Assessing the contributions to recent sea level change by combining altimetric and hydrographic data

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Overview

In order to assess the size of the different contributions to recent sea level change (period 1993 to 2003), various datasets have been assimilated into a global ocean model using the **4-dimensional variational (4DVar) assimilation method**. This poster shows the Optimized Solution for a simulation using all datasets presented in the overview, including the high resolution temperature data for the upper 700 m (kindly provided by J. Willis, in the following referred to as Willis06). These results are compared with a Reference Run without Willis06.

The Ocean Model

The simulations are performed with the **Hamburg Large Scale Geostrophic (LSG) model** (Maier-Reimer and Mikolajewicz, 1992). This global ocean model is set up on an **E-grid** and has a **horizontal resolution of roughly 2°**. Because of the implicit formulation in time, a **timestep of 10 days** can be used. The model consists of **23 layers** that extend from 20 m at the surface to a layer thickness of 750 m near the bottom. Basically designed for long climate studies, the model in the present configuration together with its adjoint code proved successful in studies of sea level change (e. g. Wenzel and Schröter, 2007). The **control vector** consists of the **initial state and forcing fields** (precipitation and evaporation, air temperature, and wind stress; first guess from NCEP).

The Models Free Surface

The model has a free surface and considers mass and volume change. Sea surface height ζ is determined by:

$$\frac{\partial}{\partial t}\zeta = \text{P - E + R} \qquad \text{freshwater flux}$$

$$+ \int_{-h}^{\zeta} \frac{1}{\alpha}\frac{\partial \alpha}{\partial T}\bigg|_{S,p}\frac{\partial}{\partial t}T\,\mathrm{d}z \qquad \text{thermosteric}$$

$$+ \int_{-h}^{\zeta} \frac{1}{\alpha}\frac{\partial \alpha}{\partial S}\bigg|_{T,p}\frac{\partial}{\partial t}S\,\mathrm{d}z \qquad \text{halosteric}$$

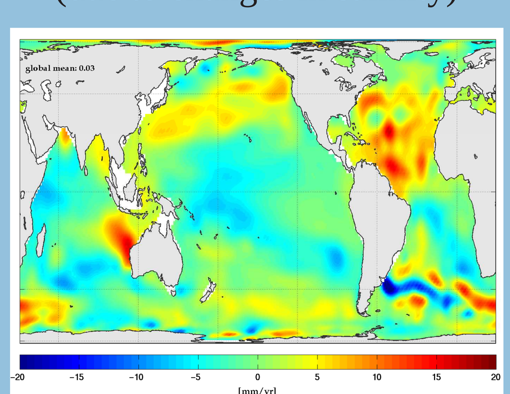
$$+ \nabla\cdot\int_{-h}^{\zeta}\vec{v}\,\mathrm{d}z \qquad \text{divergence}$$

The term P - E - R refers to the sum of precipitation (P), evaporation (E), and river runoff (R), which altogether determine the freshwater flux. T and S are temperature and salinity, p is the pressure, α is the specific volume (which is the inverse of density ρ) and $\vec{v}$ determines the horizontal velocity.

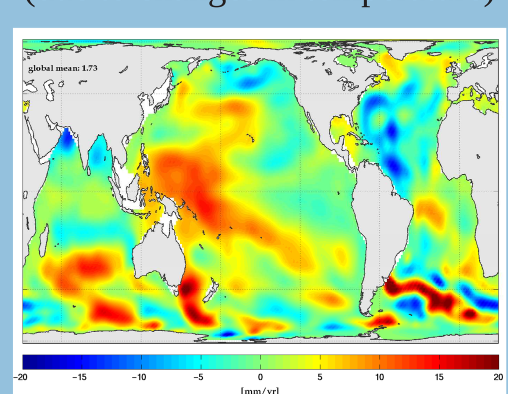
Regional Trends in Sea Surface Height (SSH)

The following figures show the regional trends for sea surface height (SSH) and the different contributions derived from the simulation that includes the high resolution temperature data. All trends refer to the period 1993 to 2003.

