Ocean circulation determined from Jason satellite altimeter data

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The spatial distribution of sea level over long timescales can be calculated with state-of-the-art dynamical ocean models able to determine the variations of the free sea surface topography in response to ocean surface fluxes. The objective of our project is to describe the temporal evolution of the sea level on a global, basin-wide and regional basis. An assimilation technique is used to obtain a model solution that is consistent with altimetry and hydrographic measurements.

Large-scale oceanic transports of heat and freshwater that have a major influence on global climate are controlled by pressure distribution in the ocean. This pressure is chiefly determined by the elevation of the free sea surface relative to an equipotential surface, i.e. a geoid. It is common practice in oceanography to use a coordinate system in which the vertical axis measures the distance to the geoid. Typical deviations of the local mean sea surface from the geoid are small. For the subtropical gyres we find elevations of about one meter and across the Antarctic Circumpolar Current, the sea level drops by about two meters.

The free sea surface can be measured by satellite altimeters such as the instrument on Jason-1. Together with measurements of the geoid, they provide an important data set that can be used to estimate the general ocean circulation.

In this project we will study the global ocean circulation and its associated transports at timescales of up to ten years by data assimilation into a coarse-resolution model. Altimetric and hydrographic measurements will be combined with the dynamics of ocean models to form an optimal description of the time-varying ocean state. We plan to assimilate data from Jason-1 and from previous altimetric missions for a period of several years into the Hamburg LSG ocean circulation model [Maier-Reimer et al., 1993], which is very efficient for intermediate-to-long timescales.

The result of the global data assimilation will be a fully consistent model that yields a time-varying three-dimensional description of the ocean with a circulation that conserves mass, heat, salt and momentum. From this solution, important climatological parameters can be computed such as meridional oceanic fluxes of heat or heat storage, which leads to a rise in global sea level by thermal expansion.

Following our experience gained with TOPEX/POSEIDON data, we will use the adjoint assimilation method [Wenzel et al., 2001]. The advantage of this scheme is that it conserves the momentum- mass- and heat balance of the model. In previous work we have demonstrated the importance of using hydrographic data obtained from research ships in conjunction with satellite altimeter measurements.

The coarse-resolution model produces only large scales adequately. To constrain the model appropriately, we calculate integral large-scale parameters derived from measurements such as regional, vertically integrated mass- salt- and heat transports or meridional overturning streamfunction, and use them as additional data in the assimilation.

An example of the ocean model's ability to reproduce the global mean sea surface is shown in figure 1.

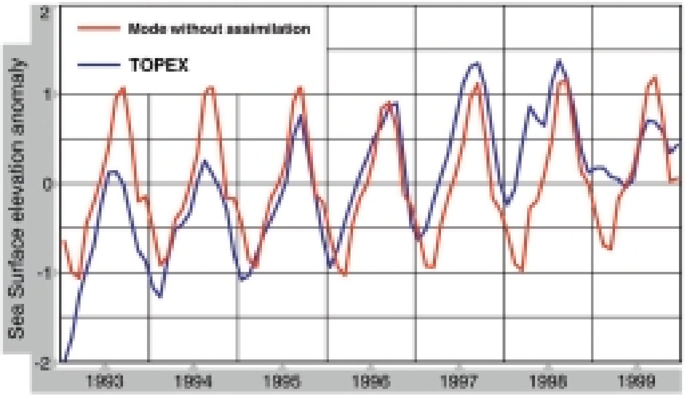

Figure 1: Mean sea surface of the ocean between 1993 and 1999. The red line describes the estimate of the global ocean model before assimilation of data. TOPEX/POSEIDON measurements are indicated by the blue line.
The model represents the annual cycle of the global mean sea level rather well. However, it was not designed to reproduce the observed trend in sea level.

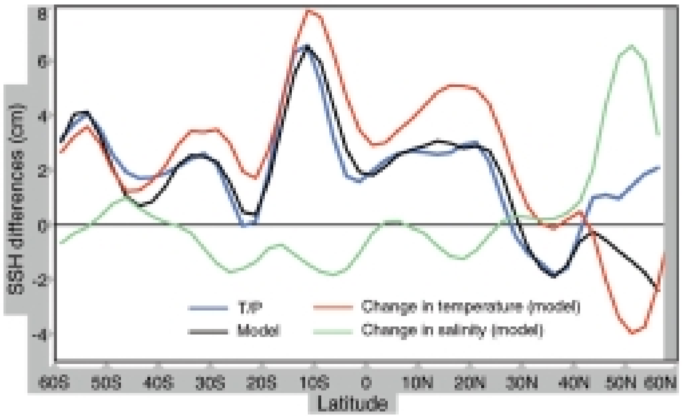

Figure 2: Sea level distribution along a north-south section at 160°E. Shown are the differences between two consecutive years, 1995 and 1996. The blue line indicates measurements by TOPEX/POSEIDON, while black is the corresponding model value. The model is capable of reproducing the change in sea level almost everywhere. A deviation is noticeable only north of 45°N.
Analysis of the model reveals that the change from 1995 to 1996 can best be explained by a change in water level due to thermal expansion (red curve) and to changes in salinity (green curve). Note that temperature and salinity effects are in general anticorrelated.

The most prominent signal is the annual cycle, which produces changes of up to two centimetres during the year. The modeled sea level matches the altimeter measurements quite closely. However, the data indicate a trend in the global mean that amounts to about one millimetre per year. This trend is absent in the ocean model, as it was designed to exhibit no significant long-term trends. We will in future allow the model to react better to changes in precipitation, evaporation and global warming and enable it to reproduce the measured trend as well.

When analyzing the model solution, we can distinguish between different physical mechanisms. We can calculate the contributions to sea level change by an increased volume of the ocean due to the melting of glaciers or to thermal expansion of sea water. Some processes change the regional distribution of the sea level. An example for regional changes is shown in figure 2.

Here we see the change in the local sea level between 1995 and 1996. Depicted is a north-south section across the globe at 160°E, in the western Pacific Ocean.
In this example we have already assimilated altimeter data and our goal is to explain the measured changes of the sea level by changes in the ocean interior and ocean circulation. Values shown in figure 2 are typical for large-scale interannual variability. The blue line indicates the change in sea surface between the two years as measured by satellite altimetry. The black line is the model equivalent, which shows us that the model is in principle capable of reproducing the measurement, with the exception of the North Pacific.

Between the two years temperature has changed. By calculating the difference in sea level, due to thermal expansion (red line), we find that the observations can readily be explained by the regional temperature change. The effect of changing salinity (green line) is much smaller but cannot be neglected. It is interesting to note that both effects on sea level are in general anticorrelated—that is, a warmer ocean is usually more saline while cooling is associated with freshening of the water.
With the availability of Jason-1 altimeter data we will be able to improve calculations and gain a better understanding of the reasons for sea level change. An important aspect here is future geodetic satellite missions, which will improve the reference geoid and make our calculations more accurate.

References

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