On the Mass Budget of the North Atlantic Ocean

M.Wenzel and J.Schröter

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

mwenzel@awi-bremerhaven.de jschroeter@awi-bremerhaven.de

Alfred Wegener Institute for Polar and Marine Research

Introduction

The mass budget of the North Atlantic Ocean is studied with a global circulation model that conserves mass instead of volume, i.e. fresh water is exchanged with the atmosphere via precipitation and evaporation and inflow by rivers is taken into account. The mass is redistributed by the ocean circulation. Furthermore, the oceans volume changes by steric expansion with changing temperature and salinity.

Recent volume changes are monitored successfully by altimetry. However, the corresponding mass changes - or bottom pressure variations - can be estimated only using secular changes in the geoid provided e.g. from the **GRACE** mission since 2003. But these data are still not accurate enough. To distinguish between mass variations and steric effects in the measured volume changes of the ocean a global data assimilation experiment was performed. For this satellite altimetry referenced to the **GRACE** geoid is assimilated together with a set of oceanographic data into an OGCM, that offers the ability to estimate the single contributions to sea level change, the steric (thermosteric, halosteric) and the non-steric effects (local fresh water balance, mass redistribution) seperately. The model has a $2^o \times 2^o$ horizontal resolution, 23 vertical layers and a ten day timestep. Nine years (1993-2001) of respective **TOPEX/Poseidon** sea surface height anomalies are assimilated into the model. In addition the SHOM98.2 mean sea surface relative to the **GRACE** geoid (GfZ) as well as sea surface temperatures and ice cover information from Reynolds (2002) are assimilated into the model. Furthermore background information from the Levitus WOA98 is used.

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). For verification the models bottom pressure anomalies are compared to the geoid variations derived from the **GRACE** mission.

Sea Level Evolution

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

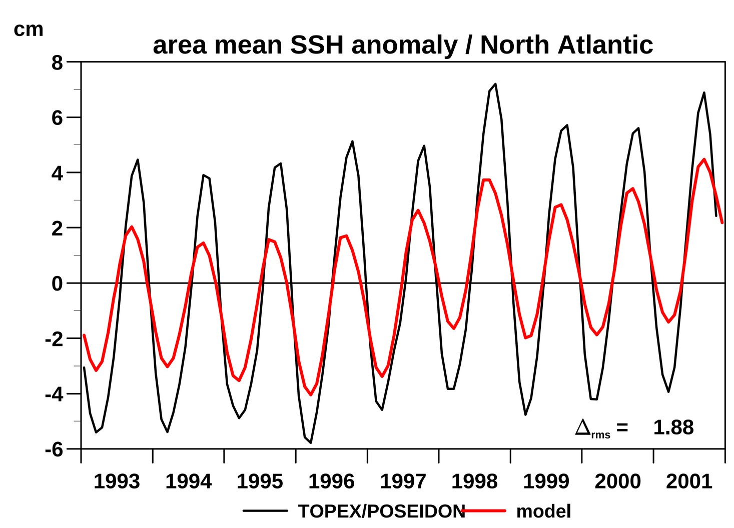
$$+ \nabla \cdot \int_{-H}^{\zeta} \vec{v}\, \mathbf{d}z \quad \text{divergence}$$

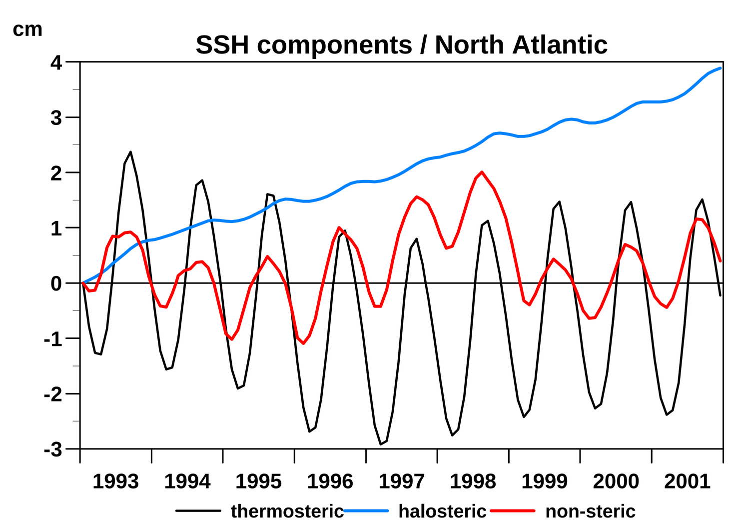
$$+ \int_{-H}^{\zeta} \frac{1}{\alpha}\frac{\partial\alpha}{\partial T}\Big|_{S,p} \frac{\partial}{\partial t} T\, \mathbf{d}z \quad \text{thermosteric effect}$$