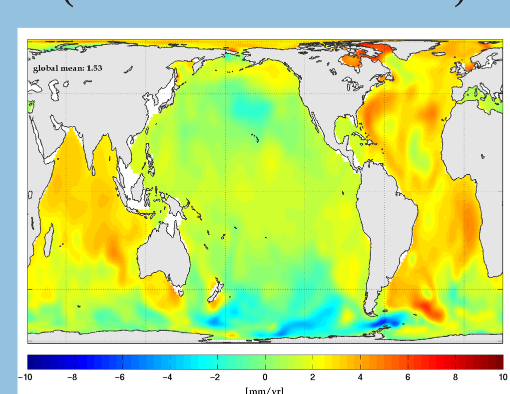
Halosteric (due to changes in salinity)



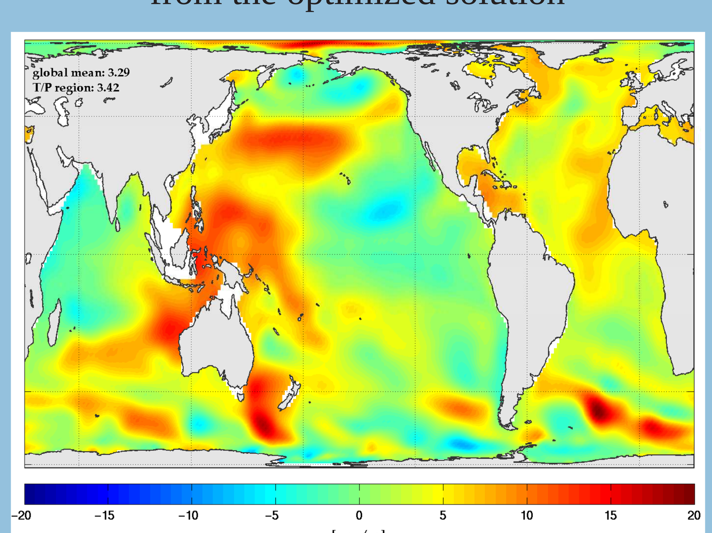
Thermosteric (due to changes in temperature)



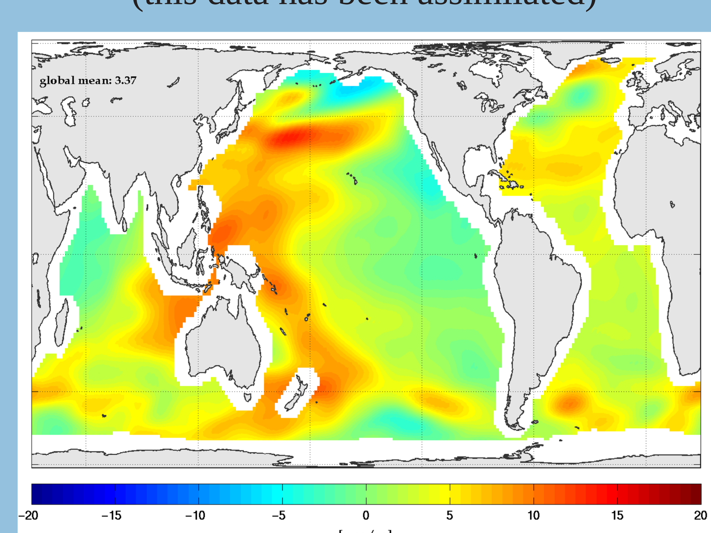
Mass contribution (**note:** different colorscale)



