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Global mean thermosteric sea level & the sea level budget

Introduction

Estimates of Global Mean Sea Level (GMSL) show a rise of 2.0 mm/yr from 1961 to 2003. However, current estimates of mass and steric contributions do not adequately explain the observed sea level rise. Infilling methods, which essentially assume no change in sparse ocean data coverage regions, particularly in the Southern Hemisphere, may underestimate the globally-averaged steric contribution (e.g., Gregory *et al.*, 2004). We attempt to overcome this difficulty by using a reduced space optimal analysis. This technique has been used to reconstruct sea surface temperature (Kaplan *et al.*, 1998), sea level pressure (Kaplan *et al.*, 2000) and sea surface height (Church *et al.*, 2004).

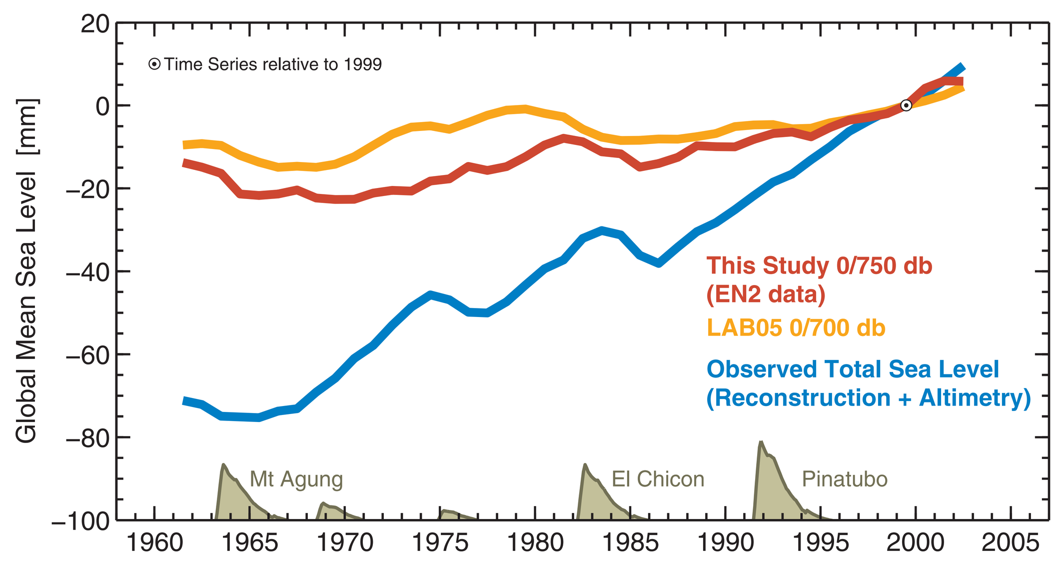
Objectives

- To reconstruct thermosteric sea level (1961–2003) using a reduced space optimal analysis.
- To revisit the sea level budget.

Thermosteric sea level reconstruction

Thermosteric height anomalies (seasonal signal removed) relative to 750 db are calculated from the ENACT (EN2) quality-controlled temperature profiles (Ingleby and Huddleston, 2006). EOFs are calculated from satellite altimeter data from 1993 to 2004. The amplitude of a limited number of EOFs and a spatially constant field are then determined for each month by minimising the difference between the sum of these fields and the observed steric heights (Church *et al.*, 2004).