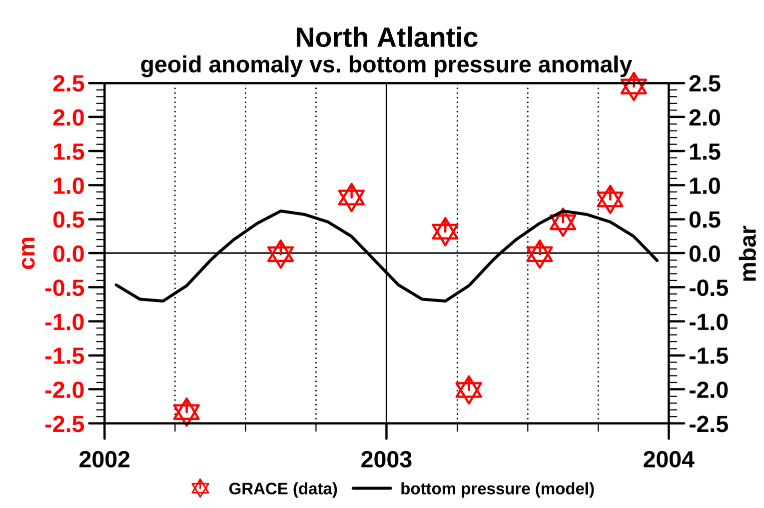
$$+ \int_{-H}^{\zeta} \frac{1}{\alpha}\frac{\partial\alpha}{\partial S}\Big|_{T,p} \frac{\partial}{\partial t} S\, \mathbf{d}z \quad \text{halosteric effect}$$

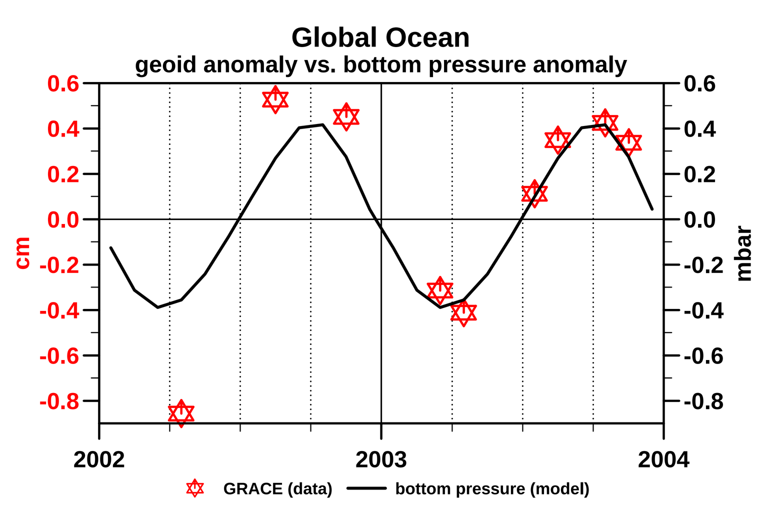
$$+ A_h\, \Delta\, \zeta \quad \text{subgrid processes}$$

