COMBINED ASSIMILATION OF ALTIMETRIC AND HYDROGRAPHIC DATA

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The general circulation of the ocean is studied with a primitive equation model. By assimilating climatological data of temperature and salinity we produce a time varying three-dimensional description of the ocean. We apply an assimilation method which conserves the mass, heat and momentum balance of the ocean model. Integral quantities such as the meridional transport of heat can easily be calculated.

In a second step TOPEX/POSEIDON altimeter measurements referenced to a geoid are assimilated in addition. The use of the satellite data leads to a significantly enhanced seasonal cycle of the global heat transport.

Introduction

A major problem in physical oceanography is the determination of the general circulation and its associated transport of mass, heat and tracers from data. Difficulties arise, because the flow field cannot be measured accurately enough by direct observation of currents. Instead we have to estimate the circulation from measured hydrographic fields (temperature and salinity) and additional data such as satellite altimetry.

Density and the internal pressure field of the ocean can be calculated from temperature and salinity. The 'thermal wind' relation then allows us to derive geostrophic currents relative to some unknown reference velocity. This reference velocity has to be estimated with great care. Finding a 'level of no motion' is only one example of many possibilities. Alternatively we may calculate a surface geostrophic velocity from the slope of the sea surface height (SSH) which is measured by satellite altimetry. The combination of altimetric and hydrographic data then provides a full description of ocean currents.

However, the general circulation estimated this way is not mass conserving. It cannot be used to calculate mass and heat fluxes.

To avoid these problems we use an ocean general circulation model based on primitive equations. It is the 'LSG' model which has been developed at the Max-Planck-Institute for Meteorology in Hamburg to study the large scale circulation for long periods of time [e.g. Maier-Reimer et al., 1993]. Into the LSG model we assimilate TOPEX/POSEIDON (T/P) data using the adjoint technique [Giering, 1995]. This technique does not disturb the model balances of mass, heat, salt and momentum. The flow can only be adjusted by changing the initial conditions or the forcing by the atmosphere. In previous numerical experiments we found how important it is to include hydrographic data in the assimilation.

We will now estimate the annual cycle of the global ocean circulation by assimilating T/P measurements from 1993 [King et al., 1994] referenced to a geoid and climatologic temperature and salinity data [Levitus, 1982]. In order to achieve a cyclo-stationary solution the same data are used repeatedly for four years. Additionally, estimates of the annual mean of the global heat transport are assimilated.

Results

Figures 1 and 2 show the modeled SSH before and after the assimilation in difference to the T/P data. Major improvements are visible mostly in the Atlantic and the Southern Ocean. High errors in areas of narrow currents can be explained by the model dynamics, which smear out sharp gradients. Some of the differences like the very high values north of Australia are possibly due to errors in the geoid. The impact of the T/P data on the heat budget is shown in Figures 3 to 5. The annual mean meridional heat transport is very close to its prescribed values with and without assimilation. The annual cycle, on the other hand, shows a significant increase in amplitude. Most of the surface heat flux is stored locally and is associated with a steric sea level change.

