# Correlation Analysis between Sea-level Change of China's Coastal Areas and the Mass Change of Antarctic Ice Caps

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***Abstract*—Impact of sea-level change on coastal areas has long been a concern of the world, especially the coastal countries. It is an important part in the research of the marine environment. Sea-level change is caused by various social and environmental reasons, among which the contribution of the Antarctic ice caps mass change is a significant factor. In order to investigate the correlation between sea-level change of Chinese coastal areas and the Antarctic ice caps mass change, several geo-statistical methods were involved in this paper. The Antarctic equivalent water height and sea level anomaly datasets were applied. First, the periods of the two datasets above-mentioned are found though the spectrum analysis and a further analysis of these periods is made. Then the correlation analysis is carried out using the time series which span from January 2004 to March 2010. Through the rapid inverse Fourier transform we obtained the cross-correlation function, drew cross-correlation function diagram and analyzed correlation degree and the lag time of these two time series. Research shows that (1) the sea level change has a year cycle as the leading period, meanwhile equivalent water height change has a half year cycle as the leading factor and display a complicated multi-scale coupling fluctuation characteristic; (2) The cross-correlation function diagram indicates that these two time series highly positive correlated when the lag time is 8 month and highly negative correlated when the lag time is 26 month. There is a teleconnection between these two events.**

***Index Terms*—sea-level change; Antarctic ice caps mass change; spatio-temporal correlation; marine environment ; glolal change**

## I. INTRODUCTION

Sea level change has become more and more important part of the global change and closely related to people's life. Tiny sea level rise will cause aggravating flooding in large tracts of land and coastal erosion and consequence is unimaginable. China's mainland coastline is about 18, 000 km long. About more than 70% of the big cities and more than 50% of the population is concentrated in the eastern coastal areas, which are the most economically developed areas in China. But they are also the most serious vulnerable regions affected by sea level change that will aggravate natural disasters and influence the social economic development in the coastal areas.

The fluctuation of the global sea-level change is mainly caused by the global sea water density and mass change. The former factor is mainly caused by the temperature and salinity changes and the latter is influenced by snow and ice ablation and cumulative, precipitation, evaporation, overland runoff and sea-air-land water circulating.

With the aggravation of the greenhouse effect, thermal expansion caused by the snow and ice melting and temperature rising has become an important reason of global sea-level change. According to the results of ocean general circulation models (OGCMs) simulation, the thermal expansion is the largest contribution to the sea-level rise in the recent fifty years, which is about 0.3~0.7mm/yr. While the sea-level rise aroused by non polar glacier melting and by Greenland and Antarctic ice mass changes is 0.2~0.4mm/yr and 0.2~0.6mm/yr respectively [1]. It's pointed that in the past decade sea-level change due to thermal expansion and non polar glacier change is totally 2.37mm/yr. Compared to the observation of 3.1mm/yr, there still is a discrepancy of 0.73mm/yr, which is the contribution of the polar ice caps changes [2].The polar ice areas are universally recognized to be sensitive and key areas in the research of global change. Investigating the mass balance of Antarctic ice caps plays a key role to make a further know about the global mean sea level changes and other related problems.

Therefore, within the framework of a global change research project, the study of the correlation between sea-level change and the Antarctic ice caps melt, as a sub subject, is of great significance to the global climate and marine environment research, which can reduce the uncertainty of evaluating the contribution of the polar ice caps melt to the sea-level rise.

The rest of the article is structured as follows: data and study areas are provided in Section 2, followed by a description of key technologies and methods in Section 3. Empirical analysis based on the observation data is presented in Section 4. Section 5 concludes with a summary and a discussion.

