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Sea level oscillations in Japan and China since the start of the 20th century and consequences for coastal management - Part 2: China pearl river delta region

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ABSTRACT

This study examines low-frequency (> 10 years) sea level variations in the Pearl River Delta (PRD) Region. The low-frequency sea level variability is relevant to regional sea level forecasting and flood risk management. Linear and parabolic fittings are applied to the monthly average mean sea levels (MSL) measured by tide gauges. A spectral analysis is performed of the time series of the MSL and the time series of the monthly climate indices of Pacific Decadal Oscillation (PDO) and El Niño–Southern Oscillation (ENSO)/NINO. Based on the analysis of a composite record of different tide gauges, the PRD Region sea levels, despite being complicated by the river discharge, have reduced similarity with either ENSO, NINO or PDO indices. The PRD Region sea levels have low frequency similarities with the sea level pattern in the Western North Pacific (e.g. Hosojima, Japan) and Western South Pacific (e.g. Sydney, Australia), while at higher frequencies the similarities reduce. One strong low frequency fluctuation of periodicity quasi-20 years is very clear and another of a longer periodicity of quasi-60 years is clear. There is then a relevant fluctuation of about 12 years of periodicity, of reduced amplitude compared to the quasi-20 years fluctuation. In the medium frequency range (< 10 years), there are several components detected, but the intensity of the fluctuations is largely reduced compared to the fluctuation of 12 years periodicity. Regionally, the sea levels in the PRD region and Japan show no significant acceleration from 1900 to present, but only oscillations. This result is consistent with the other coastal area of the world where long-term tide gauges are located. Policy making, and management, should therefore focus on adaptive measures linked to the monitoring by tide gauges and Global Navigation Satellite System (GNSS) of relative sea level rise and land subsidence. Extreme sea level rise warnings based on predictions by never validated models, or speculations, that are defocusing coastal management from every other relevant situation, should be discharged.

1. Introduction

The Pearl River Delta (PRD) Region here refers to the low-lying area surrounding the Pearl River estuary in the South China Sea. This region is one of the most densely urbanized regions in the world, often considered an emerging megacity. It is considered the largest urban area in the world in both size and population. Due to the significance of manufacturing, the PRD Region has been called the "*Factory of the World*". The cities of the PRD Region in China are among the most exposed to flooding in the world. Guangzhou, Shenzhen, and Hong Kong, the three major cities in the PRD Region, may face severe and increasingly frequent flooding events because of the urban expansion and growth within a low-lying delta and global warming. Hence, it is of primary importance to analyse the oscillations of the sea levels about the longer-term trend at both high, medium and low frequency to guide coastal management. If there are important oscillations of multidecadal periodicity, then the relative rates of rise of the sea levels should be computed by using not less than many years of continuous recording by the same tide gauge in the same location same of the periodicity, while almost two periods are needed to compute the relative accelerations.

The inter-annual, decadal and multi-decadal sea level oscillations are important, and have a large and complex literature. Some but not all of it is cited in Cronin et al. (2014). The influence of Pacific Decadal Oscillation (PDO) and/or El Niño–Southern Oscillation (ENSO) on the tropical pacific sea levels has been discussed by many, see Si and Xu (2014) or Moon et al. (2015). They all suggest some sort of correlation, even if imperfect. Wang et al.(2018) recently discussed the inter-annual sea level variability in the PRD Region, and, in the specific, its response to the high frequency ENSO. They found that the sea level cycles of 3 and 5 years are related to ENSO, with wind-driven seawater transport

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the predominant factor. Worth mentioning according to Devlin et al. (2017), the sea-level record in Hong Kong is an anomaly.

The ENSO is a relatively high frequency, periodic, fluctuation, occurring once every 2–7 years, in sea surface temperature (SST) and the overlying atmosphere air pressure across the equatorial Pacific Ocean. A global expression of the ENSO obtained by linearly regressing monthly sea surface temperature (SST) anomalies time series, for a wide Pacific Ocean domain, is provided by Deser et al. (2016). This reference also provides the power spectra of the normalized ENSO time series. The ENSO has two major peaks with about 3 and about 5 years' periodicity. The time series is adapted from Deser et al. (2010) while the power spectra are adapted from Deser et al. (2012).

The PDO, often described as a long-lived El Niño-like pattern of climate variability in the in the Northeast and Tropical Pacific Ocean, typically northern of 20° North, is characterised by ocean temperature fluctuations of similar and lower frequencies. Deser et al. (2016) also provide a global expression of the PDO obtained by linearly regressing monthly SST anomalies time series, for a reduced Pacific Ocean domain limited to the Northern Hemisphere. This reference also provides the power spectra of the normalized PDO time series. The time series is adapted from Deser et al. (2010). The power spectra are adapted from Deser et al. (2012). The PDO has also two major peaks with about 3 and about 5 years' periodicity, but they are much smaller than the largest peak at about 50 years of periodicity not shown by the ENSO.

The PDO is the leading pattern of SST anomalies in the North Pacific. Positive values of the PDO index correspond with negative SST anomalies in central and western North Pacific and positive SST anomalies in the eastern North Pacific. The positive phase of the PDO is also associated with positive SST anomalies across the central and eastern tropical Pacific. Hence, the similarities between the ENSO and the PDO of Deser et al. (2016). According to Mantua and Hare (2002), the past century experienced just two full PDO, "*cool*" PDO regimes 1890–1924 and 1947–1976, "*warm*" PDO regimes 1925–1946 and 1977 through (at least) the mid-1990's. The 20th Century PDO fluctuations were most energetic in two periodicities, 15-to-25 years, and 50-to-70 years. The analysis of Deser et al. (2016) does not show such as strong 15–25 years periodicity.

