Sea Level Rise and the Warming of Oceans over 1992--2002 in ECCO2 Synthesis

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1. Introduction

The Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project aims to produce increasingly accurate, physically consistent syntheses of all available global-scale ocean and sea-ice data at resolutions that start resolving ocean eddies and other narrow current systems. A high-quality, physically-consistent ocean and sea ice data synthesis is an important tool towards increased understanding and predictive capability for the ocean's role in future climate change scenarios, such as global warming and sea level change. ECCO2 data syntheses are obtained by least squares fit of a global full-depth-ocean and sea-ice configuration of the Massachusetts Institute of Technology general circulation model (MITgcm) to the available satellite and in-situ data. Data constraints include in-situ temperature and salinity profiles, satellite altimeter data, a mean sea surface height data product, and sea-ice thickness and concentration data. A first optimized ECCO2 solution has been obtained for the 1992-present period by calibrating a small number of control variables using a Green's function approach. The approach was used to minimize the overall misfit between model and observations and to generate a solution, which is consistent both with the model physics and with the observations. Based on this synthesis, the global sea level trend and regional pattern over the past decade are obtained and compared well with other independent estimates. This poster presents the sea level rise and associated heat content change in this ECCO2 synthesis.

2. Results

2.2 Mean and variability of SSH

The optimized solution has significant improvements against the baseline in sea surface height (SSH) and sea level anomaly (SLA) fields. Figure 1 compares the global, time-mean (left) SSH and root-mean-square (rms) variability (right) of SSH. Top row is from data (AVISO altimetry program www.avisooceanobs.com), middle row is difference between data and the baseline solution, and bottom row is difference between data and the optimized solution. In the mean SSH fields, the optimized solution significantly decreases the misfit between model and data in the Indian, Southern, and Pacific Oceans. Nevertheless, some large model data discrepancies remain in the optimized solution, for example in the North Atlantic. In the rms SSH fields, the model captures much of the variability in the energetic boundary currents and their extensions. Overall, the optimized solution leads to a more realistic reproduction of both time-mean and rms SSH fields. This lead us to investigate the sea level rise and heat content change from this solution.

