Sea level variations of Zhejiang province, China

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Abstract. This paper shows the sea level variations (SL) over Zhejiang province, China. Using Sea surface height data which obtained from the European Centre for Medium-Range Weather Forecasting (ECMWF) and Sea surface temperature (SST) data to validate the correlation of them. Monthly, seasonal, annual and decadal variations of SL over ZJ and its subareas are presented and discussed in this research. SL shows an increasing trend on the whole. However, there is a decreasing trend between the years of 1975 and 1987, then SL shows increase. Over the ZJ province, the rising rate of SL is 0.343 cm/a from the year of 1958 to 1975 and the rising rate of SL is 0.238 cm/a after the year of 1987. The overall rising rate of SL in the ZJ province is 0.172 cm/a from the year of 1958 to 2015, then we can also find that the dropping rate is 0.264 cm/a from the year of 1975 to 1987. The Maximum SL height of ZJ province is in 2012. Further SL variations have been done over the ZJ province which includes Hangzhou Bay (HZB), Ningbo (NB), Zhoushan (ZS), Shengsi (SS) and Wenzhou (WZ) areas. We have checked the steric effect with SST on SL. It was found that there was a positive correlation (CC= 0.77) between SL and sea surface temperature (SST), and the same correlation was observed in other areas of Zhejiang Province.

1. Introduction

Sea level (SL) variation is one of the important parameters of the earth's response to climate change [1]. As one of the catastrophic consequences of climate change the rise of SL is receiving increasing attention from global researchers. From a variety of perspectives, the rise of modern SL is an issue that needs urgent attention, especially because it may accelerate development and thus threaten many low-lying areas of the world [2]. Climate model projections in the 21st century show that in addition to global mean sea level changes, large-scale spatial patterns are also subject to change, which may have a significant impact on local sea level rise [3].

Since 1980, Global sea level rise rate has an increasing trend. Meanwhile, the rising rate of China's coastal sea level is higher than that of the world [4]. Since 2000, Except for a slight decline in 2005, China's coastal sea level continues to increase and 2012 reached its highest level since 1980. In 2012, coastal temperature and SST were 0.4 °C and 0.3 °C higher, respectively than the usual years [5]. The abnormality of the wind causes the accumulated water to be one of the causes of sea level rise. 2012 was a tropical cyclone landing time with a wide range of influences, especially in August 2012, when six tropical cyclones affected the Chinese coast, which had a significant impact on sea level rise during the month. In the context of global warming, sea level rise has become a major global environmental problem. The impact of sea level rise on coastal economic development, marine ecological environment
and people's production and life has become increasingly significant.

In recent decades, many experts have made a lot of investigations to get consistent understanding: In recent 100 years, the global sea level is on the rise and the average rise rate is about 1.0~2.0 mm/a according to previous studies [6]. The annual average sea level change in China's coastal areas is within the same range, but there are significant differences in different regions.

The temperature is expected to rise by 2°C-4.4°C by 2100, resulting in a global average sea level rise of 2-6 mm per year. Mean global SL and mean global sea surface temperature (SST) has strong correlation [7] which suggests that the steric effect impact sea level signature. Further this is supported by the strong similarity of the spatial distribution of satellite-observed in sea level variations and surface temperature [8]. In the long time scale, in addition to global warming factors, sea level changes are also affected by structural changes in the earth, activities during the Great Ice Age, and other factors such as the atmosphere, the thermal expansion of water, and the ocean itself [5].

2. Study Area and Data
Zhejiang is a province with the most islands in China, among which Zhoushan Archipelago is the largest. Zhejiang also boasts a coastline extending 6,486 kilometers and a total ocean area of 220,000 square kilometers. In addition, the province has a large number of bays with over 60 natural ports of different sizes, constituting a port-cluster among which Ningbo Port, Wenzhou Port, Zhoushan Port and Taizhou Port are the most important. Under subtropical and monsoon conditions, Zhejiang has four distinct seasons. It has an average annual temperature of 15-18°C, 230-270 frost-free days and an average annual rainfall of 1000-1900 mm. It has numerous rivers with a mean annual surface water runoff of over 90 billion cubic meters. Zhejiang is located in the southern part of the Yangtze River Delta on the southeast coast of China, which accounts for sediment transport to sea. In the study area we chose 26-32°N: 119-124°E. Further the coastal areas have been chosen to find out the variations of SL over Zhejiang Province and they are as follows: Hangzhou Bay (HZB) 30-31°N; 120-122°E, Ningbo (NB) 28-31°N; 120-123°E, Shengsi (SS) 122.5°E; 30.5°N, Wenzhou (WZ) 27-29°N; 119-122°E and Zhoushan (ZS) 29-32 N; 122-124°E.

Sea Surface Height data relative to Geoid over the area is obtained from the operational ORAS4 data. The European Centre for Medium-Range Weather Forecasting (ECMWF) estimates the state of the global ocean via the operational system Ocean-S4. Ocean-S4 gives an estimate of the history of the ocean from September 1957 to present (with a few days delay) via the Ocean Reanalysis System 4 (ORAS4), as well as the latest ocean conditions. In this study, the data over the period of January 1958 to December 2015 monthly data are used to show the study areas sea level variations.

