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Interannual and Decadal Variation of Sea level in the East China Sea

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ABSTRACT

Sea level variation and its dynamic and thermal processes were investigated with the TOPEX/Poseidon (T/P) altimeter data, reconstructed sea level data and tide gauge records on the interannual and decadal scale in the East China Sea (ECS). Stochastic dynamic method was used to analyze the characteristics of sea level variation. During 1993 to 2010, the sea level rising rate of the whole ECS was 2.5mm/a. The interannual and decadal sea level variations were remarkable and, focused on 2~4 and 8~10 years. The interannual sea level variation was influenced by ENSO and the amplitudes mapped non-uniform spatially. The interannual amplitude was less than 5 cm, which steric effects contributed 65%.The correlation between steric sea level and sea level can reach to 0.93. We found that ocean currents and zonal wind stress exhibited as the main oceanic dynamic factors to influence the interannual sea level variation in the ECS, as well as the vertical structure and its changes of temperature and salinity. By comparing sea level anomaly with wind stress in the ECS on the interannual scale, their correlation coefficient was up to -0.65, when the sea level lagged zonal wind stress 3 months. On the decadal scale, wind stress and steric effects acted as the important physical processes contributing to the sea level variation.

KEY WORDS: sea level variation; ECS; interannual and decadal scales; wind stress; steric effect; volume transport

INTRODUCTION

The sea level is a very sensitive indicator of climate change, it has been a topic of keen interest among international governments and scientists nowadays. In the past decades, a series of studies have devoted to estimate the sea level rising rate, reported in the IPCC Fourth Assessment Report (IPCC, 2007). Sea level trend is highly non-uniform spatially, for example the rates in some regions, such as the Pacific warm pool, are up to several times of the global mean, while in other regions sea level is falling.

The East China Sea (ECS) is one of the most wide shallow shelf and biologically productive seas in the world. Under the strong monsoon system, close to the boundary current (Kuroshio) in the east edge, the ocean thermal and dynamic environments exhibited the temporal and spatial variations in the ECS. The variations are strongly influenced by the air-sea interaction, circulations and steric effect.

It was reported that sea level variations over multi-timescale illustrated spatial non-uniformly. After the launch of the TOPEX/Poseidon satellite, considerable researches focused on the regional sea level variations and its possible reasons, such as in the ECS. Li et al. (2000) analyzed the seasonal characteristics in the ECS by using T/P altimetry data. Results from Wang et al. (2001) indicated that the interannual variation in the ECS was significant and draw a conclusion that the spatial patterns of the principal components correspond to the oceanic currents. Yan et al. (2007) obtained the averaged sea level rise was 4.9mm/a during 1993 to 2003 in the ECS, besides seasonal signals, quasi-biennial sea level oscillation was prominent. Han et al. (2010) stated that the annual sea level cycle can be approximately accounted for by the steric height variation while the interannual and longer-term sea level variability in the altimetric data were negatively correlated with the Pacific decadal oscillation (PDO), attributed in part to steric height change. Liu et al. (2010) found that ENSO phenomenon influenced wind filed of the ECS and the interannual variation of sea level.

Understanding of the thermal and dynamic processes influenced the regional sea level variation is the main research spot, especially the research between wind and sea level variations was unclear. In this paper, three types of sea level datasets were collected to analyze the reasons of the eustatic sea level on different timescales in the ECS (22º-44ºN, 116º-131ºE). We emphasized researching on interannual to decadal time scales, especially the dynamic mechanism (wind and ocean circulation).

DATA

Sea level anomaly

Sea level anomalies (SLA) data was obtained from the AVISO Altimetry data center and correspond to a reprocessing of Ocean

Topography Experiment (TOPEX)/Poseidon and European Remote Sensing Satellite (ERS-1/2) data. Media and instrument corrections (ionosphere, dry and wet troposphere, and electromagnetic bias) and geophysical correction (tidal and inverted barometer) were applied to the raw altimeter data. We extracted the data from 1992.10 to 2011.1 to analyze the interannual variation of the ECS. Prior to using, the raw weekly products with the spatial resolution of 1/3°×1/3°, were resampled into the monthly data.

The reconstructed sea-surface heights data (Church et al., 2004) and tide gauges records from PSMSL were used to study the sea level variations on decadal scale. Tide gauge observation record was the exclusive data for examining the decadal relative sea level variation historically. We selected five representative stations, these five tide gauges scattered in the ECS. Taking the length of these tide gauges records in consideration, the shortest one was more than 40 years while the longest one was more than 50 years (mentioned in Fig.6a). The reconstructed SSH data were from 1950 to 2001 with the spatial resolution as 1°×1°, the seasonal signal had been removed from the raw reconstructed data. Recently, the reconstructed SSH was another indispensable database for the research on sea level change/variation.