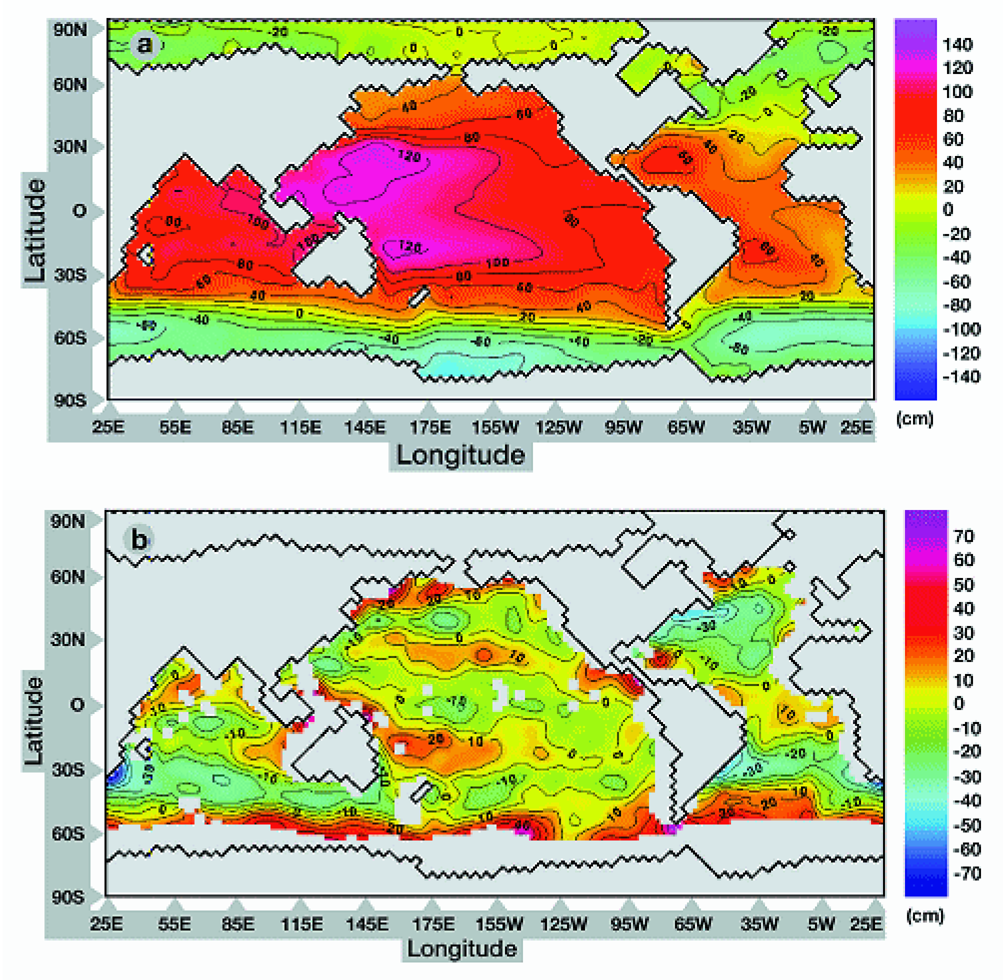

Figure 1

Sea surface height of the LSG model when only hydrographic data are assimilated (a) and (b) difference between the modelled SSH and T/P data. Units are cm. The rms value amounts to 18.2 cm. Many large scale errors such as meridional gradients in the Atlantic and Indian Ocean and the Antarctic Circumpolar Current are visible.

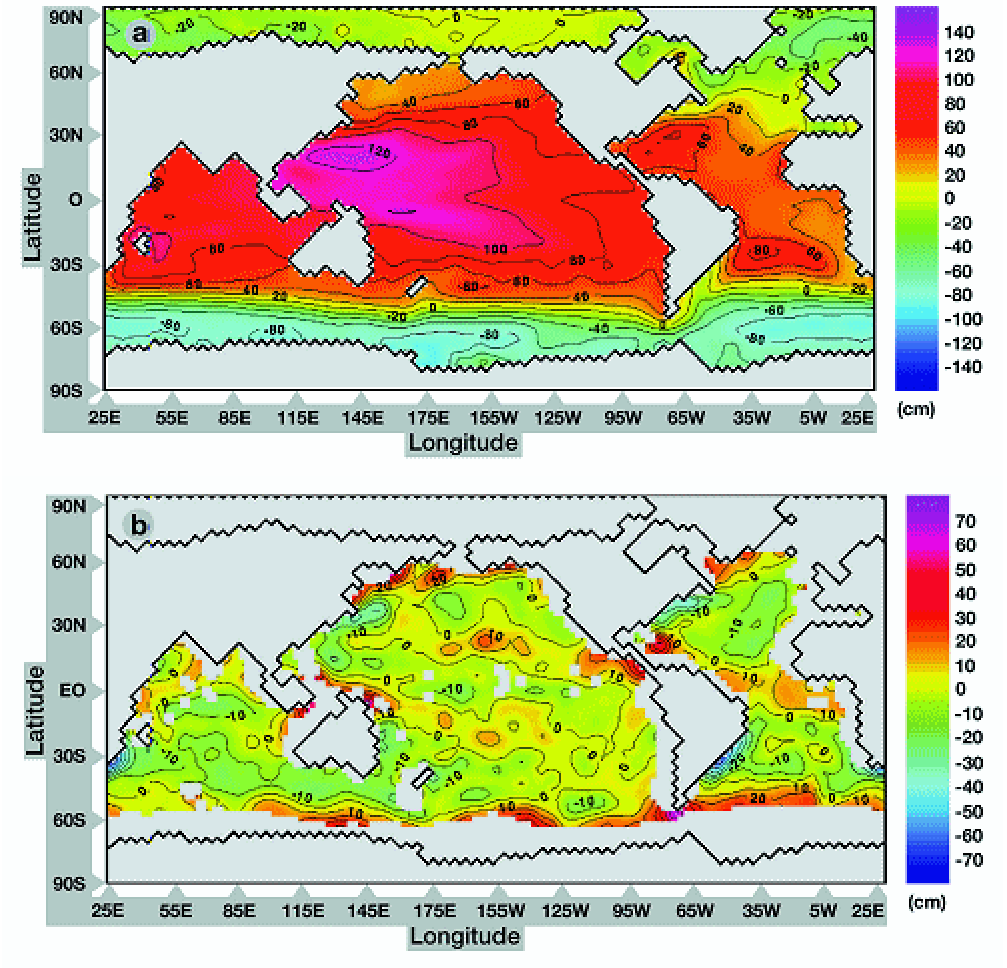

Figure 2

Annual mean SSH of the LSG after the additional assimilation of T/P data (a) and (b) the remaining difference. Units are cm. Major improvements are found. Problems remain mostly in regions of strong and narrow currents. The rms value is reduced to 13.8 cm.

