Modelling the Oceanic Heat and Freshwater Content Using a Volume Constraint

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Introduction

Eleven years (1993-2003) of TOPEX/Poseidon sea surface height anomalies, provided by GfZ Potsdam, are assimilated into a global OGCM. In addition the SHOM98.2 mean sea surface relative to the EIGEN-GRACE01S geoid (GfZ) as well as sea surface temperatures and ice cover information from Reynolds (2002) are assimilated into the model. The WGHC climatology combined with the monthly anomalies from WOA01 is used as background information for temperature and salinity. Furthermore model data from high resolution regional model runs are supplied in the Ross Sea and in the Weddell Sea.

The OGCM that is used in this study is based on the Hamburg Large Scale Geostrophic model LSG. The model has a $2^\circ \times 2^\circ$ horizontal resolution, 23 vertical layers and a ten day timestep. Furthermore the model is able to estimate the single contributions to sea level change, the steric (thermosteric, halosteric) and the non-steric effects (local freshwater balance, mass redistribution) seperately.

To adjust the model to the data the adjoint method is employed. The control parameters of this optimization are the models initial temperature and salinity state as well as the forcing fields (windstress, air temperature and surface freshwater flux). The forcing is optimized via an empirical orthogonal function (EOF) decomposition, with the first guess taken from the NCEP reanalysis.

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Model vs. Data

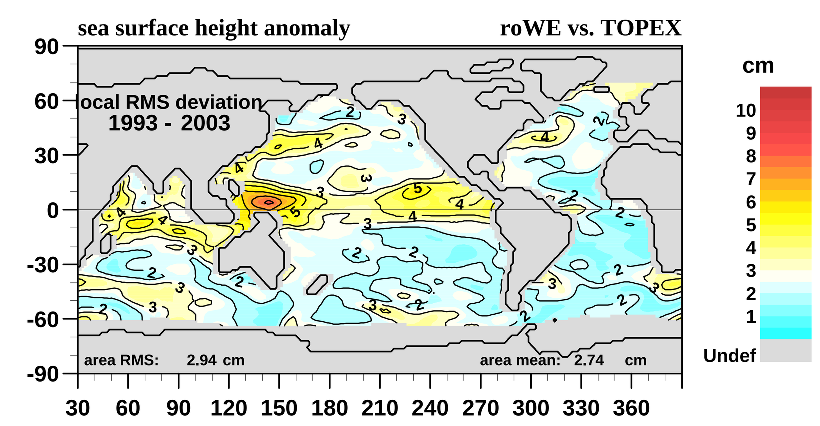

Fig. 1.1: *Local temporal RMS difference between the modeled SSHA and the TOPEX/Poseidon data*

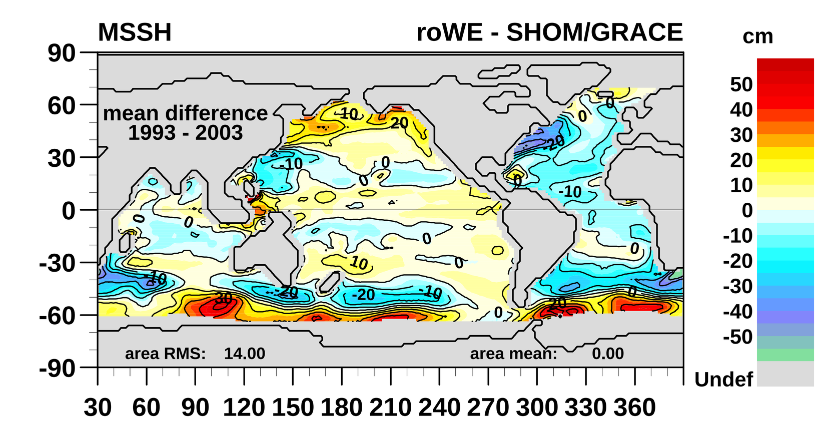

Fig. 1.2: *Modeled temporal mean sea level compared to the SHOM98.2 mean sea surface height referenced to the GRACE geoid*