Temperature and Salinity Datasets

The monthly objectively analyzed subsurface temperature and salinity (version 6.9) for the period 1945–2010 were the most recently available dataset produced by Ishii et al. (2005, 2009). The analysis is based on the latest version of World Ocean Database (WOD05) and World Ocean Atlas (WOA05) and a set of XBT observations compiled by the Japan Oceanographic Data Center. A near-real time data archive made available through the Global Temperature-Salinity Profile Program (GTSPP) was also used, which compensated the data sparseness of WOD05 since 1990. The spatial resolution of the data was 1°×1°, with 24 standard depth levels to 1500 m. The vertical resolution with depth 0, 10, 20, 30, 50, 75, 100, 125, and 150 m respectively, every 50 m to a depth of 300 m, and then every 100 m to a depth of 1500 m. The temperature and salinity during 1960-2010 were used to calculate the steric sea level height and analyze the characteristics of the thermocline in the ECS. The procedure for calculating steric sea level was elaborated in Thomson et al (1988).

Wind stress and Current Datasets

Simple Ocean Data Assimilation (SODA) was the reanalysis results of the General Circulation Ocean Model, which assimilated with the temperature and salinity observation profiles from the World Ocean Database and other projects. The ocean current and wind stress outputs were provided with resolution of spatial 0.5° × 0.5° horizontal grids. The ocean current data placed on 40 standard depth levels to 5374 m.

In this paper, the SODA wind stress and ocean current data were used to find out the dynamic processes imposed on sea level variations. Two temporal records of the wind stress data, such as 1980-2008 and 1950-2001, were analyzed to the interannual and decadal features compared with the T/P measurements and reconstructed data, respectively. The current data from 1980-2008 was used to calculate the volume transport of the Kuroshio in ECS.

RESULTS AND DISCUSSIONS

Sea level variation in the ECS

Interannual Variability

The stochastic dynamic method was performed to obtain the characteristics of the sea level variation on different time scales. The method could decompose the raw data into the polynomial, periodical and random terms. Usually, the results of the power spectral analysis were associated with the length of the samples, while the maximum entropy spectrum method (MEM) could distinguish comparatively precise cycles, especially to the short samples. Every cycle had been conducted with the significance test. The method adopted the MEM in the temporal series analysis, and then got the periods and amplitudes of the main corresponding cycles accompanied with the trend of the sea level variations.

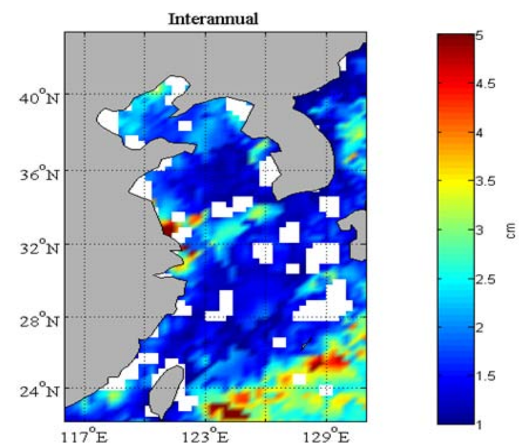

Fig.1 Geographical distribution of the significant interannual variations (shade area represented the amplitudes, unit: cm).

Sea level variation was significant on interannual scale, whose possible mechanisms would be discussed in following sections. Based on the results of the stochastic dynamic method, the amplitudes of the selected significant period on interannual scale in the ECS were shown (Fig.1). The T/P sea level variation mapped the geographical variability. Generally, interannual cycle presented little amplitudes less than 5 cm in the ECS. The prominent variability, about 3-5cm, occurred along the Jiangsu and Zhejiang coastal area and the eastern Taiwan Island region, while amplitudes were within 3cm in the other parts. The blank square in the ECS indicated there were no significant interannual signals in the area. Compared with the seasonal sea level variation, there were comparable interannual amplitudes in the area east off Taiwan Island. However, the interannual amplitudes were far smaller than the seasonal amplitudes in other part of the ECS.

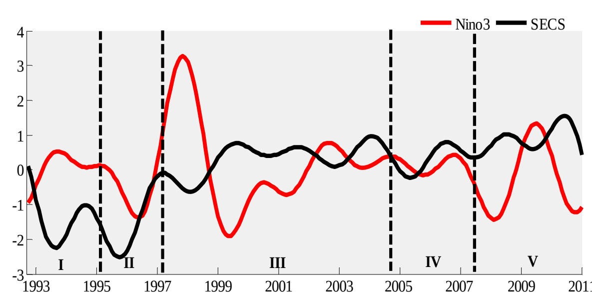

Fig.2 Normalized series of the mean sea level of the SECS and the Nino3 index during 1993-2010 (24 months low-pass filtering)

Nonuniform variations of sea level exhibited in the ECS geographically, many studies had divided the area into many regions. In this paper, the southern part of the ECS (SECS) with a range of 22°-35° N and 116°-132° E was analyzed the sea level variations and its relationship with El Niño events, where bathymetry was comparable relatively to the scale of the ocean dynamic phenomena. We analyzed low-frequency variations of sea level in the region by a two years low-pass filtering (Fig.2).

