Ocean Sci. Discuss., 6, C1025–C1032, 2010
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Ocean Science Discussions

Interactive comment on "The timescale and extent of thermal expansion of the oceans due to climate change" *by* S. Marčelja

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Received and published: 27 January 2010

Referee's comments and suggestions are accepted with thanks.

I shall describe the changes with respect to what I understood are the three major suggestions that result in significant improvements. Other comments are also very valuable and will be followed when the revised ms. is completed. I would also like to take advantage of the less formal Discussion format and show several graphs with changes made or supplementary information that will not appear in the final manuscript.

Temperature and salinity dependent expansion coefficient

This should have been implemented from the start instead of using the upper ocean average. Presently I used the average global ocean temperature, density and salinity profiles (Levitus, 1982) and an accurate 25-term approximation to the equation of state for seawater (McDougall et al., 2002) to evaluate the average thermal expansion coefficient as a function of depth.

The effect on the calculated sea level change is not large in the 1950-2003 period where comparison with the evaluation based on measured heat content is available. Using an average thermal expansion coefficient produces small errors on the decadal time scale. On the century timescale heat penetrates into deeper ocean where the thermal expansion coefficient is small and the change becomes significant. Only the corrected figures will be shown in the final manuscript, while Fig. 1. shows the change as compared to the first version of the manuscript that used the average value of the expansion coefficient.

Sensitivity of the results

The results do not show strong dependence on the average eddy diffusivity and even less on the average upwelling velocity. One reason is that the absolute value of the heat content change in the reference period is arbitrary and this gives some freedom in the fitting procedure. The procedure adopted was as follows: Levitus et al. (2009) heat content data were used in addition to Domingues et al., (2008) in order to develop some feeling for the accuracy and to add years 2004-2008 to the comparison. The heat content calculated from GISS SST was then compared to the average of the Levitus et al. and Domingues et al. heat content results with the error measured using rms. deviation. The Munk constants are Az$\approx$1.3 x 10-4 m2/s and W$\approx$1.2 cm/day and the "optimal" values found from the least-squares fit were Az$\approx$0.9 x 10-4 m2/s and W$\approx$1.2 cm/day. The average drift velocity is unchanged. Following the adjustment, rms. error decreased 12%, which may not be significant considering the error margins in estimated heat content. In Fig. 3. I show the heat content with the original Munk value for diffusivity and "optimal" value from the rms. fit.

An alternative to the GISS SST data is the HadCRUT temperature analysis. In compar-

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ison with GISS, HadCRUT analysis shows somewhat larger variability. I used the GISS data set as it attempts to interpolate in the regions where measurements are missing, which is likely to be better in case of slowly changing sea surface temperatures. The differences in the procedure and the rationale behind the GISS method are explained in the most recent posting on global temperatures by Hansen (2010).

Global projections

I adopted the three scenarios from the 2007 IPCC report, A2 ("high"), A1B ("medium") and B1 ("low"). Global temperatures until 2100 were taken as the climate model averages provided by IPCC (Meehl et al., 2007, Fig. 10.5) and used as the input for the calculation of the thermal expansion contribution to the sea level. The contribution was aligned to the average model results in the year 2000 and projected until 2100. Fig 4. shows the evaluated projections, which are slightly lower but comparable to the average projection for the same quantity using more complex climate models.