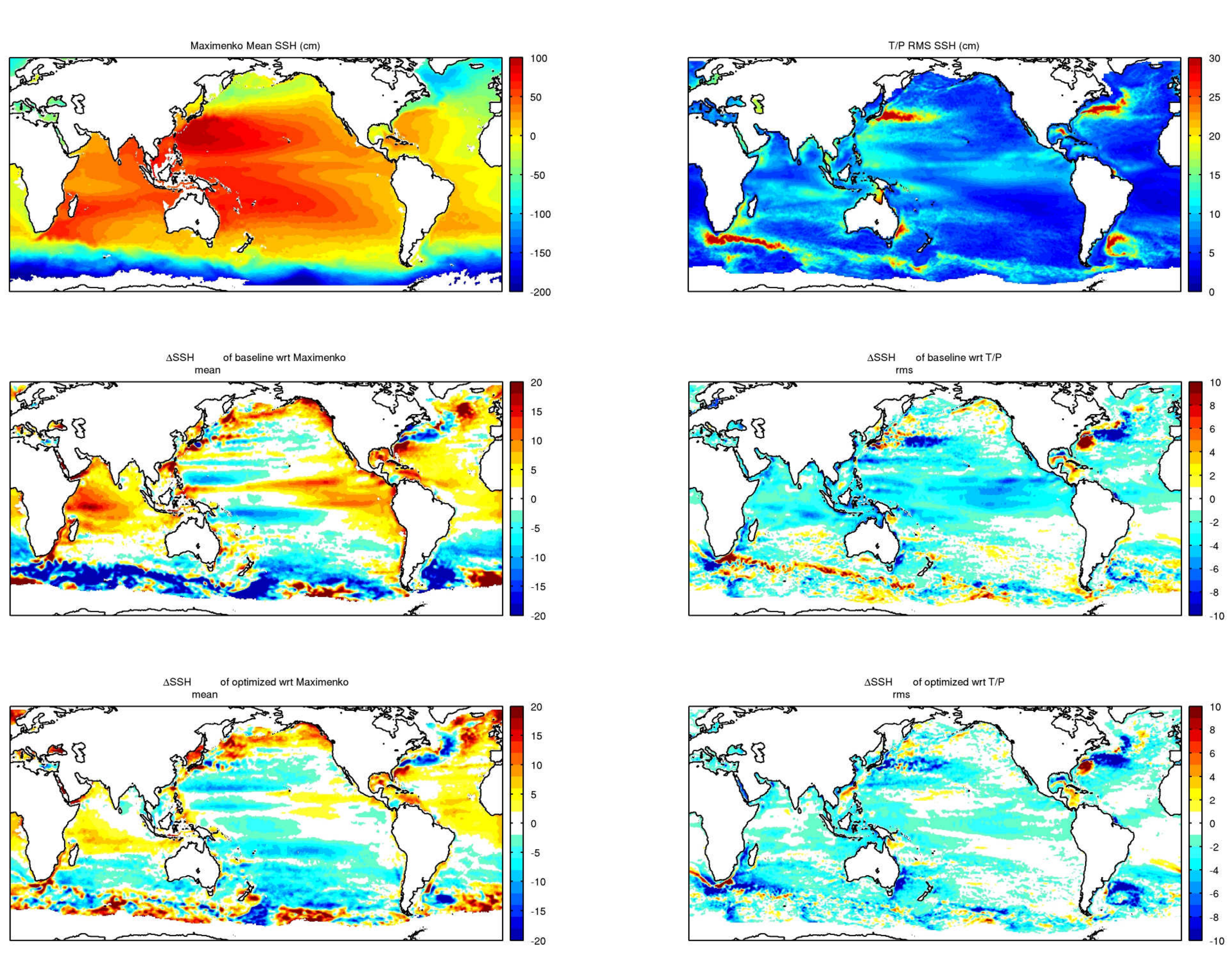

Fig 1 top row: observed time mean (left) and root mean square (right) SSH; middle low: baseline-data difference of mean (left) and rms (right) SSH; bottom: optimized-data difference of mean (left) and rms (right) SSH. A linear trend (shown in Fig. 2) was removed from the time dependent SSH fields before calculating rms.

2.2 Regional pattern of SSH trend

Figure 2 is the decadal trend in sea level change estimated from AVISO data and corresponding model results. We took the same data mask and subtracted the global mean value to facilitate comparison. The optimized solution faithfully reproduces the SSH trend observed by satellite. Both amplitude and spatial pattern in sea level trend have good agreements between estimate and observation. Compared with the global mean value (about 3.1 mm/yr), the regional amplitude is much larger. Large areas of positive anomalies exceeding the rate of 20 mm/yr are visible in the western tropical Pacific, eastern Indian, Southern Ocean and North Atlantic Ocean over the past decade. There is also a positive tongue extending into the subtropical north Pacific. While the negative anomalies are mainly found in the eastern Pacific and western Indian Ocean during the same period. However, there are some slight differences between our estimate and satellite observation. For example, in the Labrador sea, our estimate of sea level trend is larger than observed