It was indicated that the ECS sea level interannual variation was modulated by the El Niño/La Nina events significantly. SLA time series and Nino3 index were almost out of the phases during the El Niño/La Nina events (episode I, III and V, illustrated in the Fig. 2). It was found that during these three events, the mean sea level time series was definitely opposite to the Nino3 index with the coefficient of -0.65. Taking into consideration of the episode III, from the very beginning of the El Niño/La Nina event since 1997 to 2005, their phases were exactly opposite, and their correlation coefficient was up to -0.69. During the non-El Niño/La Nina events period, such as from 1995 until the forthcoming 1997/98 El Niño event (episode II) and 2005 to June 2007 (episode IV), SLA showed in phase of the Nino3 index, with 4-5 months ahead. The baroclinic Rossby waves generated at mid-latitude of the eastern North Pacific and propagated westward, would contribute to the SLA oscillations on interannual timescale associated with El Niño/La Nina events.

Seasonal Variability and Trend

Seasonal amplitudes in the ECS were extracted (Fig.3), similar to the interannual variation. It could be found that large seasonal amplitudes appeared along the Chinese eastern coastal area, generally between 10 to 14 cm, especially in Bohai and the shoal of northern Jiangsu, yielded much less off the east of Taiwan Island. Meanwhile, the region 125°~127° E, 22° to 24°N shows no significant seasonal amplitudes. Seasonal variation was small relatively around the Yellow Sea cold water mass.

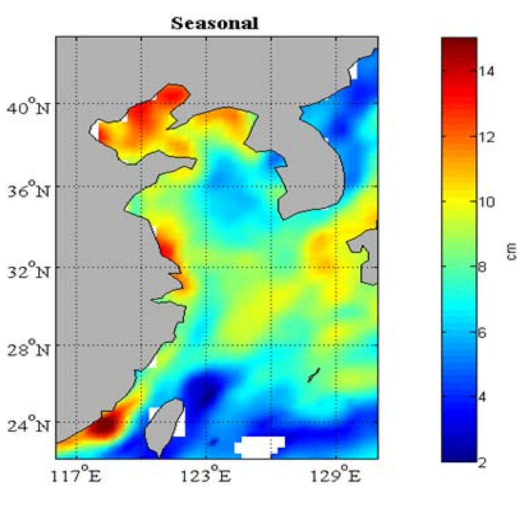

Fig.3 Geographical distribution of the seasonal variation (similar to Fig.1)

To analyze the spatial distribution characteristics of the sea level in the ECS, we showed the rising rate by using stochastic dynamic method (Fig.4). Sea level was rising during the last two decades, associated with geographical non-uniform distribution (Fig.4). In the whole ECS region, rising rate was between -1mm/a to 10mm/a. It showed significant increasing trends in the shoal of northern Jiangsu, the Haizhou Bay and the Fujian and Zhejiang coast, whose rising rate were between 3-7mm/a. Low rising rate could be found in the mid-Yellow Sea and northern part of the ECS, with the rising rate was nearly 1mm/a. The area east off the Okinawa island presented a declined tendency, the decreasing rate can up to -3mm/a.

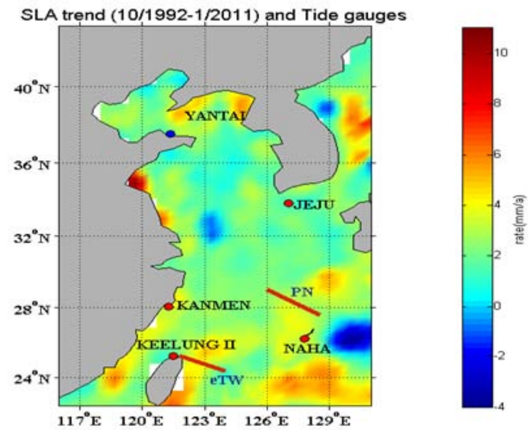

Fig.4 Sea level trend during Oct. 1992-Jan. 2011(unit: mm/a), locations of the five selected tide gauges, and the eTW and PN sections in the ECS

Decadal Variability

Mentioned from the results based on tide gauges and the computed global mean sea level in the 20th century (Holgate et al., 2007), sea level rising was superimposed on the decadal fluctuations. The decadal oscillation possibly linked to internal variability of the ocean-atmosphere system. Reconstructed sea-surface heights were derived for understanding of sea level variations by combining the benefits of the short but virtually complete coverage offered by satellite altimetry with the relatively long but spatially sparse in situ tide gauge dataset. In this paper, reconstructed SSH data from Church et al. (2004) was used to find out sea level variations on the decadal scale in the ECS.

