Recent decrease in upper ocean thermosteric sea level

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Introduction

Recently updated estimates based on in situ profile data show a decrease in globally averaged, 0/750 m thermosteric sea level between 2003 and 2005 of approximately 7 mm. The decrease in thermosteric sea level is due to a loss of approximately 3.2 x 10^{22} J of heat from the upper-ocean during this period (*Lyman et al*., 2006). Despite this decrease in thermosteric sea level, total sea level as measured by altimeters and tide gauges continued to rise at nearly the same rate during this period. If the altimeter measurements are correct, this implies that either deep warming occurred that significantly compensates the upper ocean cooling, or the rate of the freshwater input has dramatically increased.

Errors

Random error in the estimate of thermosteric sea level was estimated in a subsampling experiment using altimeter data in the manner described by *Lyman et al.* (2006). Error based on the historical in situ sampling patterns were also made in this way to illustrate the large increase in error prior to 1970 and the recent decline in error due to the spin up of the Argo array.

Figure 3. 95 % confidence limits of sampling error on annual-average, global mean sea level as computed from available in situ data. The curve is computed by testing how well the in situ sampling pattern from each year resolves global mean sea level during the 13 year altimeter record.

For the difference curve shown in Figure 2, it was important to attempt to quantify potential systematic errors as well. Errors on the 6 year trends include random error, but have also been increased by 0.4 mm/yr to account for the potential systematic drift in the altimeter data discussed by *Leuliette et al.* (2004). In addition, these error estimates were increased by 0.1 mm/yr to reflect potential changes in temperature below 700 m. This is the value of the residual between the 0/700 m and 0/3000 m 40-year trends estimated by *Antonov et al.* (2005).

The Sea Level Budget

The estimate of 0/750 m thermosteric sea level is computed using a wide variety of in situ temperature profile data in the manner described by *Willis et al*. (2004). Between 2003 and 2005, the upper-ocean thermosteric sea level decreased by 6.7 ± 1.4 mm. This was preceded by an 16.5 ± 1.6 mm increase between 1993 and 2003. The total sea level curve shown in Figure 1 is from http://sealevel.colorado.edu. The error bars shown reflect random error only. Potential systematic errors are discussed in the panel on errors.

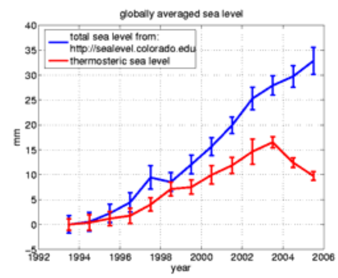

Figure 1. Globally averaged sea level. The blue curve shows total sea level based on TOPEX/Poseidon and Jason data. The red curve shows 0/750 m thermosteric sea level based on in situ profile data. Error bars are 95% confidence limits and reflect random error only.

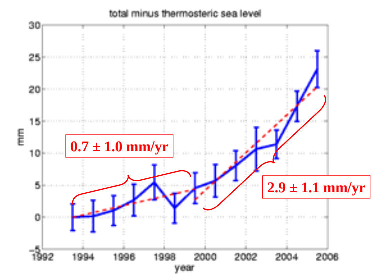

Figure 2. The difference between total and 0/750 m thermosteric sea level curves. Error bars are 95 % confidence limits and reflect random error only. If there were no changes in volume average temperature at depths greater than 750 m, this curve would reflect input of freshwater into the global oceans.

Figure 2 shows the difference between the two curves shown in Figure 1. If the volume average temperature of the ocean below 750 m was constant, this curve would represent the change in the volume of ocean due to input of freshwater. On decadal and longer time scales, this is almost certainly not true, and accounting for deep warming would probably reduce the overall amplitude of this curve. On time scales of a few years, however, the majority of the thermosteric signal should be captured by the 0/750 m estimate (*Lyman et al.,* 2006; *Antonov et al.,* 2005). Given this caveat, the two red lines in Figure 2 represent 6-year trends in this curve between the periods from1993 to 1999, and 1999 to 2005. These trends suggest an increase in ocean volume due to freshwater input of 0.7 ± 1.0 mm/yr from 1993 to 1999 and 2.9 ± 1.1 mm/yr from 1999 to 2005. Error bars on the rates reflect both random and potential systematic error as discussed in the panel on errors.

The Cooling Signal

The spatial pattern of the 2003 to 2005 cooling signal is complex and mainly reflects changes in circulation as shown in Figure 4. The zonal integral does suggest, however, that much of the cooling occurred at low latitudes.

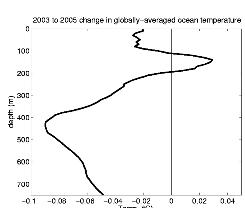

Figure 5. Globally averaged depth signature of the cooling signal.

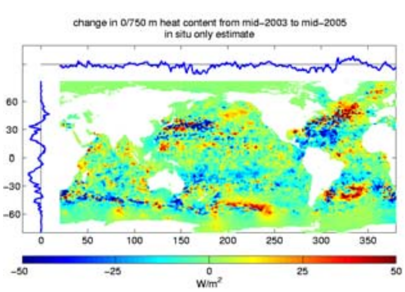

Figure 4. Spatial pattern associated with the 2 year decrease in upper-ocean thermosteric sea level between 2003 and 2005. The variable shown, heat content, is closely related to thermosteric sea level and has a very similar spatial pattern. Zonal and meridional integrals of heat content are shown along the top and left sides of the plot.

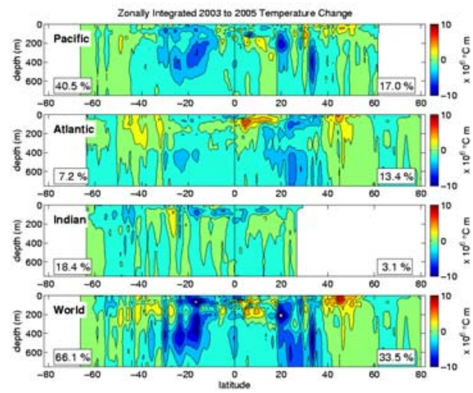

Figure 6. Zonal integrals of temperature change from 2003 to 2005 vs. depth and latitude for different basins and the globe. Although the units are not particularly useful, the zonal integrals of temperature are shown rather than the zonal averages to reflect the contribution of each basin to the global mean. The bottom panel is the sum of the top three.

Figures 5 and 6 show that the cooling signal is distributed over depth and occurs mainly in the S. Pacific.

References

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Conclusions

A decrease in globally averaged 0/750 m thermosteric sea level was observed between 2003 and 2005. Including the recent decrease, the trend in 0/750 m thermosteric sea level is 1.3 ± 0.14 mm/yr. Due to the decrease, a substantial increase in the rate of sea level rise due to the input of freshwater is inferred. The inferred rates of freshwater input are 0.7 ± 1.0 mm/yr from 1993 to 1999 and 2.9 ± 1.1 mm/yr from 1999 to 2005, where these errors include estimates of the potential systematic error