2016	0.209
Difference	61.16	0.223
Annual rate	mm/yr	3.65

Figure 4. Sea Level Trend and SLR of the extended time series at La Puntilla, San Juan Harbor.





C9 LR (1962-2016)		
Start Date	4/1/1962	0.077
End Date	3/1/2016	0.32
Difference	53.92	0.243
SLR	mm/year	4.51

Figure 5. Overlay of the Sea Level Trend of the original time series (C7, red) and the Sea Level Trend of the extended time series (C9, green) on top of the extended time series (MSL, blue). Magueyes I.

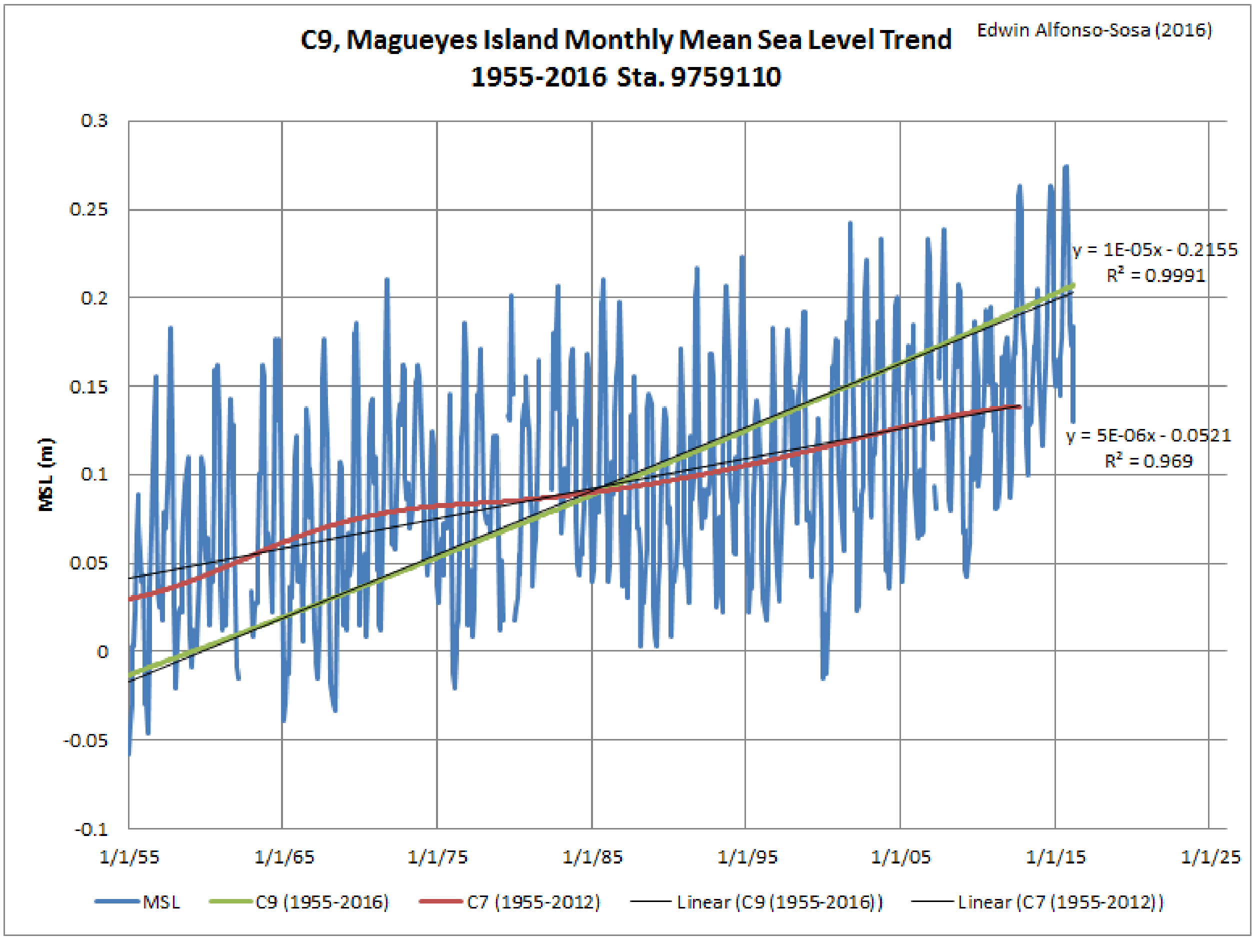


Figure 6. Overlay of the Sea Level Trend of the original time series (C7, red) and the Sea Level Trend of the extended time series (C9, green) on top of the extended time series (MSL, blue). San Juan Harbor.