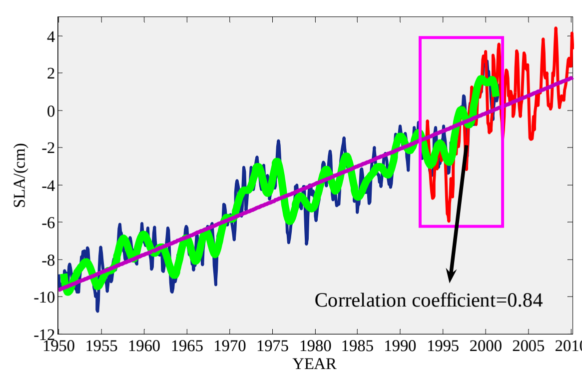

Fig. 5 Long term sea level term of reconstructed SSH combined with T/P altimetry data (unit: cm)

Conducting examinations about the accuracy of the data in detail, we found reconstructed SSH was proper to obtain the decadal characteristics in the ECS. Compared with T/P satellite era, the reconstructed SSH showed good correlation coefficient, 0.84, in the ECS (Fig.5). The results from wavelet analysis indicated the decadal variation of the mean sea level, with periods of 8~10 years in the ECS. Since reconstructed SSH had low accuracy due to the reconstructed method in the shallow water, the void raw data appeared along the coast area in the ECS.

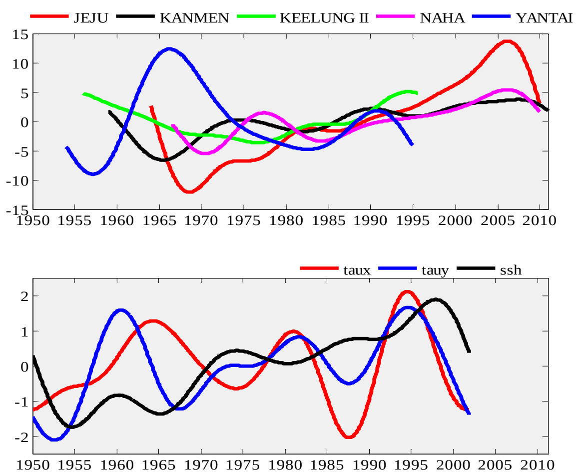

Fig. 6 Decadal variations of relative sea level and reconstructed SSH and its relationship with wind stress in the ECS (a. sea level variations of the selected tide gauges shown in Fig.4, unit: cm; b, normalized SSH and wind stress; 10-year low-pass filter)

Among the five selected stations, Sta. JEJU showed a biggest rising rate of 4.8 mm/a, while Yantai was 0.3 mm/a. These rising rates were less than corresponding T/P locations shown in Fig.4, while the annual range of sea level variation exhibited large around tide gauges. Moreover, tide gauges rising rates were derived from more than 40-yr records, while T/P era was less than twenty years. Decadal variations of the tide gauges were obtained by a 10 years low-pass filtering, shown in Fig.6a. In general, the tide gauges expressed significant decadal signals during 1960-2010, while varied spatially in the ECS. Low frequency signal of Sta. Yantai was quite different from other four stations in the SECS, due to special geographical location. Sat. Kanmen, Sta. JEJU and Sta. NAHA occurred similar characteristics, which were strongly influenced by the ocean circulation in the SECS. They came to the decadal minima in the 1960s, and then began to rise since the beginning of the 1970s, reached the decadal peaks around 2006.

Similarly to the method applied to tide gauges, ten years low-pass filtering was applied to both SSH and wind stress to analyze their relationship on the decadal scale (Fig.6b). Wind stress indicated little fluctuation during the 1970s, when prominent climate change occurred, and large range appeared during the other period. It was obviously that after the abrupt change around 1976, meridional wind stress and zonal wind stress changed in the phase, with correlation coefficient was up to 0.93. Before that abrupt, the relationship between them was not clear. Sea level followed the wind stress variation on decadal scale. During the last 50 years, reconstructed SSH lagged meridional wind stress 2 years when their correlation coefficient can be the maximum (nearly 0.55). And low frequency variation at Sta. NAHA exhibited the influence of meridional wind. However, the relationship between zonal wind stress and SSH was not obvious, and needed further research.

SLA and wind stress

In order to analyze the relationships between wind stress and sea level variations on different timescales, the distribution of correlation coefficients were shown in Fig. 7 and 8.