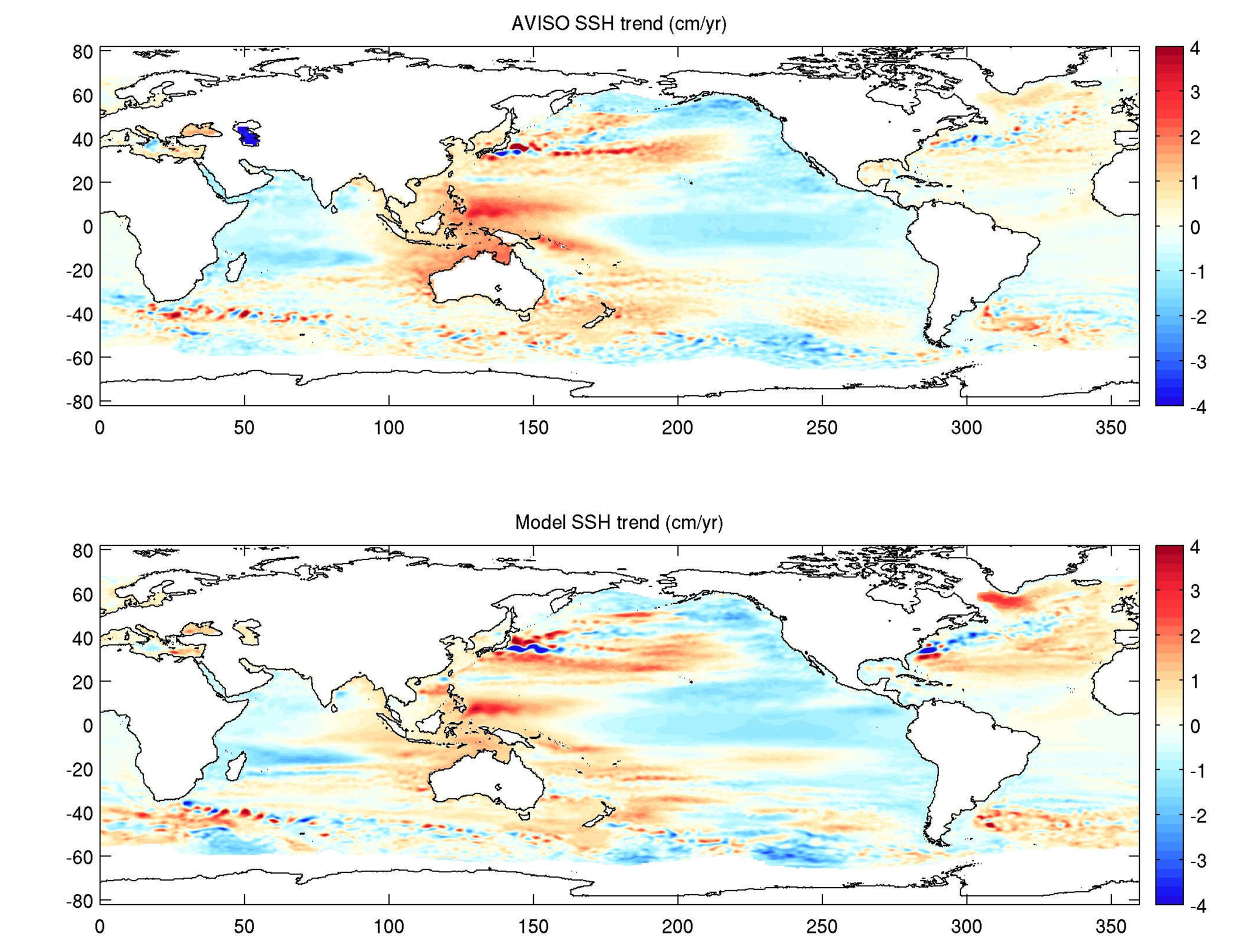

Fig 2. SSH trend (cm/yr) from altimeter data (upper panel) and ocean state estimates (lower panel).

2.3 Steric SSH trend and components

Figure 3 shows the total steric SSH trend from optimization and its two components: thermosteric and halosteric SSH trend. The close match between Figure 2(b) and Figure 3(a) shows that most of the SSH trends are actually steric and only a small residual part is due to mass redistribution. Globally the average steric SSH trend is 2.6 mm/yr. In the bottom two panels, the total steric SSH is further separated into a thermosteric part and a halosteric part. The global mean trends for the thermosteric and halosteric fields are 2.7 and -0.1 mm/yr, respectively. The thermosteric expansion is dominant in magnitude compared with the halosteric contribution. In addition, in most regions these two components have similar pattern but with opposite sign. The partial compensation causes the net steric SSH changes smaller than the thermosteric SSH changes alone. The pattern of steric SSH trends contributed from top 700 m layer is displayed in Figure 4. It is very similar to that accumulated throughout the whole water column seen in Figure 3.The comparison shows that the upper ocean makes a dominant contribution to the steric SSH change.

