Contribution of the steric and ocean mass change to the global sea level change since 2003

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Abstract—**The contribution of the water mass change and the steric change of the ocean to the long term global mean sea level trend during 2003-2011 is analyzed in this paper, basing on the data of multiple satellite altimeter, GRACE gravity satellite and the Ishii (2012) temperature and salinity dataset. A steady rising rate of the global mean sea level since 1993 is found with little change in the 2003-2011. The steric change of the water in the layer of 700-1500 m is almost as important as the upper 700 m, the upper 1500 m waters contribute 18% to the global mean sea level rise and the contribution of the mass change over the ocean is 21%.**

***Key Words*—sea level rise, steric change, GRACE.**

I. INTRODUCITON

The global sea level rise caused by the climate change has become an indisputable fact. Results basing on the observation of tidal gauge, satellite altimeter and the analysis of temperature and salinity data of sea water reveal that the global mean sea level has been rising at a rate of 1.7±0.3mm/a during the 20th century, the rate of the last 50 years is 1.8±0.3mm/yr, the rate during 1993-2003 is 3.1mm/a while for the period 2003–2009, the rate of observed sea level rise estimated by satellite altimetry, amounts to 2.6±0.4 mm/year (Church et al., 2004, 2006, 2008; Nguyen et al., 2008; Cazenave et al., 2009; Ablain et al., 2009).

The steric change caused by the change of temperature and salinity of the ocean water and the water mass change over the ocean are two important factors responsible for the global mean sea level change, and the thermal expansion of sea waters and land ice loss due to global warming are the main contributors for the recent global sea level rise (Bindoff et al., 2007, Zuo et al., 2009, 2010, Marcos et al., 2011).

The global mean sea level rise during the period 1993-2003 is well explained by the thermal expansion and land ice melting. In the total rising rate of 3.1mm/a, the thermal expansion causes a rising of 1.6mm/a and the land ice loss causes a rising of 1.2mm/a and only the remain 0.3mm/a is unknown (Wills et al., 2004; Bindoff et al., 2007). Numerous studies in recent years show the GRACE gravity satellite data is an useful tool revealing the mass change of the ocean, the ice sheet and the land water (e.g., Chambers et al., 2004; Lombard et al., 2007; Velicogna and Wahr, 2006a, b; Chen et al., 2006a, b; Lutchke et al., 2006; Ramillien et al., 2006, 2008) which can be used in the study of the mass contribution to the sea level change. Cazenave et al. (2009) basing on the data of GRACE, satellite altimetry and Argo, point out that during the period 2003-2008, the rising rate of the global mean sea level decreases and the thermal expansion of the ocean seems stagnate, the contribution of mass change is increasing. In the recent years (2005–2010), thermal expansion accounted for 0.75±0.15 mm/yr, it is 27% of the observed rate of rise (Llovel et al., 2010), the total contribution to sea level rise from all ice-covered regions is thus 1.48±0.26 mm/yr, which agrees well with independent estimates of sea level rise originating from land ice loss and other terrestrial sources (Jacob et al., 2012).

As the renewed Ishii data has included the temperature and salinity change of the water of the upper 1500 m of the ocean, the steric contribution of the water below 700 m to 1500 m can be obtained and compared with the upper 700 m. This result can help us to understand the contribution of the temperature and salinity change of the deeper ocean, which is more and more important and is expected to grow with time as the abyssal ocean shifts (Wunsch et al., 2007). And the time span of the GRACE data is approximately 10 years which can be used for a relatively accurate trend estimation of the mass change over the ocean.

In this paper, the long term global mean sea level change for the period 2003-2011 will be studied basing on multiple satellite altimeter data and explained from the respect of steric change and mass change. The steric contribution will renew the previous result to the depth of 1500 m using the data of Ishii (2012) and the contribution mass change is basing on the latest release (RL04) solutions of the GRACE data. The result is used to understand the decrease of the rising rate of the global mean sea level in recent years and the increase of the contribution of the mass change and the deeper water of the ocean.

II. DATA

A. *Sea level data*

The multimission altimeter (T/P, ERS-1/2, Jason-1, Jason-2) data from 1993 to 2011 used to analyze the characteristics of sea level variation are produced by Ssalto/Duacs and distributed by Aviso with support from the CNES (http://www.aviso.oceanobs.com/duacs/). The raw weekly data on a 1/3°x1/3° Mercator grid in the domain 81.5° S~81.5° N, 0.5~359.5° E are interpolated at monthly intervals with the 19-year mean first removed and averaged to a 1°x1° grid using a hamming weighting with a cut-off radias of 300km in order to eliminate the effect of short waves, tide and eddies.

B. GRACE data

The GRACE products used in this paper is the equivalent water height anomaly over the ocean caused by water mass change, and the product is the latest release (RL04) solutions supplied by JPL on the 1°x1° global grids at monthly interval. This new data set (available at http://grace.jpl.nasa.gov/data/mass/) includes an implementation of the carefully calibrated combination of destripping and smoothing, with a 300 km half-width Gaussian filter (Chambers, 2006). The gridded GRACE products are corrected for post-glacial rebound (PGR) and glacial isostatic adjustment (GIA) using Paulson (2007) model. The gridded time series cover the time span from January 2003 through December 2011.