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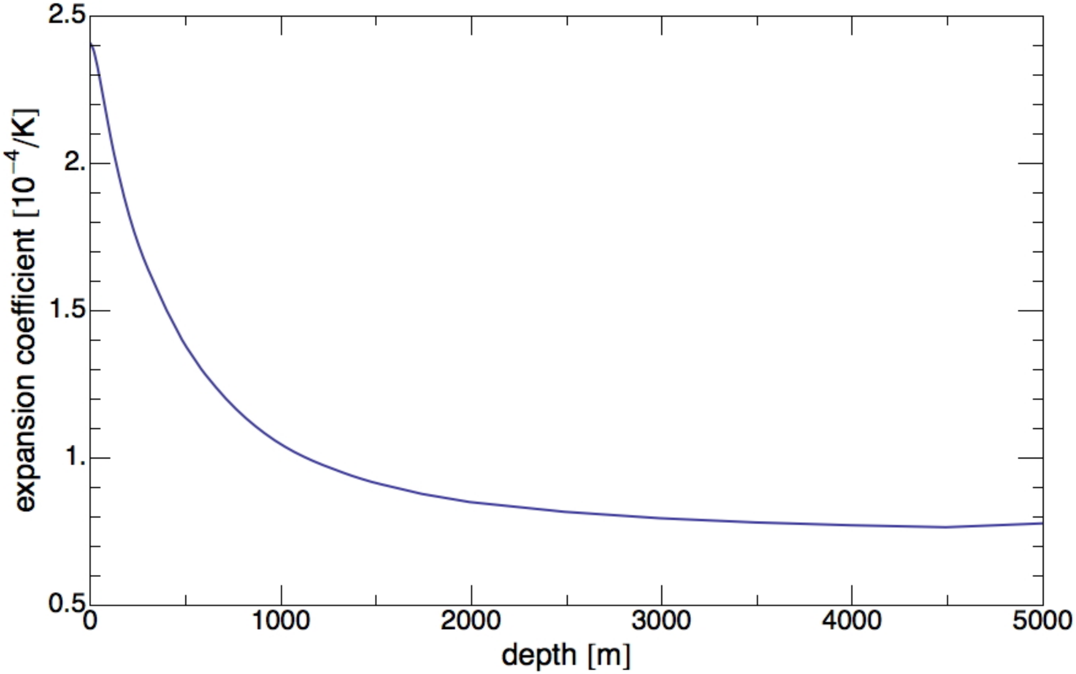

Fig. 1. Fig. 1. Average thermal expansion coefficient profile for the global ocean.

OSD
6, C1025–C1032, 2010

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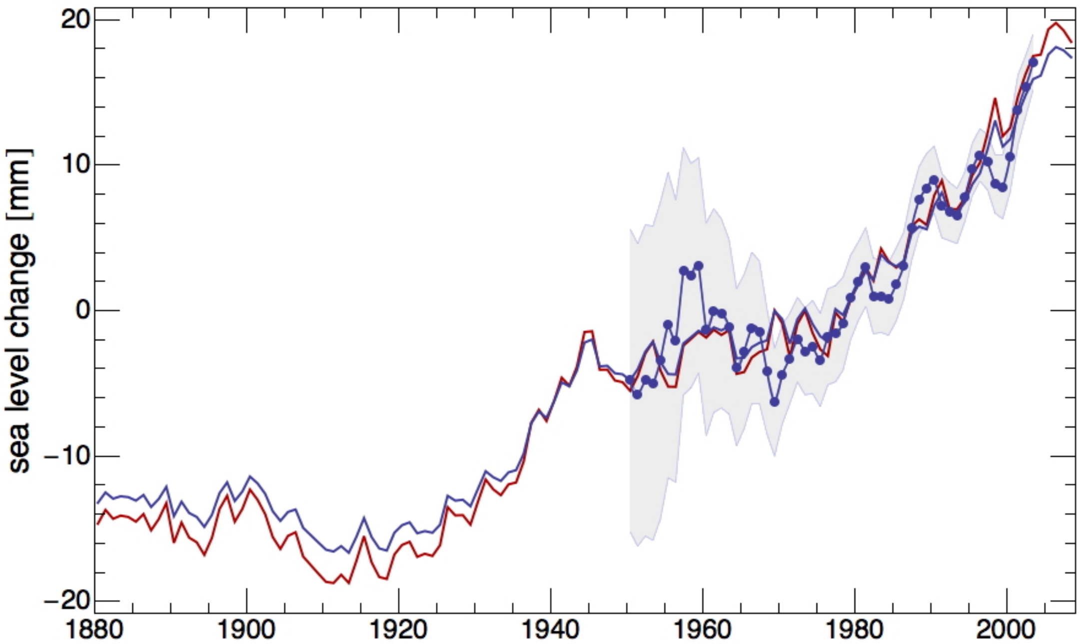

Fig. 2. Fig. 2. Sea level change calculated using average thermal expansion coefficient (blue line) and using depth-dependent thermal expansion coefficient (red line). Data points: Domingues et al.