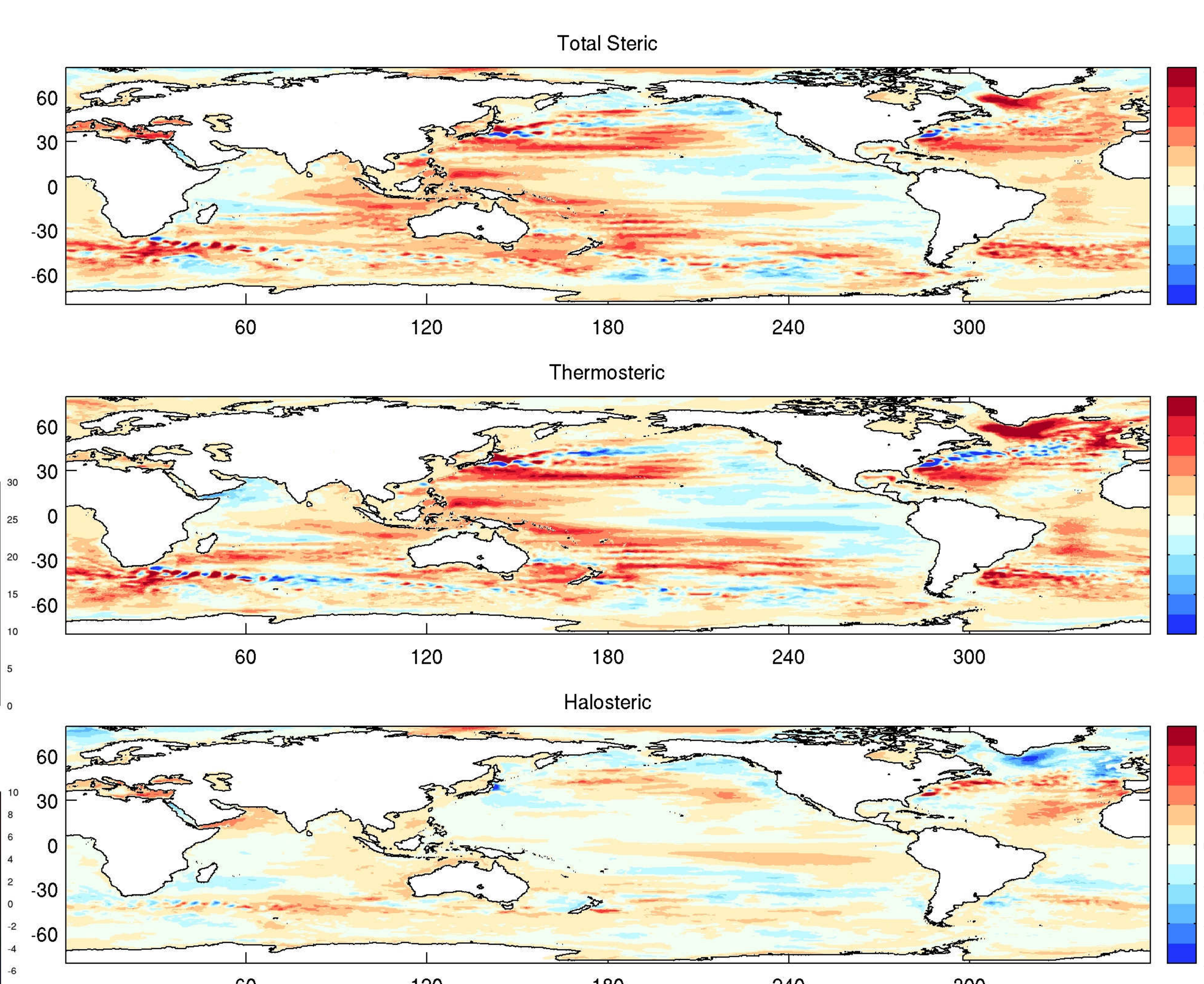

Fig 3. Model steric SSH trend (upper panel) and the components of thermosteric (middle panel) and halosteric (lower panel) SSH change for the entire water column over the past decade (cm/yr).