An oscillation in the global climate system with a period of period 65–70 years is well-known and generally accepted (Iyengar, 2009; Schlesinger and Ramankutty, 1994) so we may expect sea levels to oscillate with such a periodicity. Chambers et al. (2012) demonstrated that there is a quasi-60 years oscillation in the long-term tide gauge records of the Western North Pacific. These oscillations have similar phase of the quasi-60 years oscillation in the in the long-term tide gauge records of the North Atlantic and the Indian Ocean. The Western South Pacific long-term tide gauge records also have a significant quasi-60 years oscillation, although of different phasing. No obvious quasi-60-year cycle is evident in the long-term tide gauge records of the Hawaii or the Eastern North Pacific. The existence of quasi-20 years oscillations in the tide gauges of the Western South Pacific has been similarly shown by many authors, for example Australian Government Bureau of Meteorology National Tidal Centre (2009) and Parker (2013a, b). The periodic surveys of the Australian sea levels, last one the censored Australian Government Bureau of Meteorology National Tidal Centre (2009), always showed decadal sea-level oscillations with periods quasi-20 years, with the annual mean sea levels generally fluctuating in accordance with the Southern Oscillation Index (SOI).

Parker (2013a, b) demonstrated that the Western South Pacific sea level fluctuations are characterised by both quasi-20 years and quasi-60 years periodicities.

The goal of this manuscript is to show similarities and differences in between the medium to low frequency oscillations of the monthly average mean sea levels (MSL) recorded by the longest tide gauges of the PRD Region, the composite record of the two tide gauges of NORTH POINT and QUARRY BAY in Hong Kong, and the composite record of the tide gauge of MACAU in Macau, and NORTH POINT and QUARRY BAY in Hong Kong, the MSL recorded by the longest tide gauges of the West Pacific, SYDNEY, Australia and HOSOJIMA, Japan, and finally the oscillations of the monthly values of ENSO, NINO and PDO indices based on SST estimations.

Another goal of this manuscript is also to discuss the sea level acceleration for the area. Global mean sea level is supposed to increase because of global warming because of a growth in the volume of water by thermal expansion of the water in the oceans and by melting of ice sheets and glaciers on land (Shennan, 2013), continuing a process started in the beginning of the 20th century. However, many works, such as Boretti (2012a,b), Boretti and Watson (2012), Dean and Houston (2013), Douglas (1992), Douglas and Peltier (2002), Houston and Dean (2011), Kemp et al. (2015), Jevrejeva et al. (2006), Holgate (2007), Mörner (2004, 2010, 2013); Parker and Ollier (2015b, 2017b, c), Scafetta (2014), Wenzel and Schröter (2010), Wunsch et al. (2007), have shown that the sea levels of long-term tide gauges are not accelerating, but rising at about same rate since the start of the 20th century. The sea levels of China have been covered in many recent works. Chen, Han & Yang (2018) have recently proposed a selection of short term tide gauges for the China seas that includes carefully chosen tide gauges of China, Korea and Japan, suggesting recent high rates of rise. Parker (2018a) has shown much smaller rates of rise in all the medium-term tide gauges of China. The proposed work is the first considering the coupling of the information from the medium-term tide gauges of China, where long-term tide gauges are unavailable, with the long-term tide gauges of Japan, to properly assess the regional long-term sea level rise cleared of natural variability.

2. Method

Sea level rates of rise (slopes) and accelerations are computed by linearly and parabolically fitting the MSL measured by the tide gauges. A linear regression:

$$y_t = B + M \cdot t$$

returns the sea level rate of rise $\boldsymbol{u}$ as the slope M. A quadratic regression

$$y_t = B' + M' \cdot t + A \cdot t^2$$

returns the acceleration $\boldsymbol{a}$ taken as 2·A. These sea level data are relative to the instrument, that may move vertically by subsidence or uplift.

A spectral analysis is performed of the time series of the MSL and to the time series of the monthly climate indices of PDO and ENSO/NINO. Spectral analysis is the decomposition of a time series into underlying sine and cosine functions of different frequencies to determine those frequencies that appear particularly strong. The frequency f of a sine or cosine function is the number of cycles per unit time. The period T of a sine or cosine function is length of time required for one full cycle. Thus, $T = 1/f$. Spectral analysis may be interpreted as a linear multiple regression problem, where the dependent variable is the observed time series, and the independent variables are the sine or cosine functions of all possible frequencies. The calculations are however usually performed with the Fast Fourier Transform (FFT) algorithm.

If we have a time series y_t of length n, then we can write

$$xy_t = a_0 + \sum_{k=1}^{\frac{n}{2}-1} [a_k \cos(2\pi kt/n) + b_k \sin(2\pi kt/n)] + a_{n/2} \cos(\pi t)$$

The periodogram quantifies the contributions of the individual frequencies to the time series regression and is defined as

$$P_k = a_n^2 + b_n^2$$

where P_k is the periodogram value at frequency $k = 1, \ldots, n/2$. The periodogram of the univariate time series with the 95% Kolmogorov-Smirnov confidence intervals is computed as shown in Wessa (2017), where the source code of the R module is also provided. The public availability of the code assures the results are reproducible.