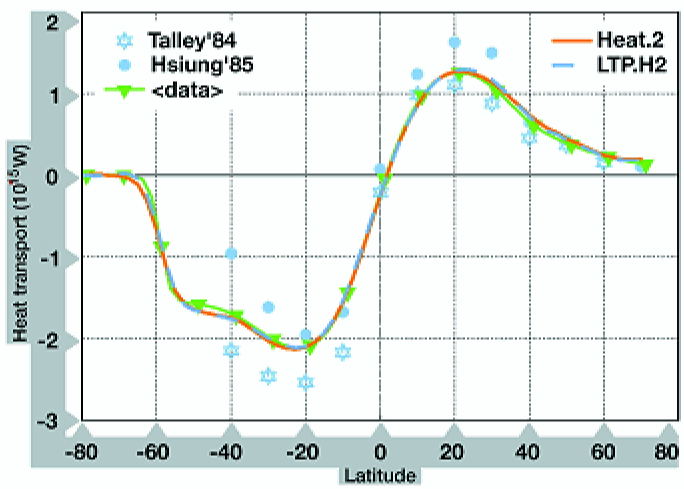

Figure 3

Global annual mean meridional heat transport of the ocean. Red and blue lines show the modelled transport before and after assimilation of T/P measurements, respectively. The green line depicts the annual average which we prescribe. Blue symbols refer to independent estimates by Hsiung [1985] and Talley [1984].

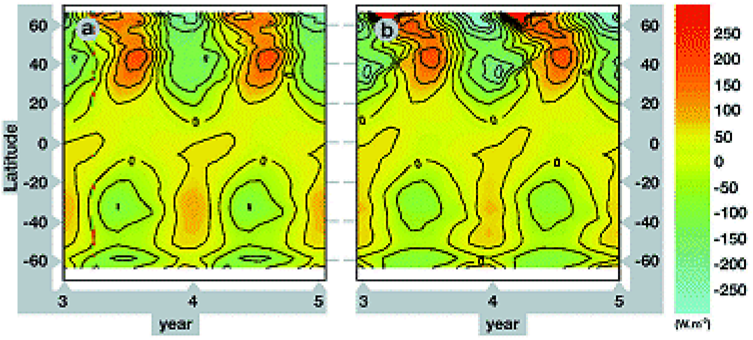

Figure 4
Annual cycle of the zonally averaged surface heat flux in m^{-2} before (a) and after (b) assimilation of T/P measurements.
Units are W.m^{-2}. Most of this strong annual signal is stored locally in the ocean. Its annual mean is depicted in Figure 3. The most visible differences due to assimilation is an enhanced seasonal cycle in mid-latitudes of the Northern Hemisphere.

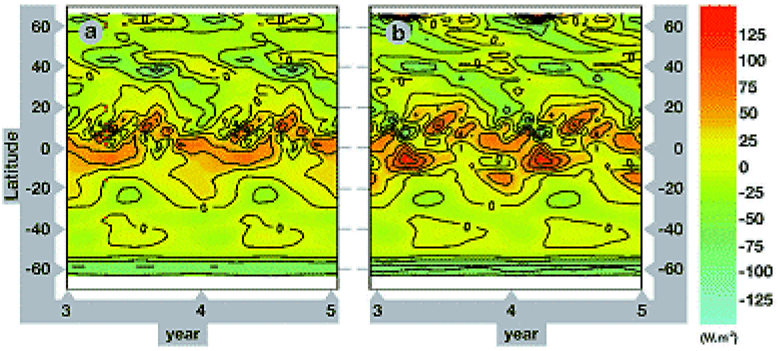

Figure 5
Annual cycle of that part of the zonally averaged surface heat flux which is advected poleward by the ocean currents (a) before and (b) after assimilation of T/P measurements. Units are W.m^{-2}. Heat enters the ocean mainly in the tropics. The annual amplitude is enhanced significantly by assimilation.

Conclusions

It is possible to assimilate T/P altimetric data referenced to a geoid, simultaneously with hydrographic measurements into a global ocean model. The annual cycle of the heat transport is enhanced significantly while the rms difference averaged over the year is reduced from 18.2 cm to 13.8 cm.

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