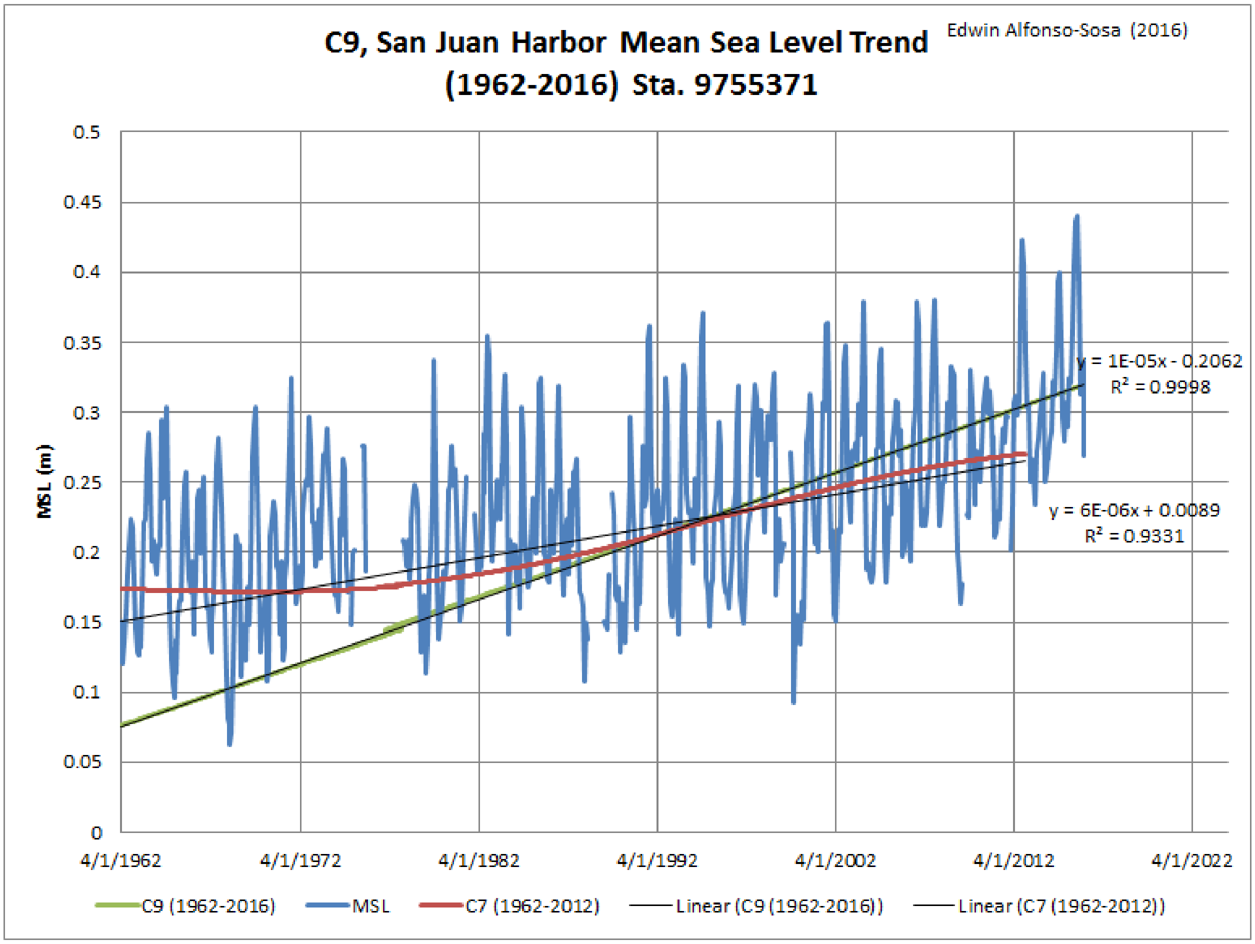
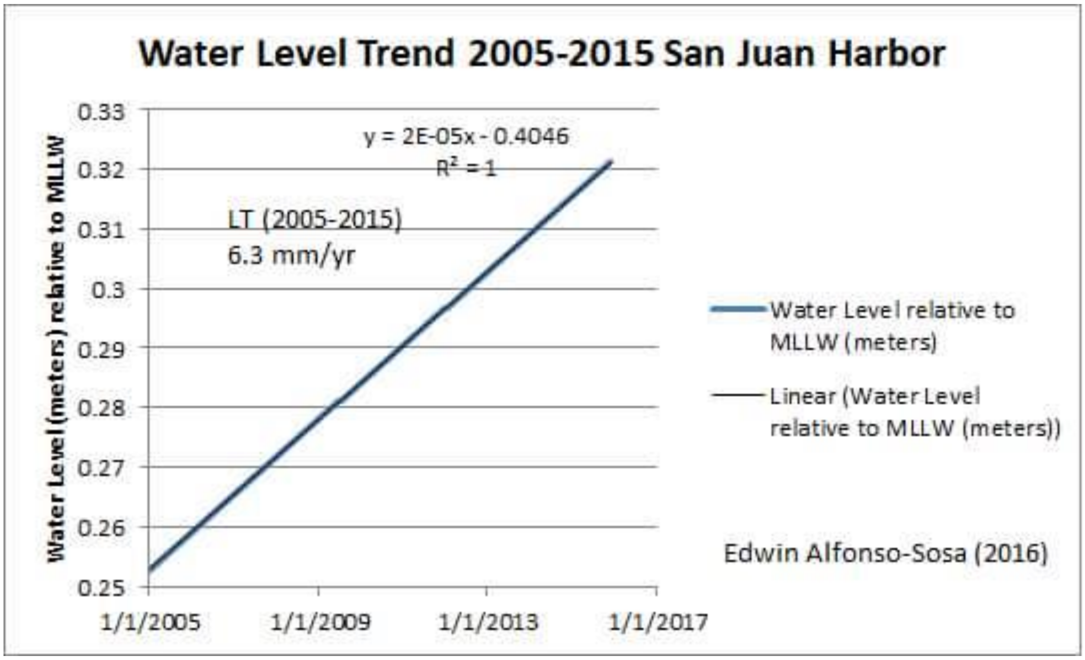