## II. DATA AND STUDY AREAS

The merged sea level anomaly (SLA) satellite altimetry data of Chinese coastal areas, provided by AVISO data center, is applied to describe the change of sea-level change in this paper. This product is a cross calibrated delay dataset from a variety of synchronous satellite, which is the sea level anomaly mesh data of the 1/3 °×1/3 °Mercator projection generated from weekly/monthly along-track data. This data has been correct for instrumental error, environmental interference (influence of wet troposphere, dry troposphere and ionosphere), hypo (Douglas deviation), tide (ocean tides, earth tides and pole tides) and Contravariant barometer's interference. In present paper, the selected data ranges from October 1992 to March 2010

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monthly in time, 24 °N to 36 °N and 118 °E to 125 °E (Chinese coastal areas) in space. The spatial resolution is 1/3 °.

About 8-year-long Antarctic equivalent water height mesh data, originated from the newly released GRACE data, is used to show the spatio-temporal distribution of ice caps changes. The selected data ranges from January 2004 to March 2012 monthly in time, 60 °N to 90 °N and 0 °E to 360 °E (the Antarctic) in space. The spatial resolution is 1 °.

The research areas is shown in the Fig. 1.The blue area stand for the layout of the SLA dataset while the green one for EWH dataset.

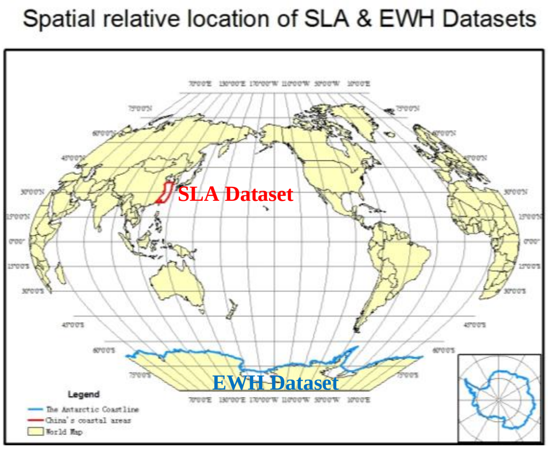


Figure 1. Spatial relative location of SLA & EWH Datasets

## III. METHODOLOGY

### A. Spectrum Analysis

Spectrum analysis is an important method to analyze the periodic change of time series, which is widely used in communication, medical science, military and many other fields. It is the frequency domain analysis based on the Fourier transform, by which the total energy of the time series is decomposed into component in different frequency. In this way, we can investigate the hidden significant period of the time series and understand its inherent character.

Energy spectral density describes how the energy of a signal or a time series is distributed with frequency. If the power of $f(t)$ is finite, namely square integrable, the power spectral density of the signal $\Phi(t)$ can be defined as

$$\Phi(\omega) = |\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(t)e^{-i\omega t}dt|^2 = \frac{F(\omega)F^*(\omega)}{2\pi} \quad (1)$$

Here ω is the angular frequency, 2π times of the cycle frequency. $F(\omega)$ is the continuous Fourier transform of $f(t)$. $F^*(\omega)$ is the conjugate function of $F(\omega)$. If the signal $f_n$ is discrete, with finite element, power spectrum density can be defined as

$$\Phi(\omega) = |\frac{1}{\sqrt{2\pi}}\sum_{n=-\infty}^{\infty} f_n e^{-i\omega t}|^2 = \frac{F(\omega)F^*(\omega)}{2\pi} \quad (2)$$

where $F(\omega)$ is the discrete Fourier transform of $f_n$. If the defined numerical number is finite, the sequence can be regarded periodic. The spectral density of infinite time series can be calculated through the discrete Fourier transform for discrete spectrum or zero fill. The multiplication factor $1/2\pi$ is not often absolute, which differs with normalization constant of different Fourier transform definition.

By means of spectrum analysis, simple characters of the complicated sea level height anomaly and equivalent water height fluctuation, such as periodicity or hysteresis, can be demonstrated with quantitative results.