C. Temperature and salinity data

The temperature and salinity data used in the paper is the Ishii (2012) temperature and salinity data provided by Japanese weather bureau, the data set consists of the monthly 1°×1° gridded temperature and salinity fields from sea surface down to 1500 m from 2003 to 2011. The Ishii temperature and salinity (available at http://atm-phys.nies.go.jp/~ism /pub/ProjD/) was used to calculate the steric height anomalies (Thomson and Tabata, 1987).

III. Results and Discussion

A. Long term trend of the global mean sea level of 2003-2011

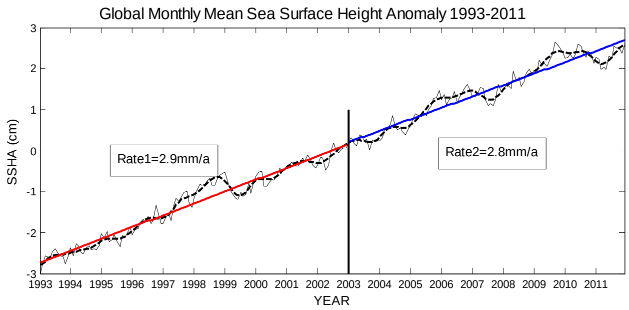

Fig.1. Monthly global mean sea level anomaly of 1993-2011

After filtered spatially, the gridded monthly global mean sea level anomaly is low-pass (12 months) filtered with the prominent seasonal and interannual signals eliminated, and then the linear long term trend of the time series is estimated by least square method (Fig. 1). Observation of the satellite altimeter shows the global mean sea level has been rising since 1993, the long term trends of the periods of 1993-2002 and 2003-2011 are 2.9mm/a and 2.8mm/a, which means the global mean sea level rise after 2003 does not decelerate much compared with the time before and the rising rate of the period of 1993-2011 is slightly less than 2.9mm/a.

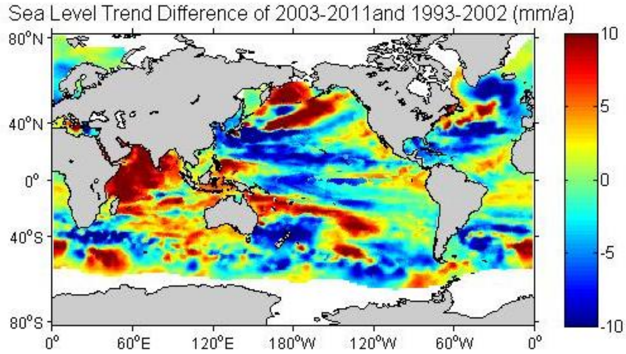

Fig.2 Difference of sea level trend between 2003-2011 and 1993-2002

The long term sea level trends of the global ocean have changes from the period 1993-2002 to 2003-2011 (Fig. 2). The rising area in the western Pacific during 1993-2002 separate in the period 2003-2011, the north part mainly spreads north and east of the Kuroshio Extension, causing the sea level of the Bering sea shift from descend to rise and the descending of the sea level in the Alaska Gulf slow down. The southern part of the rising area near the warm pool move southward and westward, causing the sea level of the North Indian Ocean begin to rise in the recent ten years and the sea level rise in the South Indian Ocean speed up. The sea level rise of the Atlantic Ocean weakens largely especially in the North Atlantic. The main sea level falling area during 1993-2002 in the eastern Pacific spreads westward in the period 2003-2011, and the maximum sea level falling moves to the central Pacific in the low latitude and mid-latitude. The sea level falling north of the Amudsen Sea strengthens in the recent years and become another maximum sea level falling area. The sea level rise along the Antarctic Circumpolar Current weakens in the last ten years too. The distribution of the long term sea level trend difference between 2003-2011 and 1993-2002 shows larger falling area than rising area, which explains the slowing down of the global mean sea level rise in the recent decade.

B. Contribution of steric change to the long term sea level trend in 2003-2011

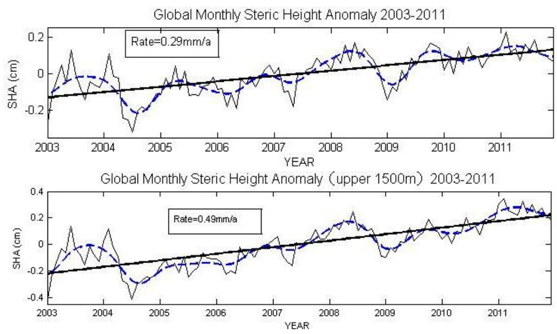

Fig. 3. Monthly global mean steric height anomaly of upper 700 m (upper) and upper 1500 m (bottom) during 2003-2011.