The temporal RMS differences between the modeled SSHA and the data is shown in Fig. 1.1 The global RMS value, which is the measure of success in the assimilation, is 2.9cm although locally we find higher RMS values (up to 7cm) especially in the tropical Pacific and in the western boundary currents. For the temporal mean SSH the deviations between the model and the data are well below 5cm in most part of the ocean giving a global RMS value of 14cm (Fig. 1.2). As for the anomalies the largest deviations (up to $\sim$ 30cm) are found in the regions with strong currents, i.e. the western boundary currents as well as the Antarctic Circumpolar Current (ACC). Especially the signature in the ACC region implies that these currents are represented too broadly by the model. For the surface temperature the corresponding RMS differences between the model and the data are 0.30K for the temporal mean and 0.51K for the anomalies (not shown).

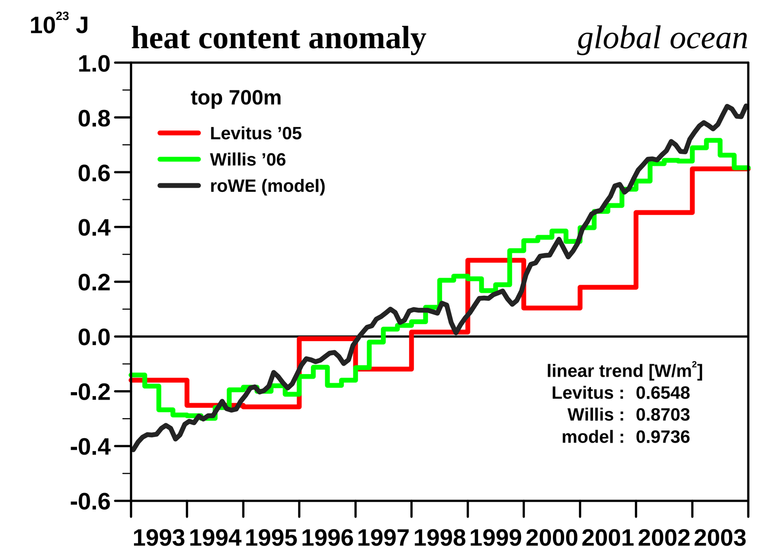

Fig. 1.3: *Global ocean heat content anomaly for the depth range [ζ-700m] compared to the WOA01 annual anomaly data (Levitus, red line) and to the Willis data (2006 update, green line)*

Using information in the Weddell Sea and the Ross Sea areas leads to a better circulation in these regions. It improves the evolution of the global upper ocean heat content. The trend now fits well to the estimates derived analysing the WOA01 and the Willis data respectively (Fig. 1.3).

Levitus S. et al.: Warming of the world ocean 1955–2003, *Geophysical Research Letters*, Vol. 32, L02604, doi: 10.1029/2004GL021592, 2005

Willis J. K. et al: Interannual variability in the upper ocean heat content, temperature and thermosteric expansion on global scales, *Journal of Geophysical Research*, Vol. 109, C12036, doi: 10.1029/2003JC002260, 2004