### B. Cross-correlation Function

Cross-correlation is a measure of the similarity of two time series or two different moments of one time series. The power spectral density and cross-correlation function of two correlated time series can be calculated by the Fourier transform. Thus the time lag between these two sequences is investigated. Then the power spectrum diagrams in the frequency domain and lag domain were drawn to learn the periodicity and hysteresis of these two time sequences [3].

$f_1(t)$ and $f_2(t)$ are time series, which are generally the complex function of time.

$$R_{12}(\tau) = \int_{-\infty}^{\infty} f_1{}^* f_2(t+\tau)dt \quad (3)$$

As in (3), $R_{12}(\tau)$ is defined as the cross-correlation function of $f_1(t)$ and $f_2(t)$.

After calculating the power spectral density of two series, we can obtain the cross-correlation function through the rapid inverse Fourier transform, drew the cross-correlation function diagram, detected the peak of it and analyzed correlation degree and the lag time of these two time series.

### C. Workflow

First of all, data is preprocessed to obtain integrated time series of mean sea level height anomaly (SLA) of Chinese coastal areas and equivalent water height (EWH) of Antarctic ice caps. Then, the periods of these two time series can be detected through the spectrum analysis method. Finally, the time lag correlation of two sequences is analyzed, which timely range from January 2004 to March 2010. The cross-correlation function is obtained through the rapid inverse Fourier transform. Then the peak of the cross-correlation function diagram is detected and correlation degree and the lag time of these two time series are analyzed. The work flow is shown as Fig. 2.

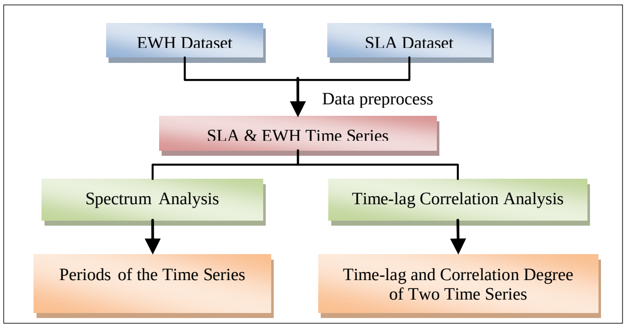


Figure 2. Workflow of the article

## IV. RESULTS AND ANALYSIS

### A. Results of Spectrum Analysis

Fig. 3(a) and (b) display the mean sea level height anomaly (SLA) of the Chinese coastal areas and the equivalent water height of the Antarctic ice caps pretreated time series, from which we can roughly find both changes present a complex cyclical fluctuation. The sea-level change has a year cycle as the leading period and it shows an ascendant trend from 1992 to 2010. Meanwhile the equivalent water height change has a more complex fluctuation and about half-a-year's fluctuation is relatively obvious. And as a whole, these two time series are negatively related. Namely equivalent water height reduces while sea-level rises.

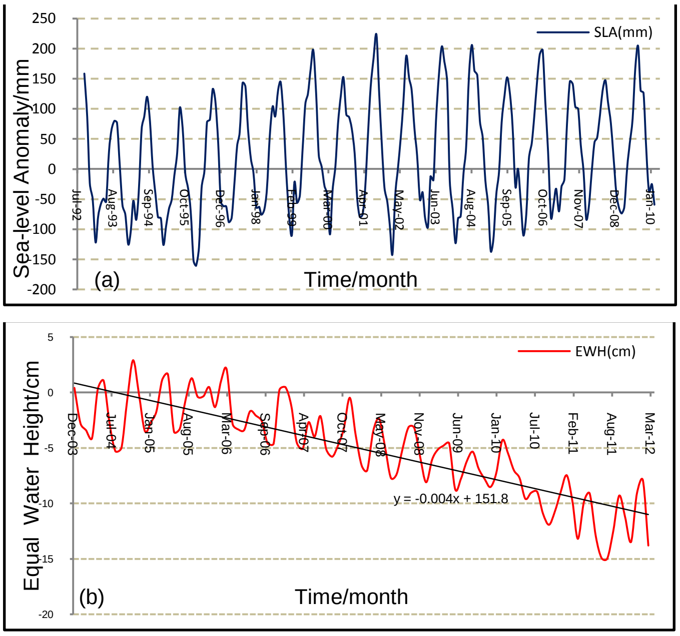


Figure 3. (a) Time Series of SLA (1992.10~2010.3), (b) Time Series of EWH (2004.1~2012.3)

