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Sea Level Variations During 1980-2014 over Zhoushan, China

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Abstract: In this paper we consider the Zhoushan Islands area to check the sea level (SL) variation. Sea Surface Height Relative to Geoid over the Zhoushan Island area has been obtained from the operational data sets produced routinely by the Global Ocean Data Assimilation System (GODAS). Monthly, seasonal and interannual variations have been presented and possible relations for variations are also explained. SL is indicating a decreasing trend, however there is an increasing trend before year 2000 and showing decreasing trend after 2000. There is 5 mm increase in SL before 2000 and 10 mm decrease in SL after 2000. Over Zhoushan, Sea surface temperature (SST) is having an inverse relation with SL, however SL is having a positive relation with Nino 3.4 SST anomalies but it is not significant.

Keywords: Sea Level, Interannual Variation, SST, ENSO

1. Introduction

Sea level rise is a good indicator for global warming and climate change. Observing sea level changes and its basis are became the top priority for scientists and society at most. Sea level displays complex variability both in space and time that reflects the broad set of geophysical forcing [1]. Modern sea level rise is a matter of urgent concern from a variety of points of view, but especially because of the possibility of its acceleration and consequent threats to many low-lying parts of the world [2], [3], [4]. Given the widespread and generally consistent reports of global warming, melting glaciers, shoreline retreat, and the clear trend of the last 20 000 yr, a compelling inference is that global-mean sea level is rising. The past decade has seen a revolution in observations of sea level rise and its causes. We now have observing systems that are capable of measuring global sea level change with an accuracy of a few millimeters, as well as systems that can directly measure the causes of this change. Woodworth et al. [5] describe observations of sea level rise over the past 100 plus years, including evidence for acceleration during the twentieth century. In addition, Tamisiea and Mitrovica [1] explain the geophysical contributions to sea level change, such as the ongoing deepening of the ocean basins, and how corrections are applied for them in various types of observations.

A major difficulty in determining sea level trends from tide-gauge data relates to the fact that the vertical position of the land upon which the gauge is situated (measured relative to the centre of the Earth) could be changing as much as the position of the sea itself. Vertical land movements can arise from geological processes both natural (long-term tectonics) and anthropogenic (ground water pumping or mining). However, glacial isostatic adjustment is the only geological process for which models are available capable of application to the correction of tide-gauge records [6]. Tide gauges, given their location near the continents, would only record ~ 60% of the 30-cm mean sea level drop due to twentieth-century water storage estimated by Chao et al. [7].

Estuaries are predominantly sedimentary environments, and are characterized by shallow coastal slope gradients, making them sensitive to even modest changes in sea level. Coastal sea level responds to atmospheric pressure and wind perturbations in the coastal region as well as to large-scale offshore forcing. This direct response to local atmospheric pressure forcing is almost isostatic in many circumstances and most of the apparent non-isostatic sea level variability comes from winds in the coastal region. Temperatures are predicted to rise by 2°C-4.4°C by 2100 leading to global average sea level rise of 2–6mm per year (20–60cms in total) up to 2100 [8] with impacts for protected coastal habitats. Local sea surface temperature changes of about 0.58C yr^{-1} are observed and would be adequate to account for that amount of sea level rise. The strong correlation between mean global sea level and mean global sea surface temperature [9] suggests that much of the observed satellite sea level signature is impacted by the steric effect. This is further supported by the strong similarity of the spatial distribution of satellite-observed sea level change and surface temperature [10], [11], [12].