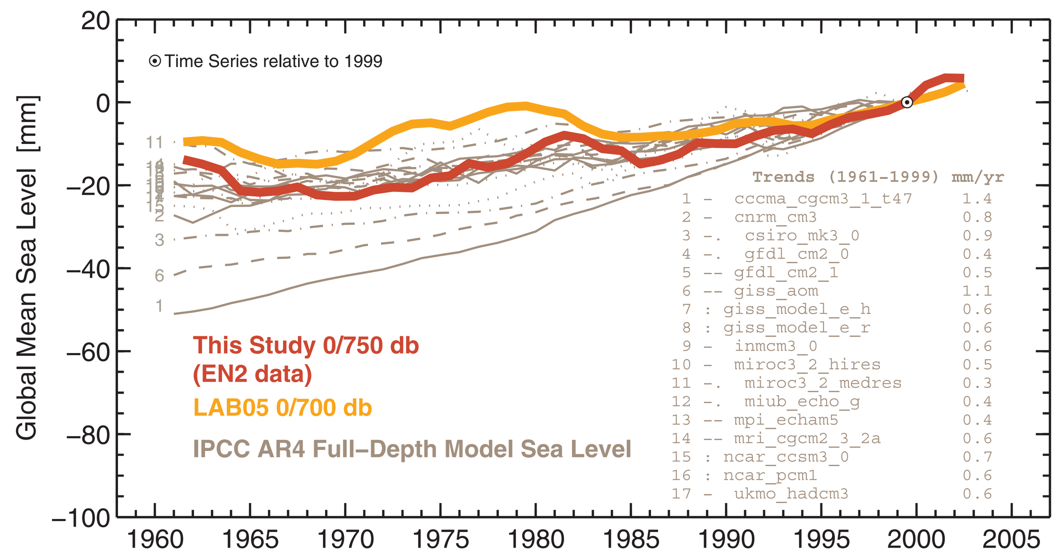
Global mean thermosteric sea level



Our time series (above) shows a larger thermosteric contribution with a steeper trend after 1985 than that calculated using gridded temperature fields described by Levitus, Antonov and Boyer (2005), hereafter LAB05. Larger discrepancies between the two time series are seen in the 1970s. The observed sea level (blue line) is a combination of sea level from altimetry (TOPEX/Poseidon and Jason-1) and a reconstruction (Church *et al.*, 2004) prior to 1993.

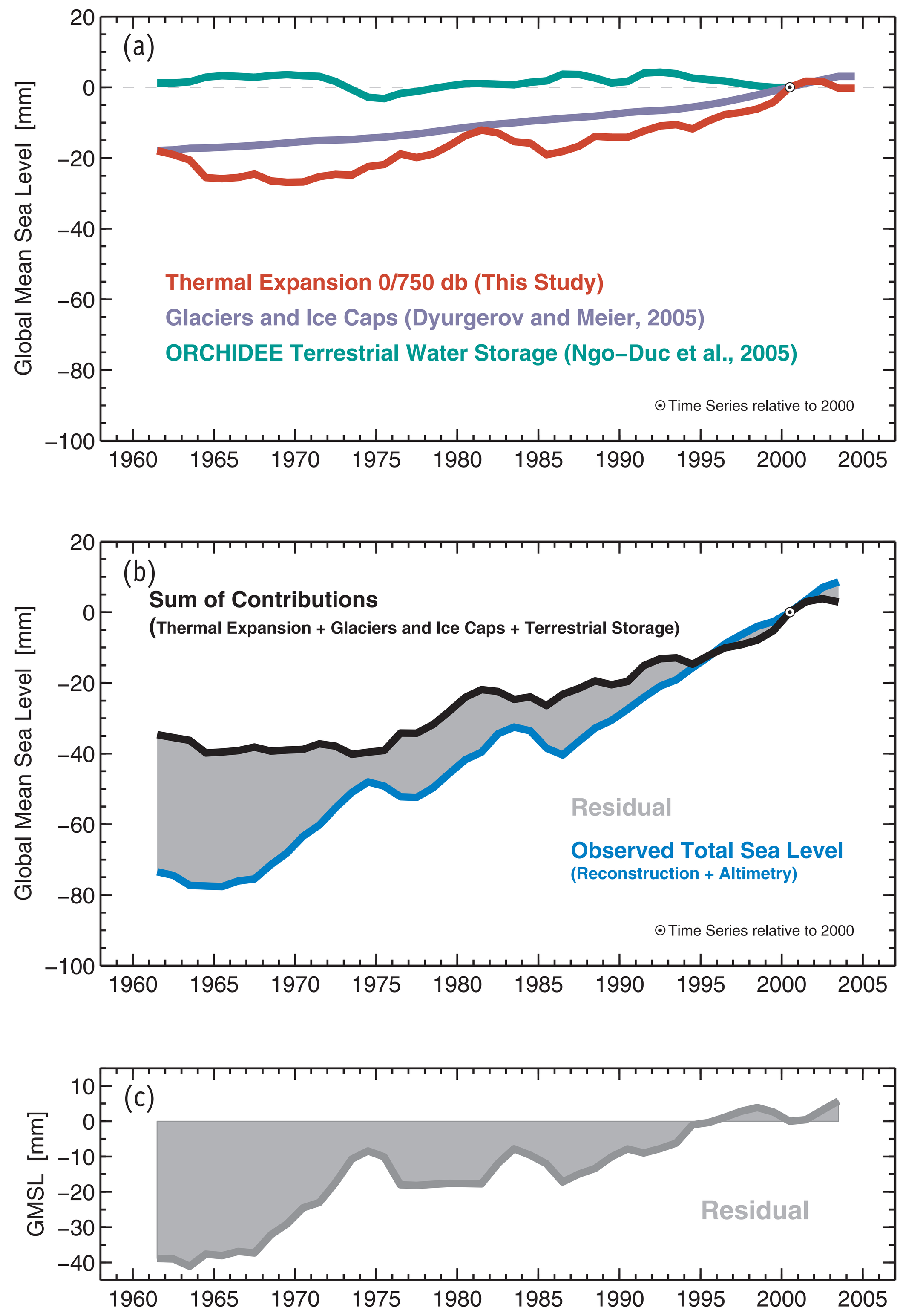
Trends [mm/yr]	1961-2003	1993-2003
This Study 0/750 db	0.6	1.6
LAB05 0/700 db	0.3	1.2