The steric contribution is calculated according to the equations of Thomson and Tabata (1989), and the density of seawater was calculated according to the equation of state of seawater 1980 (EOS80). The global mean steric height of the upper 700 m waters show a long term trend of 0.3mm/a in the period 2003-2011 and the trend of the upper 1500 m waters is 0.5mm/a. The contribution of the steric change of the upper 700 m waters is about 11% to the global mean sea level rise and the upper 1500 m waters contributes about 18%. The steric height of the upper 1500 m waters shows similar temporal pattern to the upper 700 m but with smaller interannual oscillation and larger rising rate. The ratio of the long term steric sea level trend of the upper 700 m over the upper 1500 m shows in the recent years, the steric changes of the upper layer of water in most areas are consistent from surface to the depth of 1500 m and the upper 700 m waters are just responsible for part of the total steric changes of the water column and the water below 700 m becomes significant as the rising rate of the steric sea level of the upper 700 m slows down.

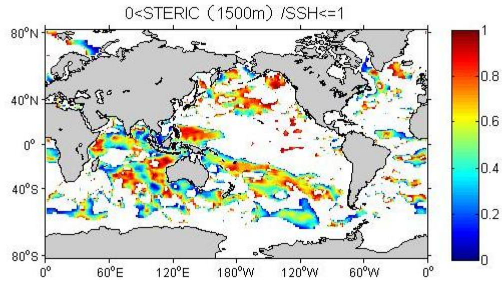

Fig. 4. Ratio of the upper 1500 steric trend over the sea level trend in the (0, 1] range

As the steric change of the upper 1500 m is more significant than the upper 700 m in most areas, the contribution of the former to the long term sea level trend is discussed and the result shows the steric change of the upper 1500 m can explain quite a portion of the sea level rise of the warm pool, the Indian Ocean and east of the Kuroshio Extension. While in the sea level falling area, the eastern Pacific Ocean of the low and mid latitude, the sea level falling caused by the steric change even exceeds the total sea level trend .

C. Contribution of the ocean mass change to the long term sea level trend

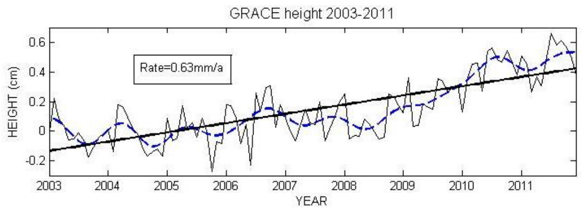

Fig. 5. Global mean sea level change caused by mass change over the ocean during 2003-2011

The global mean sea level trend caused by the mass change over the ocean during 2003-2011 is moderately more than 0.6mm/a, accounting for about 21.4% of the total sea level trend. The distribution of the sea level trend by ocean mass change shows in the past decade, the mass of the Pacific Ocean is increasing and the Indian Ocean especially the South Indian Ocean is decreasing, and the ocean mass in the adjacent seas of the Greenland and in the Amundsen Sea is decreasing quickly. The maximum but limited contribution of ocean mass change locates at the warm pool and east of the KE, not exceeding 40%. The contribution of the mass change to sea level trend in the South Indian Ocean and the central Pacific Ocean is even negative.

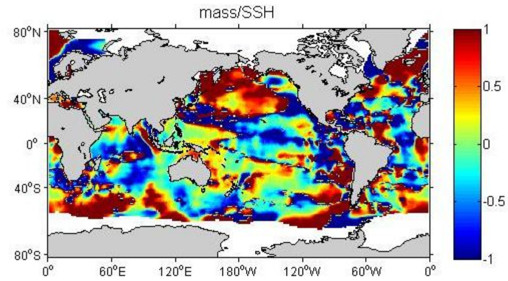

Fig.6. Ratio of the mass trend over the sea level trend

IV. CONCLUSION

The long term global mean sea level trend for the period 2003-2011 basing on multiple satellite altimeter data is 2.8mm/a, moderately less than the rate of the period of 1993-2002. The steric contribution of the upper 700 m and upper 1500 m calculated from the Ishii (2012) temperature and salinity data is 11% and 18% respectively, the mass change over the ocean causes the global mean sea level rise at a rate a little more than 0.6mm/a, accounting for about 21%. The steric change of the upper 1500 m and ocean mass change explain about 40% of the total sea level trend in the last decade.

The comparison between the steric change of the upper 700 m and 1500 m shows in most area, the steric change of the upper 700 m is not larger than the upper 1500m and the steric change of the upper 1500 m can explain quite a portion of the sea level trend of the warm pool, the Indian Ocean and east of the Kuroshio Extension and the eastern Pacific Ocean of the low and mid latitude.

The sea level rise in the warm pool and east of the KE is partly caused by ocean mass change in the area but the contribution is limited and the mass over the seas around Greenland and over the Amundsen Sea in the Antarctic is quickly decreasing, which is hard to understand but important for the sea level decreasing in these areas in the last decade.

A question that still needs to answer is why the mass change over the ocean plus the steric change can just explain part of the long term sea level trend both for the global mean and for regional areas, this needs further analyses in the consequent studies.

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