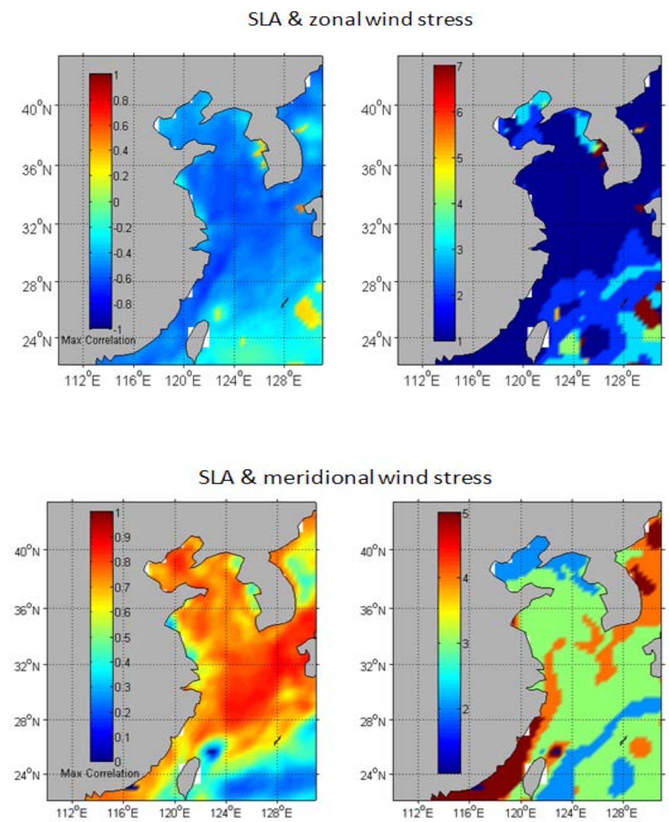

Fig.7 Maximum correlation coefficient and its lagged months between SLA and wind stress

Wind appeared as the dynamic atmospheric factor of the sea level variation in the shelf sea of ECS. Zonal wind stress worked directly on the sea surface, and caused the eustatic sea level. When zonal wind was negative (i.e. east wind stress component), onshore wind forced westward transport of the sea water. Then, the sea water were stemmed by continent and accumulated towards the shore, which could lead to high sea level along the coast. Correspondingly, when zonal wind was positive, wind forced eastward transport without stopped, and the offshore transport towards the northwest Pacific Ocean, thus sea level dropped. In most regions of the ECS, negative correlation between SLA and zonal wind stress reach maximum synchronously, between -0.5 to -0.7. Zonal wind stress affected on the sea level immediately. Their coefficients attained maximum when SLA lagged zonal wind 3 months in the northern Bohai and northeastern Yellow sea area. Combined with ocean current, especially Kuroshio, zonal wind leaded SLA with uncertain months, and indicated that their relationship was complicated.

Meridional wind illustrated the relationship with SLA variation, for the analyzing area being monsoon climate region, where annual mean wind vector was along the meridional direction. The relationship of SLA and meridional wind were positive. Strong meridional wind would contribute to the sea level distribution in the next spring (Fig.7b). By comparing SLA and meridional wind, the correlation was best when SLA lagged meridional wind 2 months in Bohai Sea, while 3 months in other parts of the ECS. It prevailed cold and strong north wind from Siberia in winter, and influenced the Bohai Sea with the reduced sea level, which led the other part of the ECS. In the south of the estuary of the Yangtze River, the sea level might be affected by the coastal current, towards the Taiwan Strait, and their lag months increased notably.

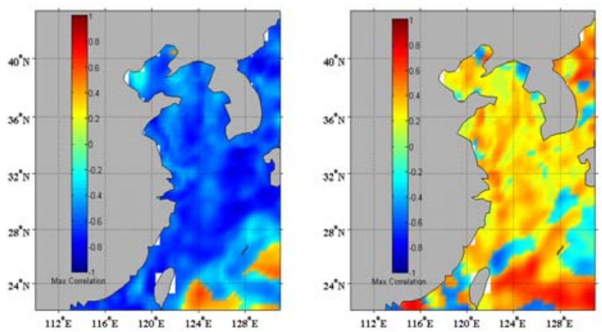

Fig.8 The maximum correlation coefficient between SLA and zonal/meridional wind on the interannual scale (with 2-yr filter)

Sea level might be influenced by zonal wind on the interannual scale in the ECS (Fig.8a). The negative correlation between low frequency zonal wind and SLA, could up to -0.5 - -0.8 in most part of the ECS, with the mean valve -0.65. On the east part of Taiwan, the correlation between low frequency zonal wind and SLA was not so good. With respect to its geographic location, ocean circulation effect might be important (illustrated in next section). Contrasting with the zonal wind, the correlations between low frequency meridional wind and sea level change were not good. While the coefficient was 0.7 when sea level lagged meridional wind 15 months in the East Sea Kuroshio (Fig.8b). It could be inferred that meridional wind would be an important factor on interannual scale, where ocean boundary current were strong and stirred the ocean.