To validate the relation between the SL and sea surface temperature relation, we have used the dataset HadISST (Hadley Centre Global Sea Ice and Sea Surface Temperature) which is a combination of monthly globally complete fields of SST and sea ice concentration for 1871-present. HadISST is primarily intended to be used as boundary conditions for atmospheric models and Version 1.1 is the current version. The SST data is used to calculate and give the relationship between SL and SST.

3. Results

3.1. Monthly Variations of Sea Level over Zhejiang province
In order to understand the SL variations over Zhejiang area, we averaged the SL data over the study area from 1958 to 2015, and the variations are presented in Figure 1. It is clearly observed that SL shows an increasing trend over Zhejiang province. A lower monthly height in SL was observed in 1961-62 and 1967-68. There was a higher SL monthly height in 1975, 2000, 2009 and 2012, which is retrieving of typhoon years. A higher SL value can be explained by the greater rainfall, resulting in higher river discharge and SST values within the study area. Monthly plot reveals that there is a seasonal variation, which are discussed in the next section.
3.2 Inter-seasonal Variations of SL at Different Seasons

Figure 2 shows the inter-seasonal variations. It can be seen that the sea level has obvious seasonal difference, which are lower in winter and spring and higher in summer and autumn. SL height in the spring season is lower than other seasons. The overall four seasons showed the same trend. In the winter of 1975-1987, SL showed a downward trend and then showed an upward trend.

3.3 Annual variations of SL

The interannual variations in Zhejiang and other places are shown in Figure 3. From the curve of change, they show the same trend. In the 1950s to 1960s, the sea level was almost less than 21 cm and in the 1970s, there was a rise process and then a decrease. 1975 was the highest. Since the 1980s, it has been increasing year by year. Previous studies have shown that large deflections of Kuroshio can cause sea level rise [9]. Because a large amount of high temperature and high salt water will be transported in the East China Sea during the Kuroshio Bend, which has a great influence on the marine environment of the East China Sea [10], sea level change is the appearance of this effect. During the El Niño phenomenon, sea levels fell. In our research time series, the strongest years of El Niño were 1957~1958, 1965~1966, 1972~1976, 1982~1982, 1991~1992, 1993, 1994~1995, 1997~1998, 2007 and 2015. During the formation and development of the El Niño, the equatorial westerly wind is abnormal. The tropical Pacific warm water is from west to east, and the eastern Pacific is warming, and the sea level is rising, and the western Pacific sea is cold, causing sea level to fall.
3.4 Decadal variations of SL
The interdecadal changes of SL are shown in Figure 4. It shows the average change in SL every decade. From 1958 to 1987, it was negative, but the sea level has been rising, and by 1997 the sea level was close to zero. From the year of 1998 to 2015, it increased rapidly.

3.5 Sea Level trend analysis
The sea level change rate is shown in Figure 5. We plot using anomalous data values, which is calculated from the average monthly sea level height minus the monthly average of years. Showing that 1958-2015 increasing rate is 0.1715cm/a, 1958-1975 is 0.3431cm/a, and from 1987 to 2015 is 0.2377cm/a. And from 1975 to 1987 is decreasing trend, the change rate is -0.2635cm/a.

3.6 Spatial variations 1993-2012
Figure 6 shows the geographical distribution of the sea level change trend did by the Maps of Sea Level Anomalies (MSLA). Generally, the sea level of the entire coastal area of Zhejiang rises at different rates. It can be seen that the sea level is declining in Taizhou and Wenzhou areas from 1993 to 2000. Figure 7 shows that most places are positive, indicating that sea level is rising from 2000 to 2012. One of the main reasons may be the increase in sea surface temperature.

3.7 SL variations related to SST
Changes in sea surface temperature inevitably affect sea level changes. In this paper, the sea surface temperature (HadISST) data is used to calculate the change of sea surface temperature in Zhejiang Province. We used HadISST (1958-2015) temperature data and sea surface height data to calculate annual changes and compare them, and then we get Figure 8. The results show that the sea surface
temperature was the lowest in Zhejiang Province in 1970, and around 1970, the sea surface temperature in the northern hemisphere suddenly dropped [11]. Since then, the increase in SST has reached its maximum until 1998. During this time, sea level has also been rising.

To further investigate the correlation between SL and SST, we analyzed the correlation between the two data, and Figure 9 is a correlation function graph of the two. From 1958 to 2015, the correlation coefficient between sea level and sea surface temperature was 0.7284, indicating that sea level changes are closely related to changes in sea surface temperature.

4. Conclusion
It can be seen from the monthly average change, seasonally and interannual variation that the SL in Zhejiang Province is on the rise. From 1958 to 2015 as, SL increased by 0.1715cm per year. From 1975 to 1987, SL decreased by 0.2635 cm / a. As previous studies have shown that sea surface temperature has the same effect on SL, we find a positive correlation between SST and SL in Zhejiang area and the correlation coefficient is 0.7284. Local sea surface temperatures, river excretions, and sediments in the water have an effect on SL. However, the Zhejiang region experiences several typhoons and rains almost every year, which may also have a sufficient impact on SL.

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