An inspection of any of the main climate indices, such as the El Nino Southern Oscillation (ENSO), demonstrates variability on timescales of several years to decades. Inspection of most long sea level records also demonstrates such variations. Their global-average sea level time series demonstrated considerable decadal variability (e.g. that related to ENSO), in addition to a long-term change, similar to that determined from a tide gauge only [13]. Holgate & Woodworth [13] concluded that the 1990s experienced one of the fastest recorded rates of global-coastal sea level rise. Church et al. [14] also found higher rates than normal in the 1990s although somewhat smaller rates than Holgate and Woodworth's [13]. The 1990s experienced a higher rate of global sea level rise than normal, at a time when global air and sea temperatures achieved record high sand when high rates of glacier melt were reported. Whether the 1990s are indeed the start of a sustained higher rate of sea level rise remains to be seen. The variations in extremes in this period were often related to changes in regional climate (e.g. to ENSO related indices in the Pacific). Satellite altimetry provides near-global coverage of the world's oceans and thus the promise of determining the global-averaged sea level rise, its regional variations, and changes in the rate of rise more accurately and quickly than is possible from the sparse array of in situ gauges. A satellite would observe a fall in sea level of about 20.3 mm yr^{-1} throughout much of the oceans as a response to melting of ice age ice sheets.

2. Study Area, Data and Methodology

Zhoushan consisted of many islands, having different small and big islands, on which there are ports have been constructed and fishing harbours also exits. Figure 1 illustrates the Study area chosen (29-32°N: 122-124°E). Zhoushan has the most abundant deep-water coastline resources in China, and the widely distributed islands made complex well-sheltered environments. The Zhoushan area is mainly controlled by Yangtze, Qiantang and the Jiangzhe rivers, with high suspended sediment concentration. Fine grain size sediments are broadly developed in harbour area, mainly silty mud and muddy silt [15], [16]. The tide type of the study area is irregular semidiurnal tide, with the average ebb-tide duration longer than the average flood-tide duration. The tide currents are affected and controlled by coastline, depth contour, topography and sub-tide-current, the route of current are much complex.

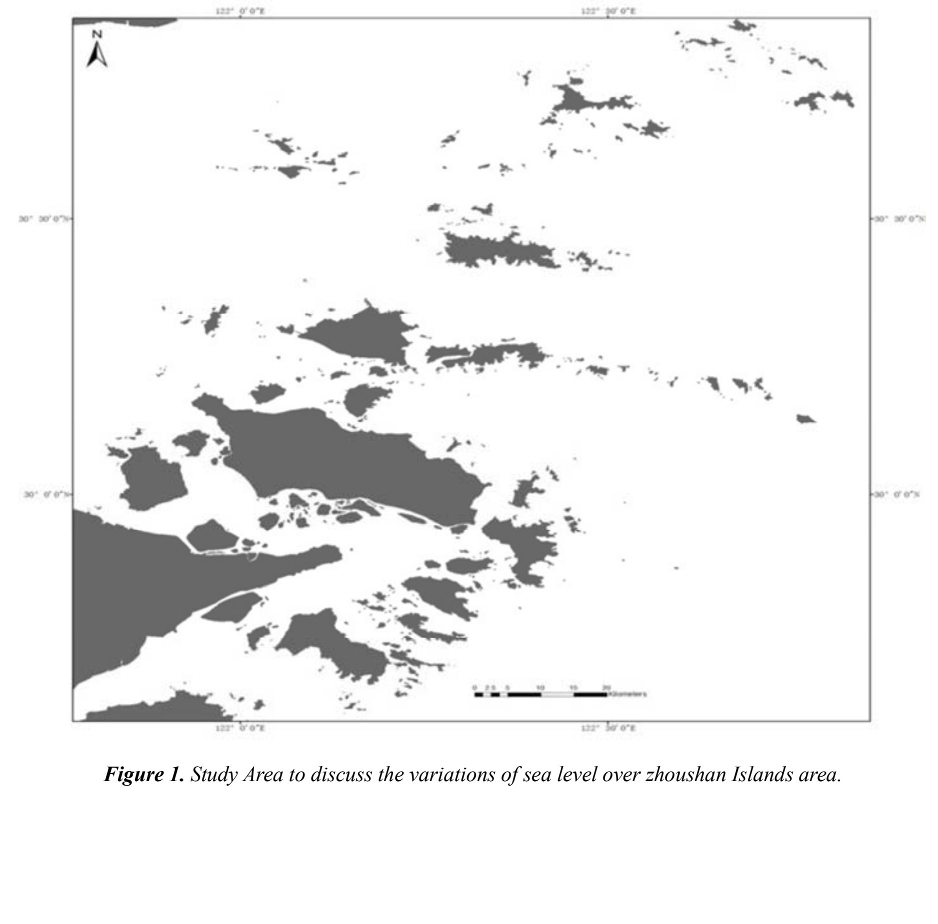

Figure 1. *Study Area to discuss the variations of sea level over zhoushan Islands area.*