Heat / Temperature

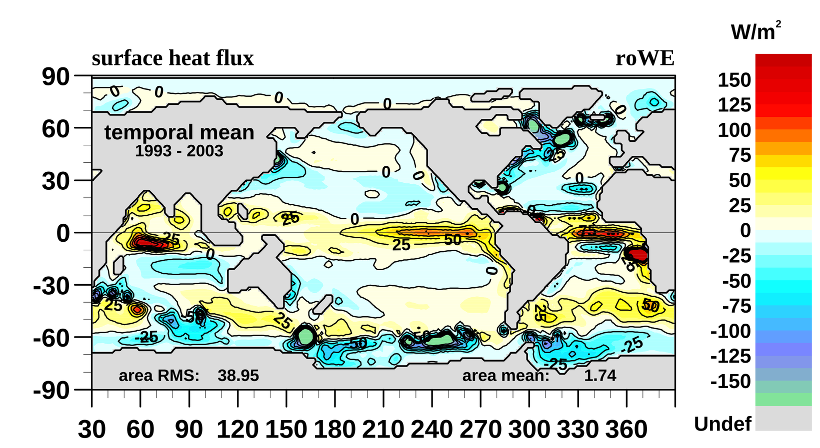

Fig. 2.1: *Temporal mean surface heat flux*

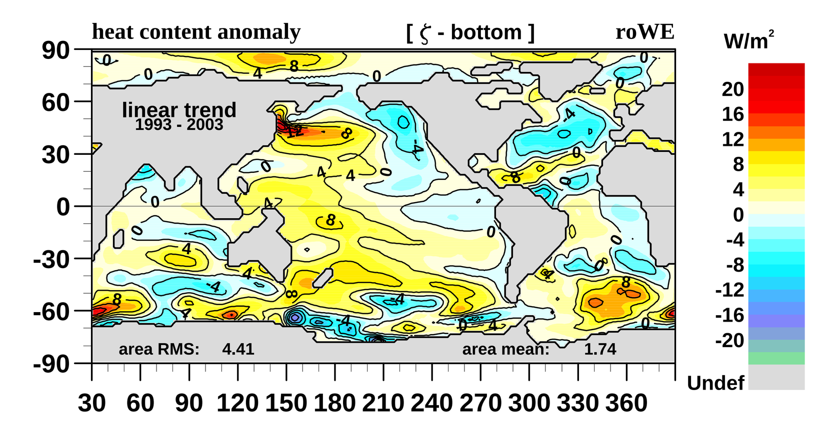

Fig. 2.2: *Local linear trend of the oceans heat content*

Heat

The estimated temporal mean surface heat flux (Fig. 2.1) exhibits a reasonable horizontal structure. However, there are several 'cold' and 'hot' spots visible. These are caused by deficiencies in the models horizontal circulation. Due to its coarse resolution the models currents appear too broad and follow a slightly wrong path. Without the assistence of these spots this would induce unsatisfactory surface temperature fields as compared to the constraint (Reynolds SST data).

The heat gained through the surface is not stored locally but carried around by the circulation. This leads to a totally different picture when looking at the trend in the local heat content (Fig. 2.2).

Temperature trends 1993–2003

The Fig. 2.3 to 2.5 show the trend in the zonally averaged temperatures for the Atlantic, the Pacific and the global ocean, respectively. One finds upper ocean warming nearly everywhere with only few exceptions like in the North Pacific (Fig. 2.4). Compared to this the trends in the deep ocean are much smaller except for the convective regions and a strong warming found in the Atlantic (Fig. 2.3) north of the equator. However, because of the thickness of the deep ocean layer the trends therein cannot be neglegted when looking at the total watercolumn heat content.