Sea level variation and circulation

The ocean dynamic environment could also be influenced by the ocean circulation in the ECS, such as the Taiwan-Tsushima Warm Current System combined with the East Sea Kuroshio (ESK). The Kuroshio was considered to enter the ECS through the so-called East Taiwan Channel between Taiwan and Yonaguni−jima Island which lied 108 km from the east coast of Taiwan Island and was the southernmost one of the Ryukyu Islands chain (Yang et al. 2011). Because of the geographic and topographic features of the ECS, the East Sea Kuroshio was the most important water transport compared with the other river runoffs in the ECS, for example, the volume transport of the ESK was 1000 times of that of the Yangtze River. In order to examine the transport of the ECK in the East Sea, we imagined the eTW (east of Taiwan Island) section (121.75°E, 25.25°N -- 124.25°E, 24.25°N) as the entrance passage, and the PN section (126°E, 29°N--27.5°E, 128.2°E) as the exit passage (shown in Fig.4). As mentioned in previous papers, the ECK surface water intrusion occurred between the two sections. Consequently, the transport difference of the two sections was illustrated in Figure 9, in order to depict the intrusion events in the ECS. While, the transport across the Taiwan Strait was neglected, as its volume transport (1.03 Sv, mentioned in Yang et al., 2011) was negligible compare with that of the eTW section.

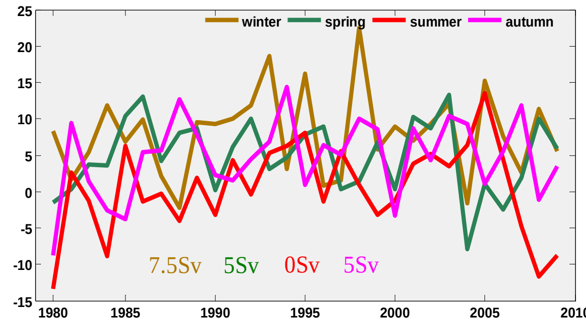

Fig.9 The seasonal variation of the transport differences between the eTW and PN section (dashed line indicates the corresponding mean values of different season.)

Seasonal variation of the surface water intrusion was robust (Fig. 9). Relative to the eTW section, the transport of the PN section was stronger in summer which accounted for the equivalent mass and smallest in winter. That is, the difference was nearly 7.5 Sv in winter and approximately 5 Sv in spring and autumn, and around zero in summer. It indicated that the ECK surface water intruded to northwest shelf strongly in winter, relatively weaker in autumn and spring, and there was no intrusion in summer, similar to the former result of Hu et al. (2008). The winter intrusion events exhibited the interannual oscillation during the past 30 years, especially in the El Niño events. When intrusion events provideded great mass of water stirring in the SECS, and forced by the potential vorticity theory, the ocean circulation was an important qualitatively process to regional sea level variation.

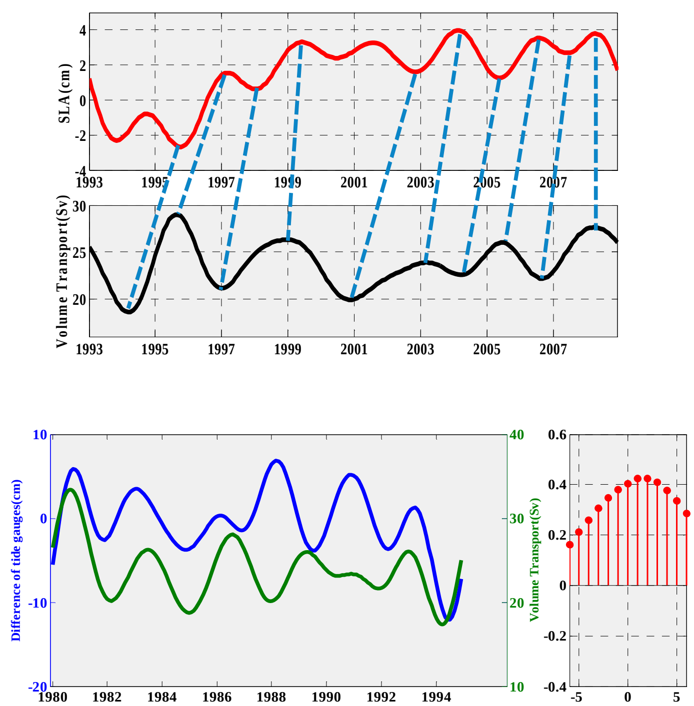

Fig.10 The sea level variation (a, T/P sea level anomaly during 1993-2008; b, sea level difference between sta. Naha and sta. Keelung during 1980-1994) and volume transport of the eTW section (low frequency).