The water temperature of East China Sea exhibits a general trend of high in southern and low in the northern part, with the average water temperature in the northern part between 10 and 18°C, and the near bottom temperature of the near shore area has a dramatically seasonal variation. Besides, there are lots of islands in study area, with many natural developed channels formed between islands or island-land.

Sea Surface Height Relative to Geoid over the area has been obtained from the operational data sets produced routinely by the Global Ocean Data Assimilation System (GODAS) developed at National Center for Environmental Prediction (NCEP) are a valuable community asset for monitoring different aspects of ocean climate variability and assessing benefits of NOAA´s extensive investment in global ocean observing program. The GODAS is based on a quasi-global configuration of the GFDL MOM.v3. The model domain extends from 75° S to 65° N and has a resolution of 1° by 1° enhanced to 1/3° in the N-S direction within 10° of the equator. Sea level data has been obtained from GODAS for this study. To check the relation between the sea level and sea surface temperature relation we have used the 2°x 2° gridded Extended Reconstructed SST (ERSST) dataset [17]. The ERSST analysis is one of the major parameters for examining the status and variations of the ocean. ERSST uses the most recently available International Comprehensive Ocean-Atmosphere Data Set and statistical methods and optimum interpolated that allow stable reconstruction using sparse data. The most recent is version (V3b) of the Extended Reconstructed Sea Surface Temperature (ERSST) analysis. So in this study we considered ERSST. Oceanic Nino index (ONI) done with 3 months running mean of Nino 3.4 region SST, El Nino and La Nina year have identified from Climate prediction center (CPC) with three months running means (http://www.cpc.noaa.gov/products/analysis_monitoring/enso stuff/ensoyears.shtml). The El Nino and La Nina years are used from CPC with ONI criteria used for the study.

Zhoushan harbour is one of the main accesses to Pacific Ocean in East China. It locates at the southern joint point of East China Sea and Yangtze River, the most important economic zone of China, producing the highest GDP and population density. So SL variation study is very important. The main aims of this paper are to identify the SL variations in different time scales and the relation of SL with SST over Zhoushan area SST anomalies also with ENSO events.

3. Results

3.1. Monthly Variations of Sea Level over Zhoushan

To understand the SL variations over Zhoushan area, we have averaged the SL over the study area and the variations are depicted in the figure 2. It is clearly observed that SL is showing a decreasing trend over Zhoushan. SL is varying between -0.07 cm and 0.46 cm with a standard deviation of 0.12 cm. lower SL monthly variations can be observed in 1998-99, 2007-08. The range in 1998-99 is 0.04 to 0.31 cm which is a La Nina year and in 2007-08 is -0.02 to 0.28 cm which is retrieving of La Nina year. Lower values of SL can be explained as the lower rainfall leading to lower river discharge and lower SST values over the study area. Monthly plot is revealing there is a seasonal variation, which is discussing in the next section.