Our 1993-2003 linear trend of ~1.6 mm/yr is similar to that calculated by Willis *et al.* (2004) and Lombard *et al.* (2006), whose work relied on sea level from altimeters for infilling to estimate steric height.



Estimates of steric sea level for a number of IPCC AR4 models (J. Gregory, pers. comm.) are shown above. The model results are closer to our thermosteric estimate than that based on LAB05. Note that model time series are for full ocean depth while the observed series are for the upper 700/750 db.

Sea level budget



Our thermosteric reconstruction is presented above (a), together with other sea level contributions. The glaciers and ice caps series includes all perennial ice masses other than the Greenland and Antarctic ice sheets (Dyurgerov and Meier, 2005). The terrestrial water storage time series is from the ORCHIDEE land surface model (Ngo-Duc *et al.*, 2005) and shows little trend. Glacier melt and ocean thermal expansion are major contributions to sea level rise. The latter is larger than the former and displays low frequency variability, as does the observed sea level. The difference between the observed sea level and the sum of the contributions (b) leaves a residual, smaller than 20 mm after 1972 but as large as 40 mm before that (c). Other contributions that could help to explain this residual are melting of the Greenland and Antarctic ice sheets and thermal expansion of the deep ocean (> 750 db).

Trends [mm/yr]	1961-2003	1973-2003	1993-2003
Thermal Expansion 0/750 db (This Study)	0.6	0.7	1.6
Glaciers and Ice Caps	0.5	0.6	0.8
Greenland and Antarctic Ice Sheets*	0.2	0.2	0.4
Deep Ocean (750/3000 db) Thermal Expansion**	0.1	0.1	0.3
Sum of Contributions	1.4	1.6	3.1
Observed Total Sea Level	2.0	2.0	3.1
Residual	0.6	0.4	0.0

* Source: IPCC AR4 Summary for Policymakers (SPM), 14 February, 2007.

** Following Antonov *et al.* (2005), we assume that the estimate of the upper 750 db is 85% of the estimate in the top 3000 db.

Conclusions

1993–2003

Our thermosteric sea level trend (0/750 db) is 1.6 mm/yr, similar to estimates from Willis *et al.* (2004) and Lombard *et al.* (2006). The sea level budget is closed within error bars.

1961–2003 and 1973–2003

Our thermosteric sea level trend (0/750 db) for 1961-2003 (1973-2003) is 0.6 mm/yr (0.7 mm/yr), larger than the 0.3 mm/yr (0.4 mm/yr) calculated using the gridded data described in LAB05 (cf. Antonov *et al.*, 2005; Ishii *et al.*, 2006). The sum of the contributions is close to explaining the observed total sea level for 1973-2003, with a residual trend of 0.4 mm/yr. However, there are significant discrepancies before 1973.

Acknowledgements

Bruce Ingleby and the Hadley Centre, UK Met Office, for the ENACT/EN2 temperature data; Mark Dyurgerov and Mark Meier for the glaciers and ice caps time series; Thanh Ngo-Duc and Anny Cazenave for the ORCHIDEE terrestrial water storage time series; NODC for the hydrographic fields described in LAB05; Jonathan Gregory for the IPCC AR4 model time series; and JPL PO.DAAC for satellite altimeter data.

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