Figure 7. Sea level trend in the last decade (2005-2015). The value of SLR was **6.3** mm/year.



Discussion

The extended water level time series revealed that the SLR accelerated in the last four years from around 2 mm/year to 3.65 mm/year at Magueyes Island and 4.51 mm/year at San Juan Harbor. This sudden increase in SLR motivated us to calculate the SLR from 2005 to 2015 at San Juan harbor. Inside that time period the SLR value is 6.3 mm/year, it is smaller than the 9.44 mm/year calculated for the same station by linear least-square fitting of the filtered data spanning from January 2010 to September 2016 by Aurelio Mercado and Harry Justiniano (2016). But we have to point out that our data does not include the values from 2016, excluding La Niña conditions. The 6.3 mm/year value is similar to SLR values estimated from satellite altimetry (2006-2015) near Puerto Rico (see map on Thompson et al., 2016). Mercado and Justiniano applying linear least-square fit to the whole monthly data obtained values of 1.77 mm/year and 2.01 mm/year for Isla Magueyes and San Juan harbor, respectively. These values are similar to the ones we obtained from EMD analysis of the shorter original time series. This means that once we added the extra 42 months the residual increased and our SLR values increased substantially. Our findings sustain that SLR accelerated in the last four years.

Conclusion

Empirical Mode Decomposition of monthly sea level data (1962-2016;1955-2016) in the north and south coast of Puerto Rico reveals a positive sea level trend with a Sea Level Rise (SLR) of 4.51 mm/year at San Juan Harbor and of 3.65 mm/year at Magueyes Island. The SLR accelerated between 2012 and 2016 and before 2012 the SLR values were around 2 mm/year.

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