The annual eTW volume transport ranged from 20 to 31 Sv. During the prominent El Niño event (1997/98), the volume transport of the eTW section in the winter of 1997 was minimum combined with the largest seasonal range. The circulation was strongly influenced by ENSO phenomena, the circulation transferred the energy and heat from the source Kuroshio to the ECS, thus influenced the sea level variation of the ECS. During 1993 to 2008, mean sea level of the SECS derived from the T/P satellite lagged volume transport of eTW section nearly 1 to 1.5 years on interannual time scale (Fig.10). Based on the relative sea level record measured from the sta. Naha and sta. Keelung, the sea level gradient fluctuated with the local ocean transport, their correlation coefficient was 0.43 when the sea level difference lagged volume transport of the eTW section 1 month. It was found that the sea level gradient cross the jet stream varied with the ECK transport, such as the larger transports accompanied with the large gradient in 1992/93 and 1998/99. Moreover, after 2000, the calculated sea level gradient based on the geostrophic adjustment was smaller than the measured SLA gradient.

Sea level variation and steric effect

The variations of sea water temperature field were the important influences of the regional sea level variation/change on seasonal to decadal time scales and long term.

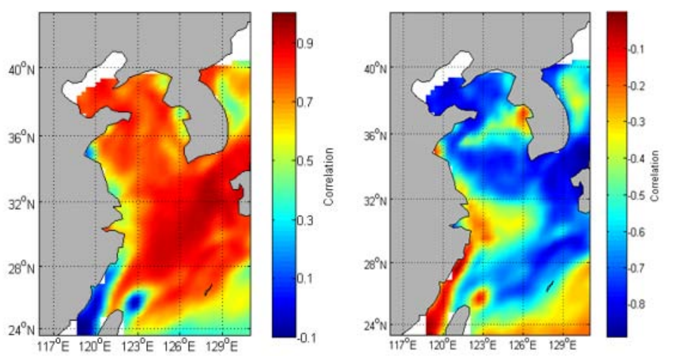

Fig.11 the correlation coefficient between T/P sea level variation and steric effect (a. correlation between temperature and SLA; b. correlation between salinity and SLA)

Thermal and halosteric effects of sea water contributed to sea level variations in the most ECS, when sea water became warmer, sea water began swelling due to thermal expansion; and sea level rising with seawater fresher with less dense water on halosteric effect (Fig. 11). Their contributor was highly non-uniform spatially. In the inner region of the ECS, the correlation coefficients could up to 0.9 and -0.8 respectively. But the correlation was weak along the ECS coast. The existence of this lower salinity layer established the stratification of sea water and induced by the loss of heat on the sea surface, and therefore, maintained the higher temperature of the subsurface water (Chen et al., 2006).

The steric height considering with the thermal and halosteric effects was calculated by the steric sea level mode introduced by Thomson et al (1988). Analyzing the correlation between SLA and steric effects on the interannual timescale, it was shown that their low-frequency series matched well, especially in the southern part of the East China Sea. The distribution of the correlation coefficient indicated that the steric effect influenced sea level variations markedly, whose coefficients reached more than 0.8 with a maximum of 0.93. Different from the distribution shown in Fig.11, the coefficient in the SECS was high values on the interannual timescale. Examining the two series in detail (Fig.12b), SLA derived from altimetry illustrated the tiny interannual amplitudes imposed on a long-term sea level rising, while steric SSH represented the apparent interannual and decadal oscillations, and reached the decadal maximum in 2001. Sea surface height induced by the steric effect was 0.6 cm on the interannual scale which could contribute to the 65% interannual variance of the sea level. During 1996 to 1999, both the sea level and steric SSH experienced the fastest rising periods. After the 1997/98 El Niño event, steric SSH exhibited a fluctuation state, and sea level presented a monotonous secular trend.

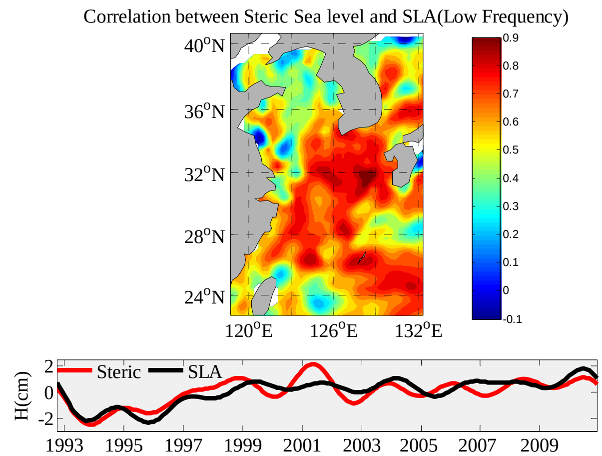

Fig.12 Normalized series of steric sea level and T/P SLA (low frequency) and their correlation coefficients in the ECS

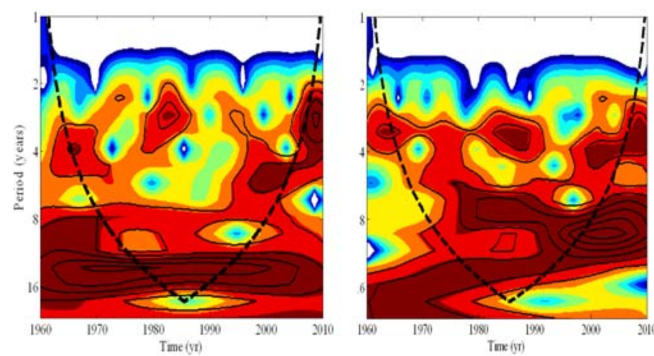

Fig.13 Wavelet analysis of the temperature in the lower layer (left) and the salinity in the upper layer (right) during 1960-2010.