The data was standardized to eliminate the interference of short-term error. To standardize a data set, individual values are converted to z-scores by using the mean and standard deviation of the data set. According to the principle of the frequency spectrum analysis, these two time series are analyzed by the Matlab programming. The power spectrum density is calculated and spectrum diagram is drawn respectively (Fig. 4(a) and (b)). Periods are shown in Table I (a) and (b).

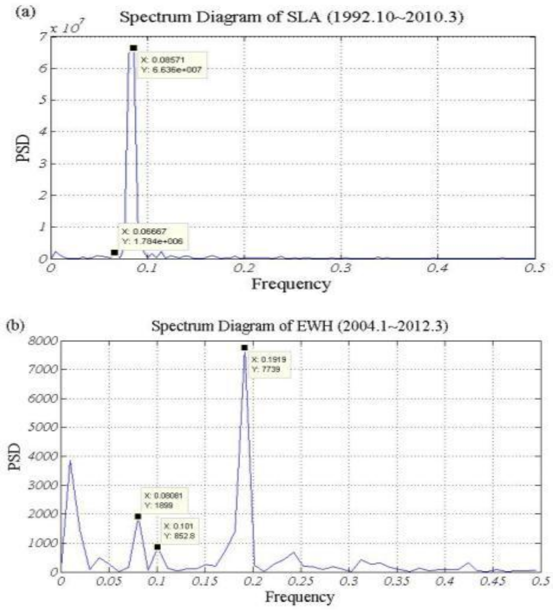


Figure 4. (a) Spectrum Diagram of SLA (1992.10~2010.3), (b) Spectrum Diagram of EWH (2004.1~2012.3)

TABLE I. TABLE TYPE STYLES

| Periods of SLA (month) | |
|---|---|
| ***Frequency*** | ***period*** |
| 0.06667 | 15 |
| 0.08571 | 12 |

a. Periods of SLA

| Periods of EWH (month) | |
|---|---|
| ***Frequency*** | ***period*** |
| 0.0808 | 12 |
| 0.101 | 10 |
| 0.1919 | 5 |

b. Periods of EWH

The first peak in Fig. 4(a) and (b) presents the period of approximate the length of the observation records, so it won't be discussed. The results show that mean sea-level change has a leading period of a year, which obviously change with the seasons. It is seen that it reaches the maximum in September to October and minimum in February to March.

Equivalent water height changes in a leading period of 5 months. Because when the tidal model is used to remove tides in the process of GRACE products' calculating, the sun semidiurnal tidal S2 signal of the ocean tide model is mixed in the time series. Therefore, when using GRACE time-variable gravity to calculate the change of the mass of the Antarctic ice caps, there is a period of 161.3 days, namely 5 months [4].

### B. Cross-correlation Analysis

Considering the different temporal scale of two time series, the time lag correlation analysis is carried out based on the selected preprocessed data from January 2004 to March 2010 (Fig. 5).

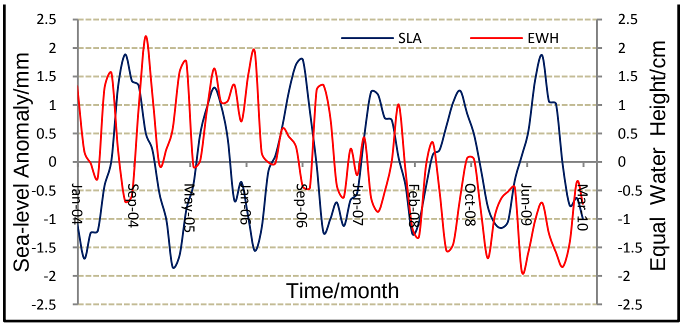


Figure 5. Time Series of Standardized SLA and EWH (2004.1~2010.3)

First the standardized data ranges from January 2004 to December 2007 is calculated through the rapid inverse Fourier transform to get the cross-correlation function of two time series. Then Fig. 7 is the cross-correlation function diagram, through which the correlation degree and time lag time can be obtained by peak detection. Finally, the results are confirmed with the data after January 2008.