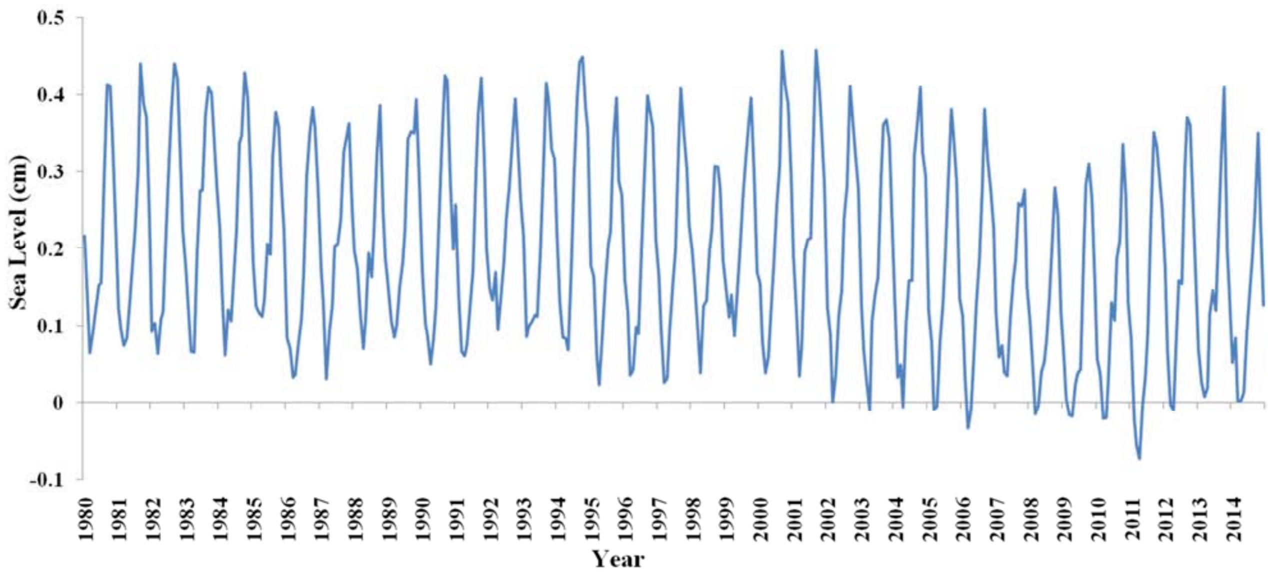

Figure 2. *Monthly variations of Sea level over Zhoushan.*

3.2. Intraseasonal Variation of SL over Zhoushan

Zhoushan SL indicating the seasonal changes, which are given in the figure 3. From the figure 3, one can clearly observe the variations in seasonal variations. Intraseasonal variations are indicating SL is varying during the seasons. However, in some years the variations are lower i.e., on 1998-99 and 2007-2008. The year 2011is indicating negative values, this clearly indicating that SL is decreasing trend. Over all intraseasonal variations are indicating decreasing trend especially since 2000 (or 21st century).