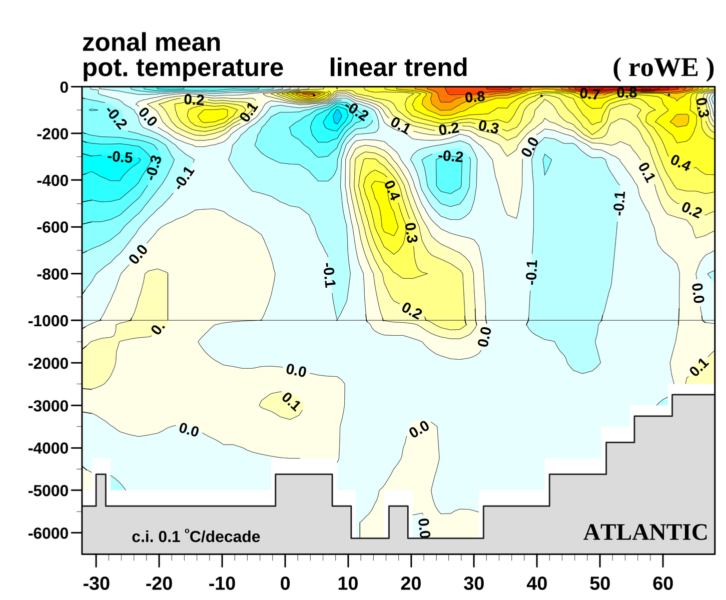

Fig. 2.3: *Linear trend of zonal mean temperature (Atlantic)*

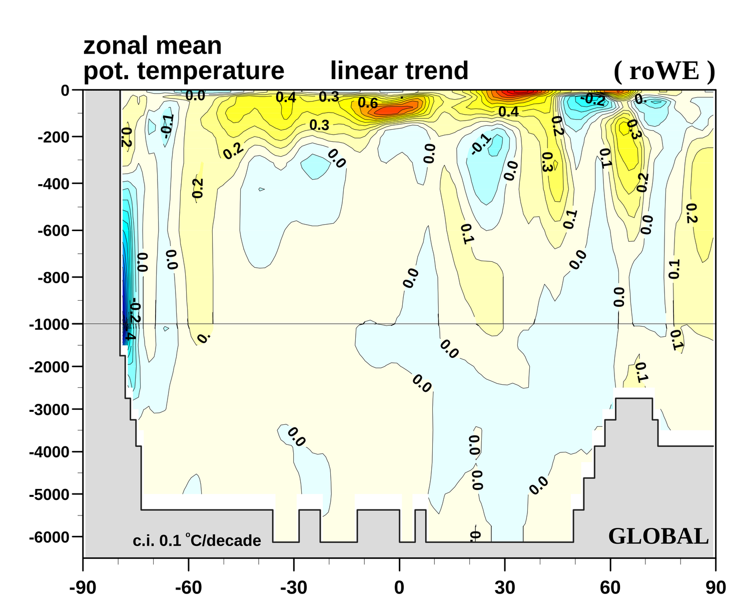

Fig. 2.5: *Linear trend of zonal mean temperature (global)*

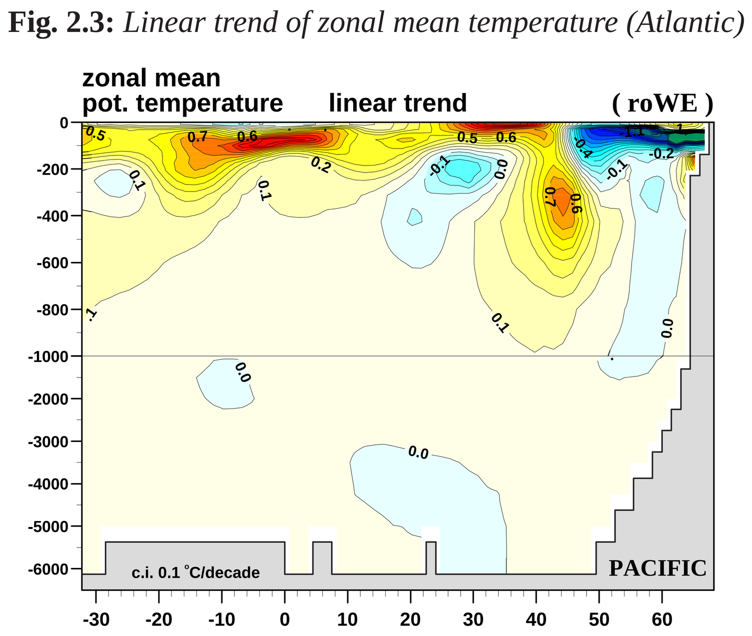

Fig. 2.4: *Linear trend of zonal mean temperature (Pacific)*

Freshwater / Salinity

Freshwater

Aside heat the oceans freshwater budget is the main contributor to global sea level change. Fig. 3.1 exhibits the estimated temporal mean surface flux that reflects the balance between precipitation, evaporation and run-off. In contrast to the surface heat flux (Fig. 2.1) it stays close to its first guess and does not show any 'spotty' features. The latter is obviously due to the fact that there are no constraints on surface salinity.