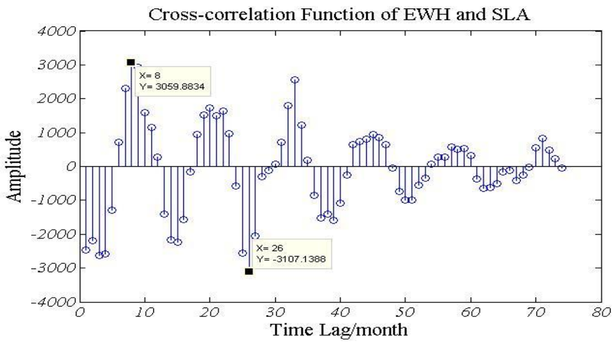


Figure 6. Cross-correlation Diagram of Standardized SLA and EWH

The time delay between two series is shown by the cross-correlation function peak detection. As shown in Fig. 6, two series highly positive correlated when time delay is 8 month and relatively highly negative correlated when time delay is 26 months.

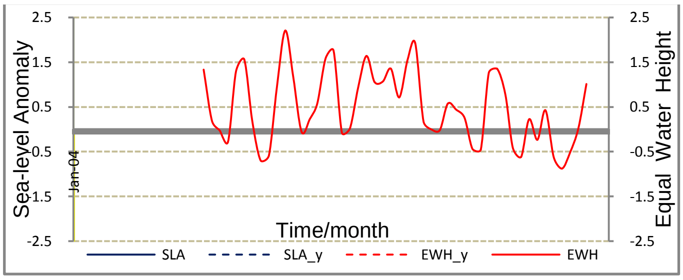


Figure 7. Time Lag Analysis

As shown in Fig. 7, the blue and red solid curves represent the analyzed records of SLA and EWH ranging from January 2004 to December 2007, while the dotted curves respectively stand for the confirmation observations from January 2008 to March 2010. To December 2007, the last time that sea-level rises while equivalent water height rises occurred in June or July 2007 (the first green line). According to the cross-correlation function and time lag analysis, it can be inferred that this phenomenon should appear about 8 months later, namely around March 2008 (the second green line). Similarly, the sea-level anomaly decreases while the equivalent water height rises in December 2007 and the EWH reaches a peak of the curve (the first yellow line). The next time this phenomenon should appear 26 months later, namely in February 2010 (the second yellow line). In this way, the results of the time lag correlation are confirmed.

In conclusion, the study above shows that there is a teleconnection between the polar ice and snow change and the sea-level change through the time lag correlation analysis of the sea-level anomaly in Chinese coastal areas and equivalent water height of the Antarctic ice caps.

## V. DISCUSSION

In this paper, the main task is to study the relationship between the polar ice caps mass change and Chinese coastal areas sea-level change. Research shows that the sea-level change has a year cycle as the leading period, meanwhile equivalent water height change has a half year cycle as the leading factor and display a complicated multi-scale coupling fluctuation characteristic. And the existence of possible teleconnections between these two changes is investigated through the spectrum analysis, the cross-correlation function and the time lag correlation analysis. But the correlation of these two time series seems not very significant, because the collected research data of Chinese coastal areas sea-level anomaly and the Antarctic ice caps equivalent water height differs much in time scale. Further research will be made on the basis of extracting the impacts of local factors and important atmospheric and hydrological events on these two time series.

## ACKNOWLEDGMENT

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