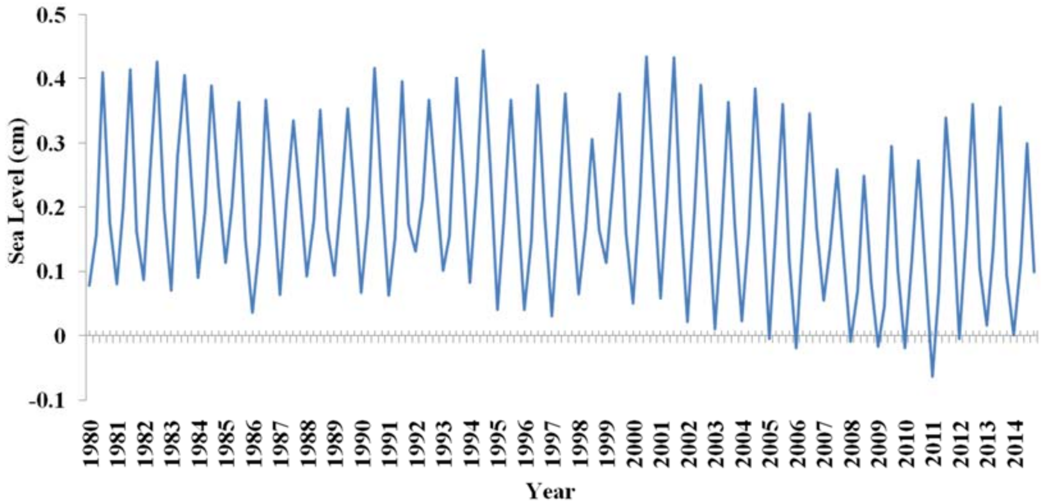

Figure 3. *Intraseasonal variations of sea level over Zhoushan Islands area.*

3.3. Interannual Variations of SL at Different Seasons

Interannual variations clearly indicating that spring is having lower SL and autumn having higher SL. Winter season SL is showing decreasing trend, however it is found that from 2000 SL decreasing rapidly than before year 2000. During the year 2011, SL increased due to it is a La Nina year which produces higher rainfall; more river discharge leading to more sediment transport from river to sea leading to higher SL. SL in the spring season is lower than other seasons. An interannual variation of spring season is also revealing decreasing trend and decreasing higher from 2000. Higher SL can be observed in 2007, which is also a La Nina year. However 2011 is also a La Nina year but the SL decreased maximum than other years which opposite effect when comparing winter season.

Interannual summer season variations also indicating decreasing trend same as winter and spring seasons. SL is indicating lower in 2009. The year 2009 is an El Nino year, rainfall is lower than the normal, lower river discharge and higher sea surface temperature leading to lower SL. Year 2011 is indicating secondary lower of SL, this may be due to continuation of spring season SL. Normally summer time SST will be higher, However during La Nina higher rainfall occur in summer monsoon over the land then through rivers water will be discharged to sea. So SST will be higher over the coastal waters leading to decrease in SL. SL during Autumn season is higher than other three seasons. As other seasons, autumn season SL also following the decreasing trend. During 2011-13, SL indicating higher values, this may be due to lower sea temperatures, higher river discharge and may be due to higher typhoon activity. The annual variations of SL showing a rapid decrease from 2001, however increased in 2012 then decrease. Overall interannual variations indicating decreasing trend especially from year 2000 it is higher.

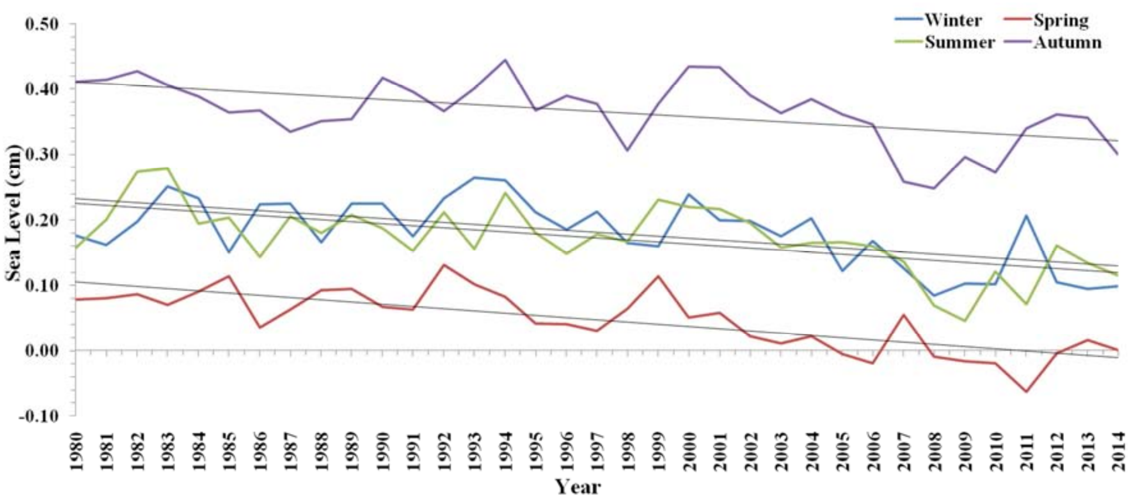

Figure 4. *Interannual variations of seasonal sea level over Zhoushan Islands area.*