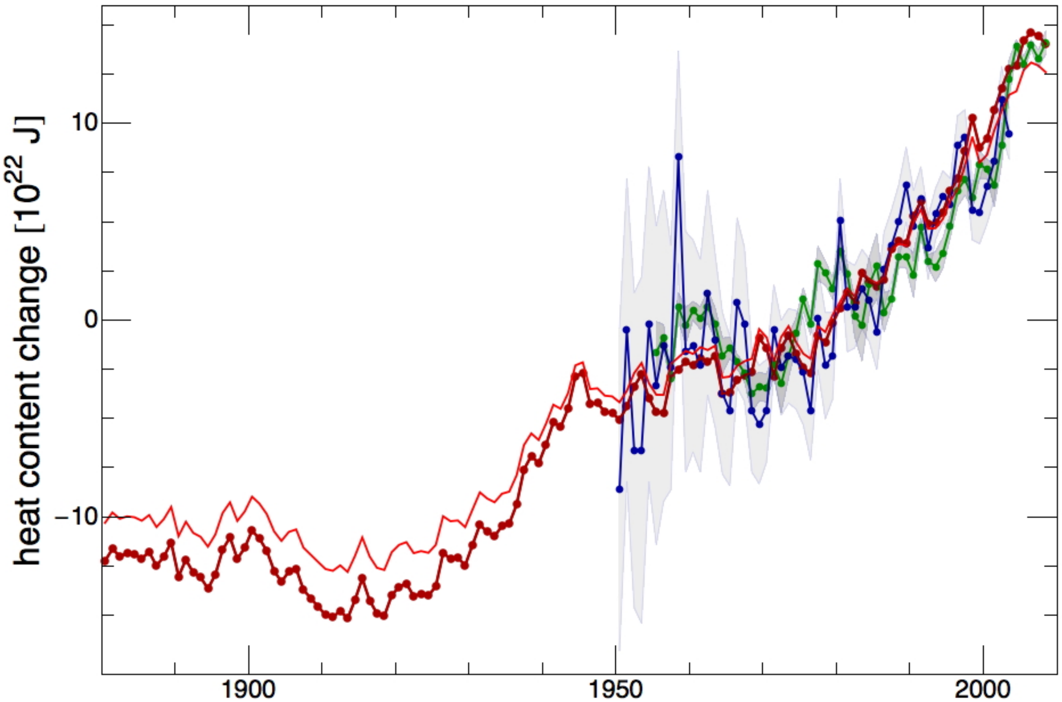

Fig. 3. Fig. 3. Heat content change calculated using the Munk value Az≈1.3 x 10-4 m2/s for eddy diffusivity (thick red) and using Az≈0.9 x 10-4 m2/s (thin red). Blue: Domingues et al., Green: Levitus et al.

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6, C1025–C1032, 2010
Interactive Comment

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6, C1025–C1032, 2010

Interactive Comment

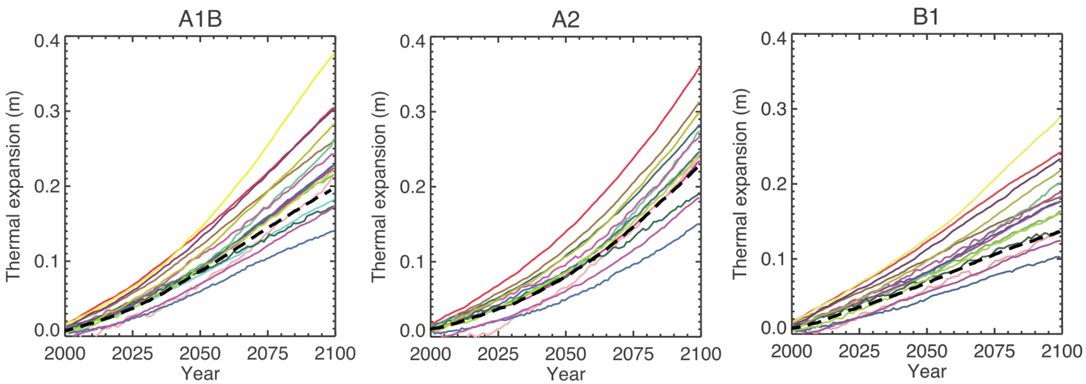

Fig. 4. Fig. 4. Climate model projections for the thermal expansion contribution to the sea level change (Meehl et al., 2007, Fig.10.31) with the present model calculation superimposed on the original figure.