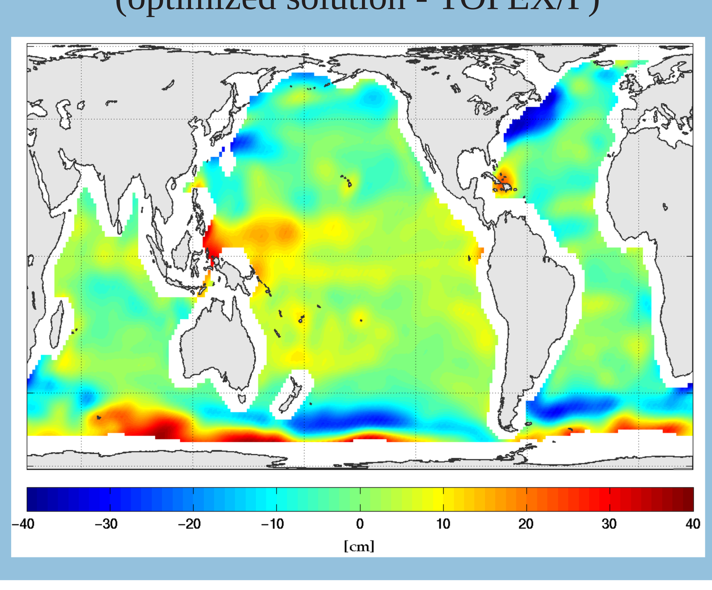
Trends in SSH from the optimized solution



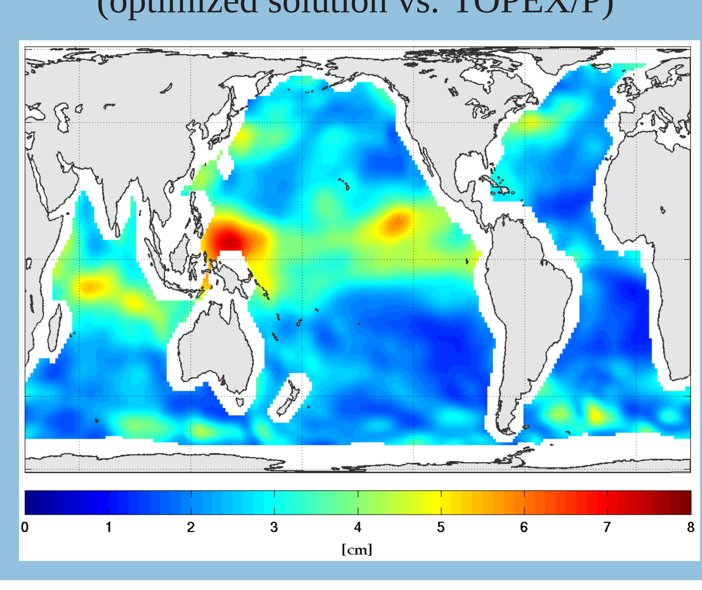
Trends in SSH from TOPEX/P (this data has been assimilated)



Mean Difference in SSH (optimized solution - TOPEX/P)



RMS of SSH Anomalies (optimized solution vs. TOPEX/P)



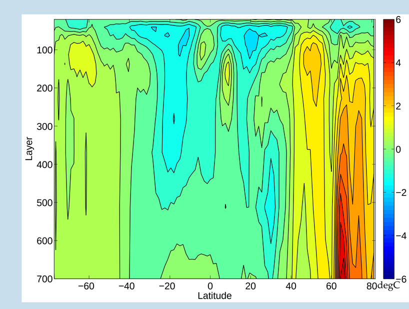
The Assimilated Datasets

The most important datasets are the altimeter data from TOPEX/Poseidon (T/P), which serves as constraint for the total sea level changes, and the high resolution temperature dataset to constrain the thermosteric contribution (pers. comm. Willis, 2006, referred to as Willis06). The latter covers the upper 750 m with data every 10 m. The horizontal resolution is about 1° and 4 datasets per year are available (analysis described in Willis et al., 2004).

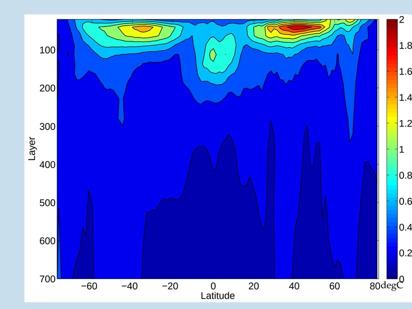
Kind of Data	Origin
SSH (sea surface height)	TOPEX/Poseidon
Reynolds SST (sea surface temperature)	NOAA
transports	various origins
sections in Ross and Weddell Sea	model results (BRIOS)
Temperature climatology	WOA01
Salinity climatology	WOA01
high resolution Temperature dataset	*by J. Willis (2006)*

Model Performance (Optimized Solution)

Comparison with assimilated data (Willis06)



Model – Observations (zonal mean)



STD (zonal mean)

Largest differences occur at high latitudes, especially in the deeper layers. Besides relative small weights of the observations in these regions, this might be explained (at least for the North) with problems in the representation of convection.