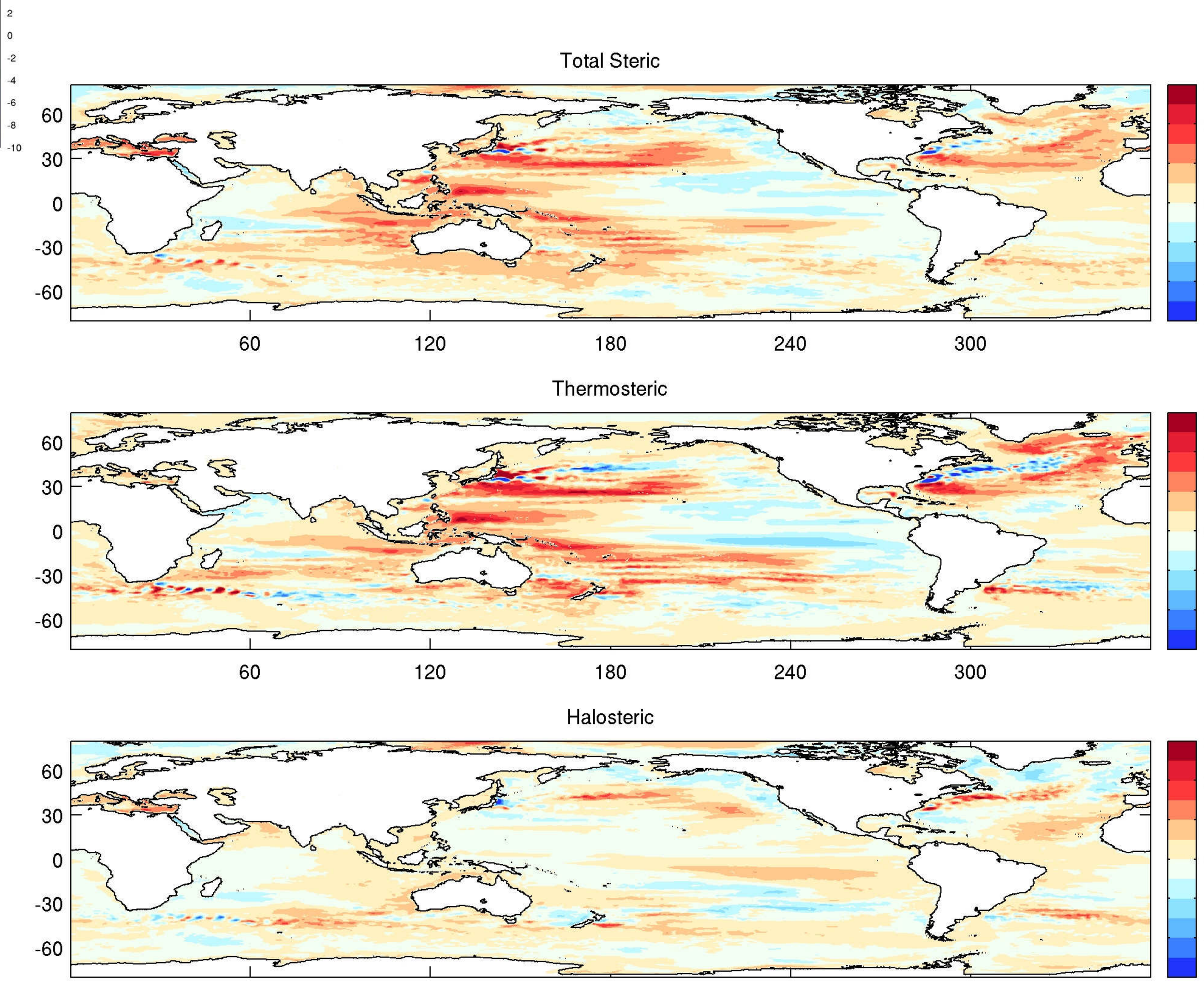

Fig 4. Same as Fig 3 but for the upper ocean (top 700 meters).

2.4 Steric SSH trend in individual basins

The individual oceans have quite different characteristics in SSH trend. Figure 5 shows the SSH trends in the zonal average of the steric SSH over the last decade, as well as the separate temperature and salinity contributions for the Atlantic Ocean, the Pacific Ocean, the Indian Ocean, and the world ocean. It is normalized by multiplying the trend of each latitude belt by the total ocean surface area of that belt and divided by the total surface area of the world ocean. So the sum of trend in each ocean is equal to the trend in the world ocean. It clearly shows the relative contribution from the three major basins to the global trend. First, for the southern Ocean, the Pacific Ocean makes a major contribution; Second, the Pacific Ocean and the Atlantic Ocean contribute equally to the SSH trend in the latitudes of 20°N--40°N; Finally, the Atlantic makes a sole contribution to the SSH trend in the region of high latitudes of the Northern Hemisphere.