Latitudinal interseasonal variations of SL over the study area and study period are depicted in the figure 5. From the figure 5, it can be observed that in the lower latitudes of study area revealing higher SL and lower SL at higher latitudes. Highest SL can be observed in 1992 and 1998, however the SL is decreasing and there are some exceptions of higher SL from year 2000. Lower and negative SL can be observed at higher latitude of study area since 2000. There are some low SL patches can be observed in 1986 at higher latitude. Figure 5 clearly indicating SL variations are depending on Sea temperature, river discharge, sediment present in the water (Zhoushan is having higher sediment in the sea water). However typhoons may also have the effect on the SL, which need to study further in future work.

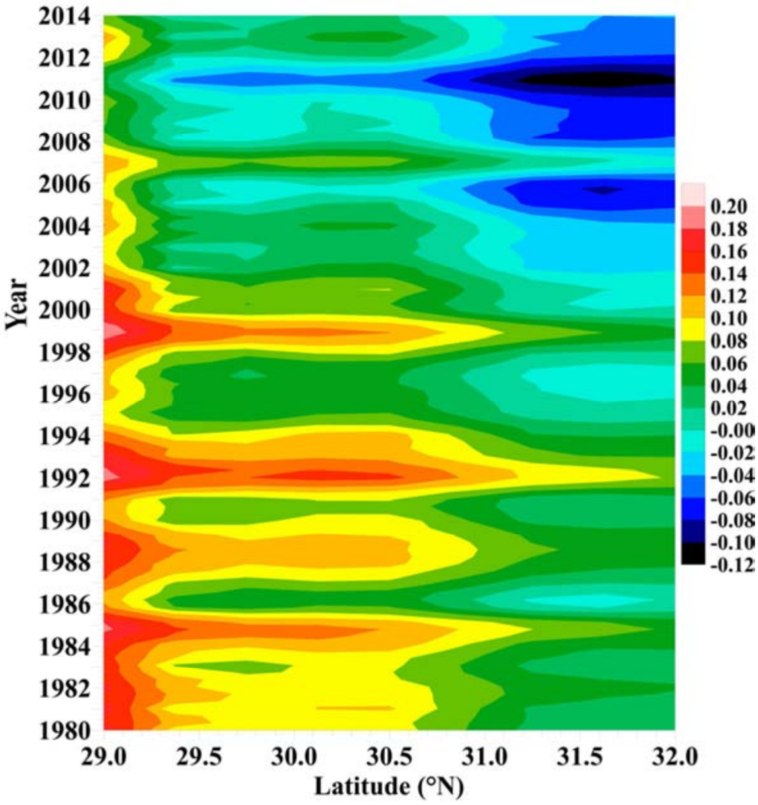

Figure 5. *Latitudinal Sea level variation over the study period (1980-2014).*

4. Discussion

Zhoushan is located in East China Sea, SL variations from this study indicating there is a decreasing trend. Zhen and Wu [18] estimated relative rates of SL rise in China of 0.5 mm yr^{-1} in the north and about 2 mm yr^{-1} in the south. However over the Zhoushan Islands area SL is decreasing especially from 2000. There is an increase in SL before 2000 is 5% and after 2000 there is a decrease in SL about 10%. The SL increase between 1980 and 2000 is ~0.05 cm, however the decreasing in SL from 2000 to 2014 is 0.1cm. Fiedler and Conrad [19] found that increased water storage on continents over the twentieth century would lead to smaller sea level fall along the coasts compared to the ocean. During the twentieth century, there is no increase in the rate of sea level rise has been detected [20], [21] although the longest records do indicate an increase in the rate of sea level rise over the last two to three centuries [22]. Church et al. [23] and Lambeck [24] suggested that regional variations in the rate of sea level rise may explain some of these differences. Indeed, regional variations are to be expected with climate change (whether natural or anthropogenic) as air–sea fluxes of momentum, heat, and freshwater change [25]. Support for regional variations in sea level rise comes from estimates of ocean thermal expansion for the period 1955–95 [26], [27]. Using the historical ocean dataset of, Antonov et al. [26] Cabanes et al. [27] and Levitus et