Comparison with independent data (GRACE)

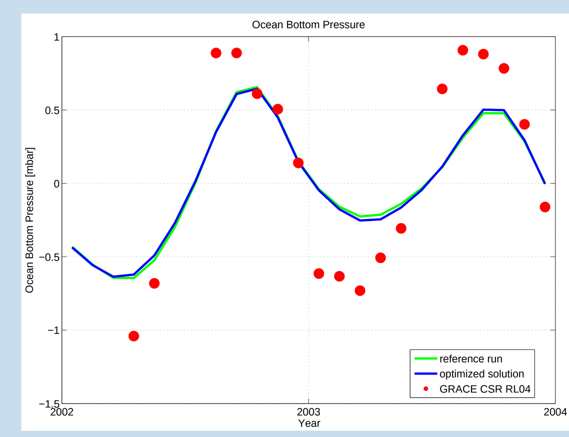
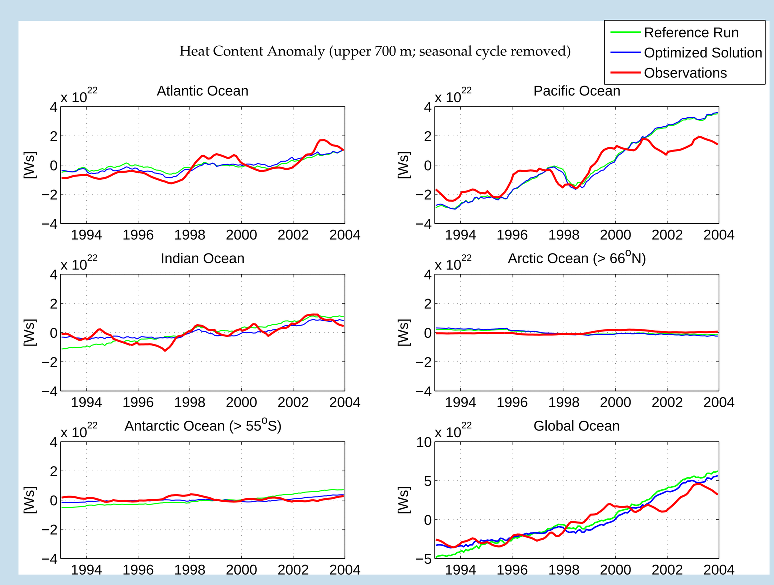
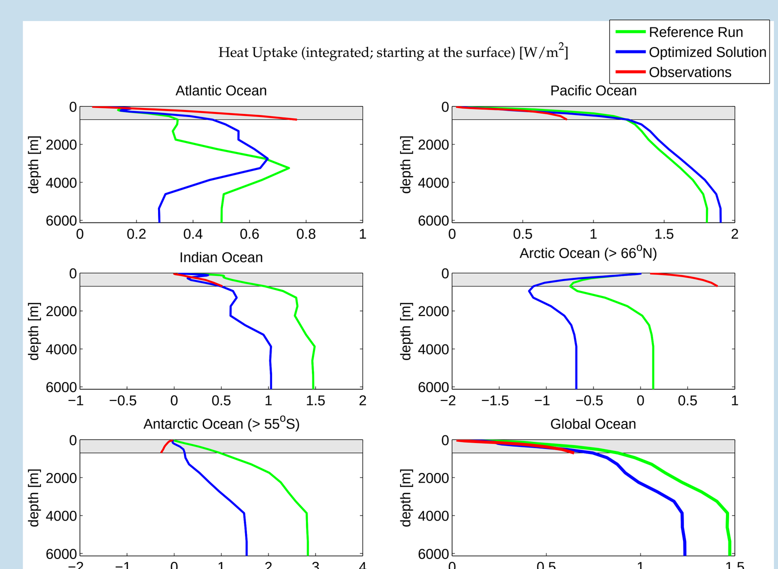


Figure 1: Comparision of model results for ocean bottom pressure (OBP, colored lines) with OBP from the Gravity Recovery and Climate Experiment (GRACE; CSR RL04).

