Steric and Eustatic Effects: Understandably managed sea level rise by data assimilation

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Model Setup

Eleven years (1993-2003) of TOPEX/Poseidon sea surface height anomalies, provided by GIZ Potsdam, are assimilated into a global OGCM. In addition the SHOM 2.0 mean sea surface relative to the EUGEN-GRAACE05 geoid (GIZ) as well as sea surface temperatures and ice cover information from Reynolds (2002) are assimilated into the model. The WGHM climatology combined with the monthly anomalies from WOA01 is used in background information for temperature and salinity. Furthermore 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° × 2° 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) separately.

To adjust the model to the data the adjoint method is employed. The control parameters of this optimization are the model's initial temperature and salinity state as well as the forcing fields (wind stress, 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.

Validation

The temporal RMS differences between the modelled SSHA and the data is shown in Fig. 1 The global RMS value, which is the measure of success of the assimilation, is 2.9 cm although locally we find higher RMS values (up to 7 cm) 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 5 cm in many parts of the ocean giving a global RMS value of 14 cm. For the surface temperature the corresponding RMS differences between the model and the data are 0.30 K for the NCEP model and 0.51 K for the anomalies.

In using information in the Weddell Sea and the Ross Sea areas leads to an improved 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. 1.2). Further independent data are given by global ocean mass changes as derived from the GRACE mission. The modelled annual cycle for 2003 fits well for these data in amplitude while the phase of the models signal seems to be about one month earlier (Fig. 1.3).

Conclusion

In contrast to other studies we find no significant seasonal signal for the global steric expansion. In addition, we estimate a strong expansion from the ocean below 500m. Showing our analysis is not falsified by GRACE.

Local Sea Level Trends

Figure 2.1 shows that the model reproduces the global mean sea level data well. This is true especially for the interannual variability, while the amplitude of the annual cycle is slightly underestimated by the model. The latter appears to be a general deficit of the OGCM used that leads to the high RMS values apparent in Fig. 1. Figure 2.1 also shows that the linear trend in the modelled global sea level change originates mainly from the steric while the eustatic contribution is smaller but essential. Furthermore, the global eustatic sea level rises nearly all the 'short term' temporal variability (annual cycle) of the global mean sea level. On regional scale, e.g. for the North Atlantic (Fig. 2.2a) the modelled trend amplitude of the steric component is comparable to the steric changes are about five times smaller and they vary on very large scales. In summary, there is no steric sea level rise in all basins. But this rise is not evenly distributed: throughout the Atlantic and the Indian Ocean the steric trends are positive (~2 mm/year) on a fairly constant level while they are well below 1 mm/year in most parts of the Pacific.

Regional Sea Level Evolution

In Fig. 2 the modelled total local sea level trend is split into its eustatic, thermosteric and halosteric part. The spatial distribution of the trend as estimated from the altimeter data is well reproduced by the model (Fig. 2a). Much of its spatial structure is already due to the local changes in heat content (thermosteric trend, Fig. 2c), but there are large regions, where the halosteric part (Fig.2d) becomes essential. Here both steric components have the same order of magnitude for the trend (~5 mm/year global area RMS), but in many regions of the world ocean, especially in the Atlantic, they are opposite in sign thus compensating each other at least by part. On local or regional scale the eustatic sea level changes (Fig.2b) are the residual of the horizontal mass transport divergence and the surface freshwater fluxes. Compared to the steric changes (Fig.2c,d) the eustatic changes are about five times smaller and they vary on very large scales. For example, in the North Atlantic the steric contribution is comparable to the steric changes are about five times smaller and they vary on very large scales. In summary, there is no steric sea level rise in all basins. But this rise is not evenly distributed: throughout the Atlantic and the Indian Ocean the steric trends are positive (~2 mm/year) on a fairly constant level while they are well below 1 mm/year in most parts of the Pacific.

Sea Level Trends [mm/year]

Global Ocean

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North Atlantic

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<tr>
<td>model</td>
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Fig. 3.1: Temporal evolution of the global mean sea level anomaly as compared to the TOPEX/Poseidon data (a). The evolution of the trend area and the eustatic component is also included to (a). The contributions to the thermosteric and the halosteric component from different depth ranges are shown in (b) and (c) respectively.

Fig. 3.2: same as Fig. 3.1 but for the North Atlantic [20°-65°N]

Fig. 3.3: Annual evolution of the global mean sea level anomaly [cm water column] as compared to the TOPEX/Poseidon data (a). The evolution of the trend area and the eustatic component is also included to (a). The contributions to the thermosteric and the halosteric component from different depth ranges are shown in (b) and (c) respectively.