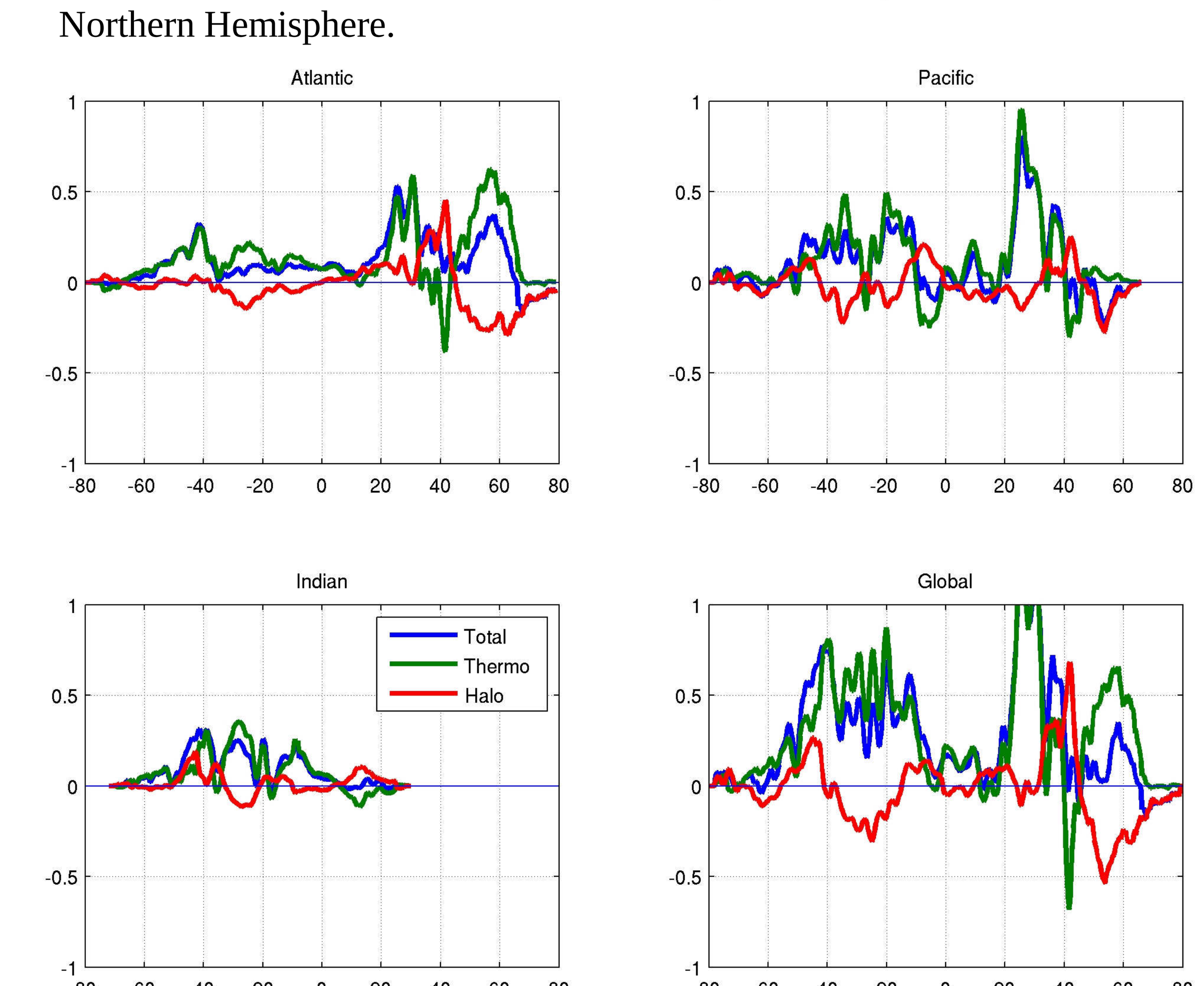

Fig 5 Normalized linear trend (cm/yr) of the zonally averaged steric, thermosteric and halosteric sea level change for the Atlantic Ocean, Pacific Ocean, Indian Ocean and world ocean for the entire water column over the past decade.

2.5 Heat content change in individual basins

The thermosteric SSH trend seen in Figure 5 is directly related to the temperature and heat storage change over the same period. Figure 6 shows individual ocean heat content as a function of time from 1992 to 2003 and their contribution to the world ocean. The heat content change in the global ocean is dominated by the upper ocean layers. The model results suggest that the top 700 m layer contributes 1.4e22 J/yr, about two thirds to the total growth rate of 2.1e22 J/yr. The heat content in each basin is characterized by different seasonal and interannual variability. The dominant feature in the Atlantic Ocean is that the deep layers makes a significant contribution to its total water column heat content change.