Heat Content and Heat Uptake





The trends for heat content (right figure) are improved with the Willis data, although the misfit on basin scale can still be considerable. Especially the polar regions show large differences though this misfit is considered less problematic because the data base in these regions is sparse. Note that all simulations indicate quite a considerable increase in global heat content in the deeper layers.

Mean Sea Level Changes

Global mean sea level (MSL) changes show a clear seasonal cycle (black line). Yet, as a model artefact, the seasonal cycle of the thermosteric changes is less pronounced than observed. This is also true for the mass contributions (represented by the dotted green line, see also Fig. 1). **Note:** the margenta dots present the MSL induced directly from the TOPEX/P data that covers only the region $\pm$ 66°, while all other curves refer to a global mean from the whole model domain.

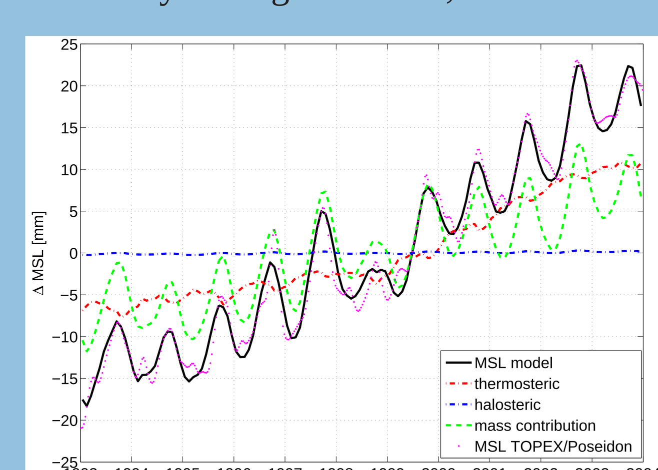


Figure 2: Mean sea level for the optimized solution (including high resolution temperature data).

MSL (global)	3.29 mm/yr
MSL (TOPEX/P region; $\pm$ 66°)	3.42 mm/yr
MSL (directly from TOPEX/P)	3.37 mm/yr
thermosteric contribution	1.73 mm/yr
halosteric contribution	0.03 mm/yr
mass changes	1.53 mm/yr

Overview: Trends for the optimized solution

Summary

The simulations successfully reproduce the most important ocean features and lead to reasonable dynamics, though the seasonal cycle of thermosteric and mass changes is underestimated.The best estimate for the sea level trend derived from the simulations is a rise in global mean sea level (GMSL) by about 3.3 mm/yr for the period from 1993 to 2003 (compared to 3.1 $\pm$ 0.7 mm/yr from T/P; IPCC, 2007). According to the present study, thermal expansion contributes 1.7 mm/yr to GMSL rise, while mass input accounts for 1.5 mm/yr. The global mean halosteric trend is close to zero. While most of the thermosteric expansion takes place in the upper 700 m, the simulations indicate that there is a significant contribution of about 1/3 of the total thermosteric height change from the deeper layers.

References

IPCC (2007). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Maier-Reimer, E. and Mikolajewicz, U. (1992). Report No.2, The Hamburg Large Scale Geostrophic Ocean General Circulation Model (Cycle 1). Technical report, Deutsches Klimarechenzentrum (DKRZ).

Wenzel, M. and Schröter, J. (2007). The global ocean mass budget in 1993-2003 estimated from sea level change. *Journal Of Physical Oceanography*, 37(2):203–213.

Willis, J. (2006). personal communications.

Willis, J., Roemmich, D., and Cornuelle, B. (2004). Interannual variability in upper ocean heat content, temperature, and thermosteric expansion on global scales. *Journal of Geophysical Research*, 109(C12036).