The local freshwater input is nearly totally compensated by the horizontal circulation. This results in an eustatic sea level change (Fig. 3.2) that is fairly constant within the single ocean basins. Nearly all basins show a sea level rise which is biggest in the Atlantic and the Indian Ocean. The main exception is the region between Australia and Drake Passage in the Antarctic Circumpolar Current.

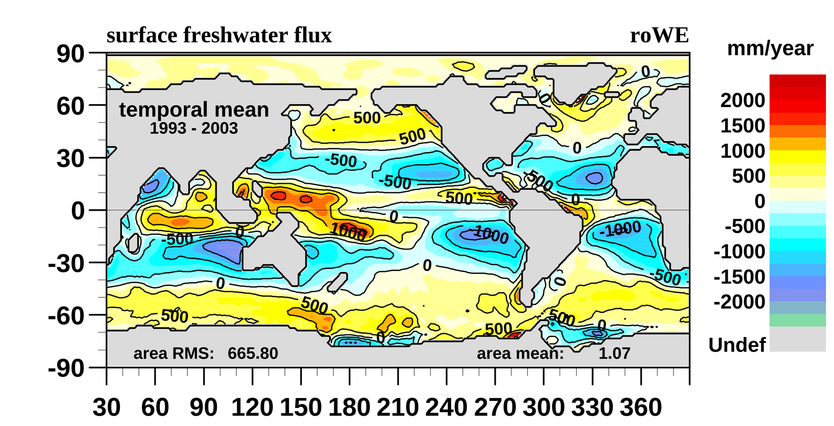

Fig. 3.1: *Temporal mean surface freshwater flux*

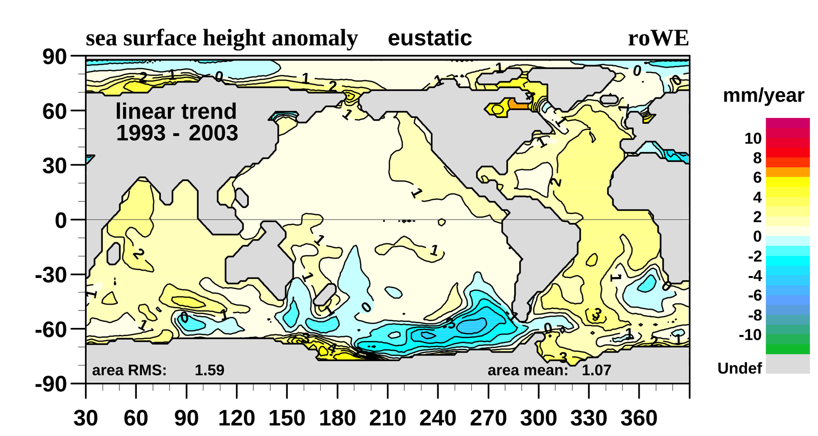

Fig. 3.2: *Local linear trend of the oceans freshwater induced sea level change.*