It was hypothesized that the decadal oscillation in the ECS could be explained by the variations of temperature in the lower layers and salinity in the upper layers. To research the vertical structures of temperature and salinity fields were of great importance in study their relationship with sea level variations. Taking the PN section as an example, where the section across the isobaths from 125 to 1000 meter, after a series of calculating the periods of the temperature and salinity by wavelet analysis method, we divided the whole sea water into two layers, such as the upper layer (0~150m) and the lower layer (150m~1000m). The wavelet analysis was conducted to the average temperature with eliminating seasonal signals in the two layers. The temperature in the lower layer and the salinity in the upper layer exhibited the significant decadal signals during the 1980s, with the interannual signals within 2~4 years, while the temperature in the upper layer and the salinity in the lower layer did not show the decadal signals (Fig. 13). The temperature characteristics of the lower layer were more capable of demonstrating the decadal temperature variation.

SUMMARY

Sea level variations were investigated with the TOPEX/Poseidon (T/P) altimeter data, reconstruction sea level data and tide gauges records on the interannual and decadal scale in the East China Sea. Stochastic dynamic method was used to analyze the characteristics of sea level variations. The atmospheric wind, ocean current, temperature and salinity were expressed as the dynamic and steric contributors to regional sea level variations.

Sea level in the ECS varied with significant interannual variation and the distribution mapped geographically. Interannual cycle presented the amplitudes about 3-5cm in the ECS. The prominent variability occurred along the Jiangsu and Zhejiang coastal area and the eastern Taiwan region

The interannual variation of SECS sea level was modulated by the El Niño/La Nina events significantly. SLA derived from altimetry data and Nino3 index were almost out of the phases during the three El Niño/La Nina episodes, the correlation coefficient up to -0.69 during 1997 to 2005. During the non-El Niño/La Nina events period, SLA showed in phase of the Nino3 index, with 4-5 months ahead. Meanwhile, the baroclinic Rossby waves associated with the ENSO phenomena generated at mid-latitude of the eastern North Pacific and propagated westward to the ECS would contribute to the SLA oscillations on interannual timescale.

On the interannual scale, Sea level variation was influenced partly by wind stress in the ECS. In most regions of the ECS, the relationship between SLA and zonal wind stress was negative, while it was positive between SLA and meridional wind, their absolute coefficients can reach up to 0.7. The coefficients attained maximum when SLA lagged zonal wind 3 months in the northern Bohai and northeastern Yellow sea area. Strong meridional wind would contribute to the sea level distribution in the next spring.

The ECK surface water intruded to northwest shelf strongly in winter, and no intrusion in summer. The winter intrusion events exhibited the interannual oscillation associated with the El Niño events during the analysis period. During the prominent 1997/98 El Niño event, the winter volume transport of the eTW section was minimum combined with the largest seasonal range. During 1993-2008, sea level in the SECS lagged volume transport of eTW section nearly 1 to 1.5 years. Sea level gradient between the sta. Naha and sta. Keelung fluctuated with the local transport by one month lag. Sea level gradient cross the jet stream varied with the ECK transport, that is, the larger transports, the larger gradient. Moreover, after 2000, the calculated sea level gradient based on the geostrophic adjustment was smaller than the measured SLA gradient.

Thermal and halosteric effects of sea water contribute to sea level variations in the most ECS. Steric sea level contributed to nearly 65% variance of the sea level interannual variability. T/P SLA illustrated different interannual pattern with steric sea level after the 1997/98 El Niño event. It was found that SLA represented the interannual oscillation imposed on secular rising, while steric sea level varied on the interannual and decadal timescales.

Decadal sea level variation was found by the reconstructed SSH data with periods of 8~10 years in the ECS. Moreover, the tide gauges expressed decadal signals in the past 50 years. Influenced by the ocean circulation in the SECS, the Sat. Kanmen, Sta. JEJU and Sta. NAHA showed similar decadal features. The variations of temperature in the lower layer and salinity in the upper layer contributed partly to the decadal oscillation in the ECS. During the last 50 years, reconstructed SSH followed the meridional wind stress variation on decadal scale, with 2 years lag, as well as the Sta. Naha records.

Besides the interannual and decadal variations, seasonal and secular variations of sea level during the last two decades were found, associated with geographical non-uniform distribution. Large seasonal amplitudes, around 14 cm, appeared along the China eastern coastal area.

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