al. [28] find a maximum in steric sea level rise (thermal expansion alone not including other contributions to sea level rise) over the 40-yr period 1955–95 of over 2 mm yr^{-1} in the eastern equatorial Pacific and a fall in steric sea level of about 2 mm yr^{-1} in the western equatorial Pacific. However over the Zhoushan there is an increase in SL of 1.4mm per year till 1999 and decrease in SL of 2 mm per year. The relation between the sea temperature and SL is given in the figure 6. There is an inverse relation can be seen between SST and SL with the correlation of -0.32. When compared with the Nino 3.4 region SST, positive relation can be seen not prominent but the correlation is 0.14. When comparing with Nino 3.4 region SST, the 'inter-annual noise' is a major reason why no definite long-term acceleration of sea level has been identified using twentieth century data alone [21], [29] Church et al. [3] have estimated that at least half of the long-term rise in sea level is from ocean temperature/density effects and, as evidenced by the strong 1997/98 El Nino–Southern Oscillation event, on short decade timescales this steric effect is a dominant control of sea level. The trends are more frequent, persistent, and intense ENSO events as evidenced by the SOI since the mid-1970s [30]. The tendency to more El Nino–like conditions in the equatorial Pacific is also revealed in observations of subsurface ocean temperatures and thus trends in surface steric height from ocean thermal expansion.

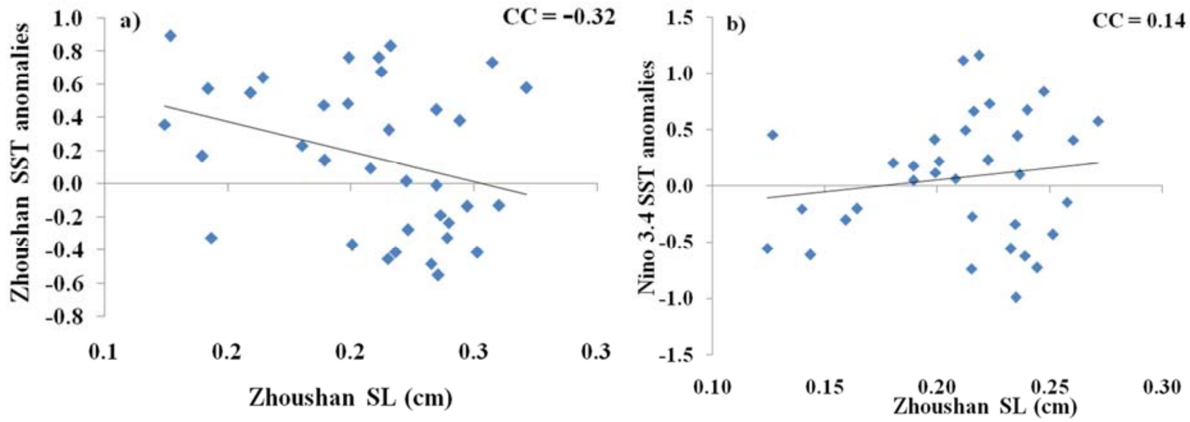

Figure 6. *a) Relation between Zhoushan area Sea level and Zhoushan area SST anomalies and b) same as a) with Nino 3.4 SST anomalies.*

5. Conclusion

Over the Zhoushan area is revealing a decrease trend in SL in monthly, seasonally and interannual variations. SL is increased 5% per year before 2000 and after 2000 there is a decrease in SL about 10%. As previous studies indicating that sea temperature in having an impact on SL, we found there is an inverse relation between Zhoushan area SST anomalies and SL. However there is a positive relation with Nino 3.4 SST anomalies but not significant. Local SST, river discharge, sediment present in the water are having sufficient impact on the SL. However Zhoushan area experience several typhoons and also rainfall, which may also having sufficient effect on SL.

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