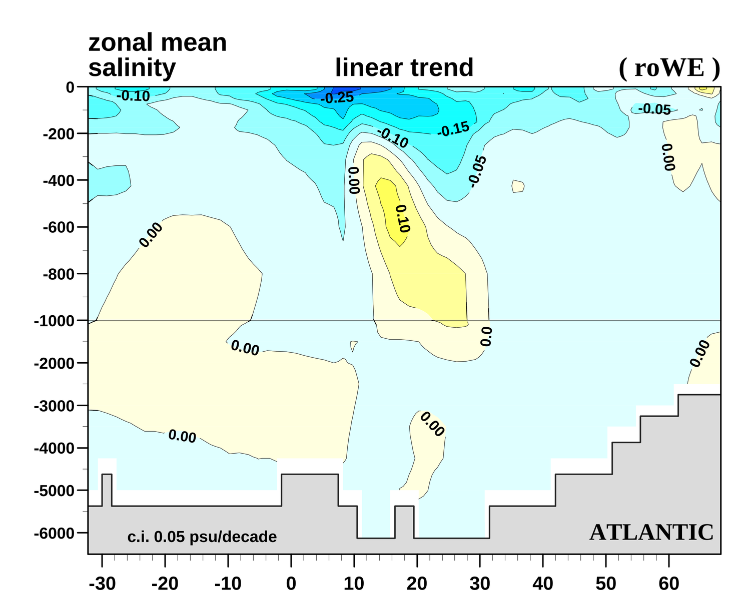

Fig. 3.3: *Linear trend of zonal mean salinity (Atlantic)*

Salinity trends 1993–2003

Changes in the oceans salinity are caused by the surface freshwater exchange and the circulation. The resulting zonally averaged trends are shown in Fig. 3.3 to 3.5 for the Atlantic, the Pacific and the global ocean, respectively. Most conspicuous is the strong similarity to the temperature trends in the Atlantic especially below the 200m depth level. This simularity is not that pronounced for the other oceans, neither for the Pacific nor for the global ocean.

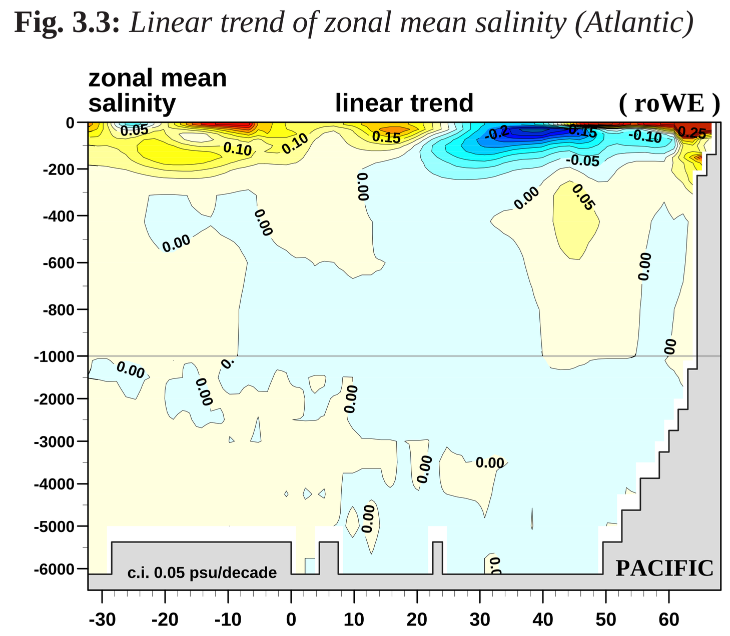

Fig. 3.4: *Linear trend of zonal mean salinity (Pacific)*

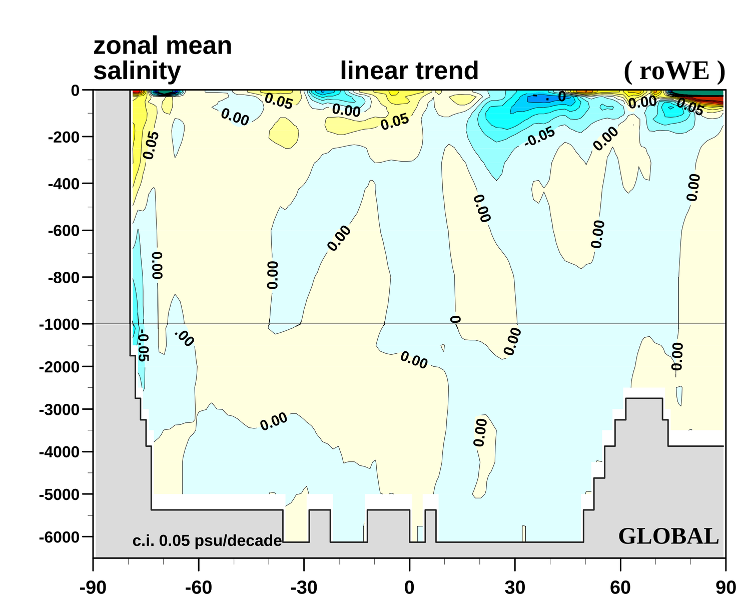

Fig. 3.5: *Linear trend of zonal mean salinity (global)*