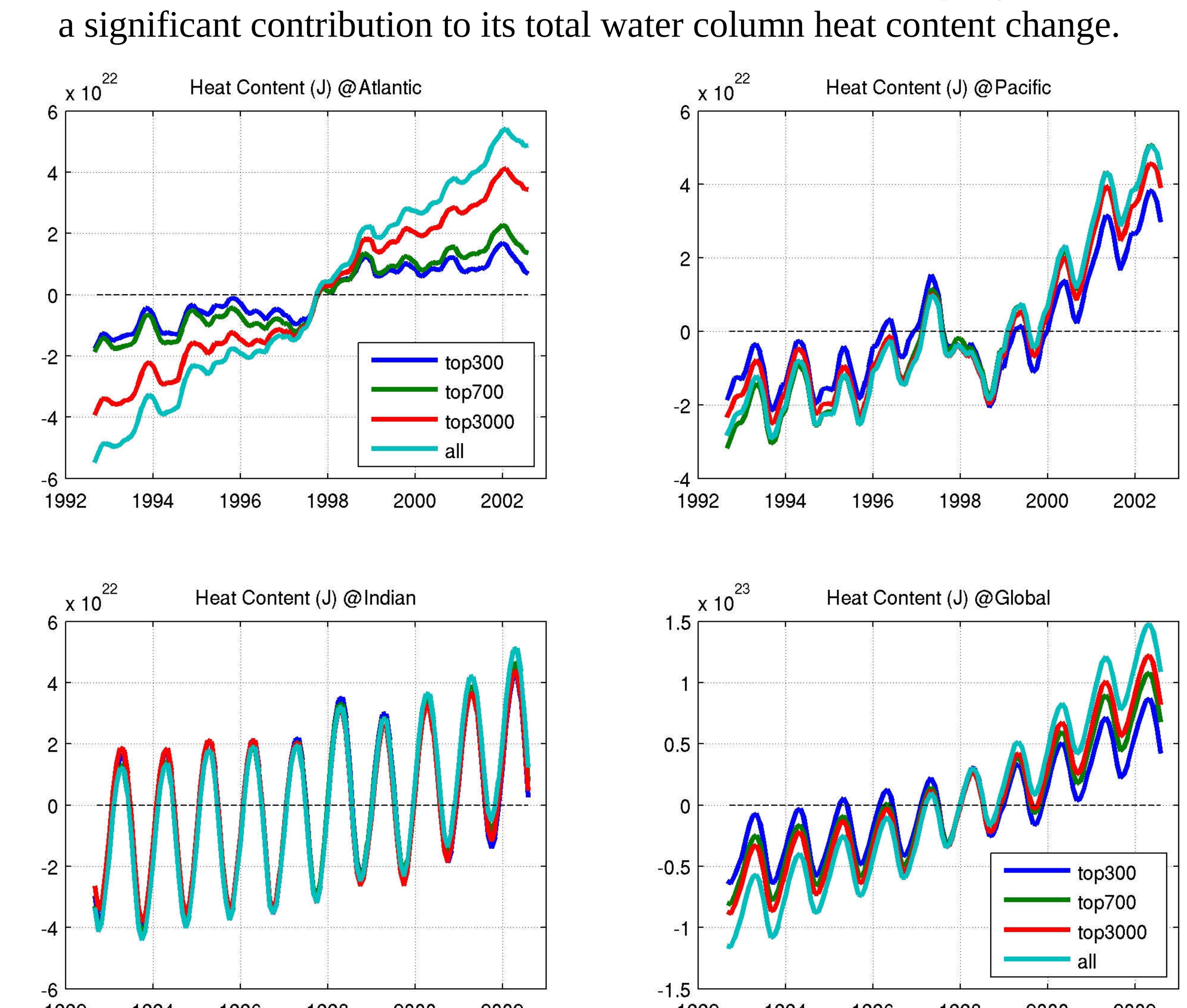

Fig 6 Time series of heat content (J) for the Atlantic Ocean, Pacific Ocean, Indian Ocean and world ocean over the past decade.

3. Concluding Remarks

- Our ocean state estimates show that the steric component explains most of the observed SSH trend and the thermal expansion makes dominant contribution to the global steric sea level change. The upper ocean dominates the heat content change but the contribution from deep ocean is not negligible;
- Longer time series of ocean state estimates are required to distinguish the natural variability and anthropogenic trend in sea level change. The ongoing ECCO2 project is making progress in extending the ocean state estimate to span a multi-decadal time scale.

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