SSH / Bottom Pressure



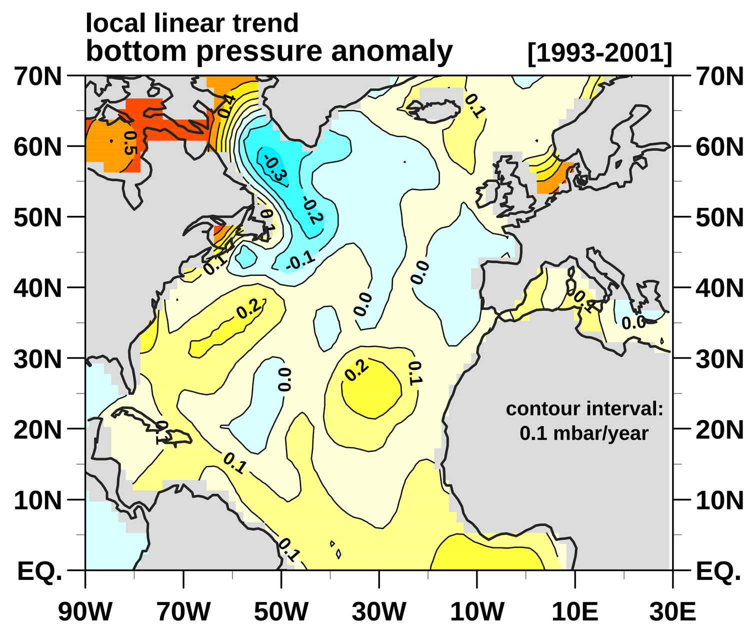


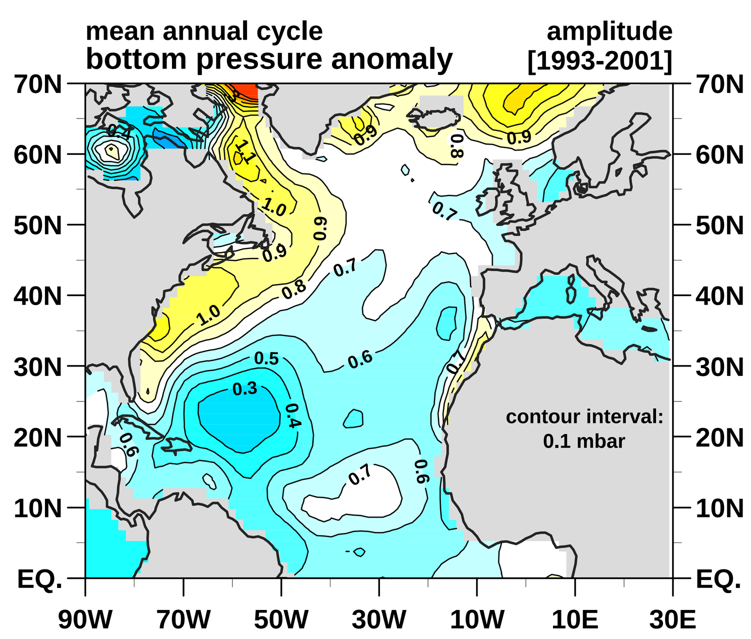


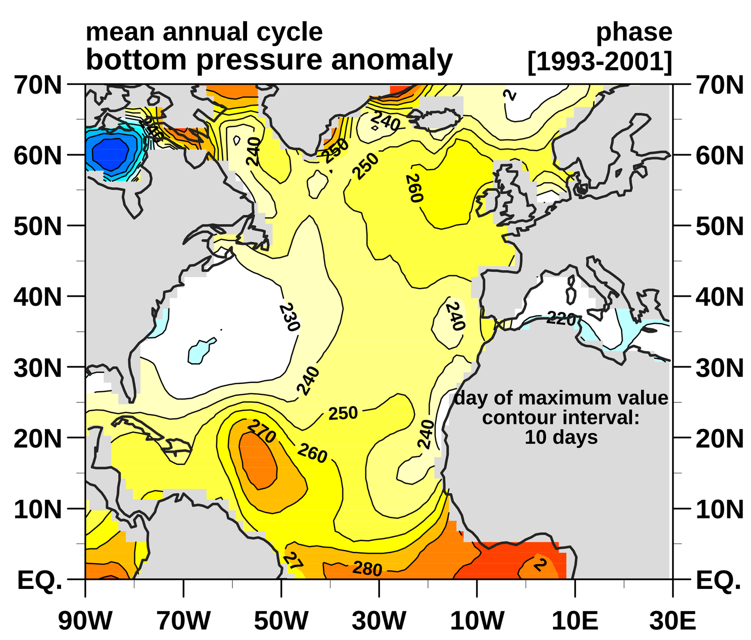


The upper left figure shows the North Atlantic mean sea surface height anomaly (between 19^{o}N and 65^{o}N) as estimated by the global model. It fits the altimeter measurements well, although the amplitude of the annual cycle is underestimated as compared to the **TOPEX/POSEIDON** data (black curve). Aside the strong seasonal cycle that is mainly caused by thermosteric effects (upper right figure, black curve) there is also a positive linear trend visible that is due to the halosteric part (blue curve). The volume changes through mass variations (non-steric part, red curve) are much smaller in amplitude and exhibit only a negligible positive trend. The comparison of the corresponding bottom pressure anomalies (mean annual cycle) to the geoid variations estimated from the **GRACE** mission (in cm watercolumn analog, lower left figure) shows that the model again underestimates the seasonal amplitude and that it leads the measurements by about two month. Especially for the phase the comparison gets even worse when looking more locally, but it gets better when looking at larger area means, e.g. the global ocean (lower right figure). However this comparison should be treated with caution because the **GRACE** data are still rather preliminary.

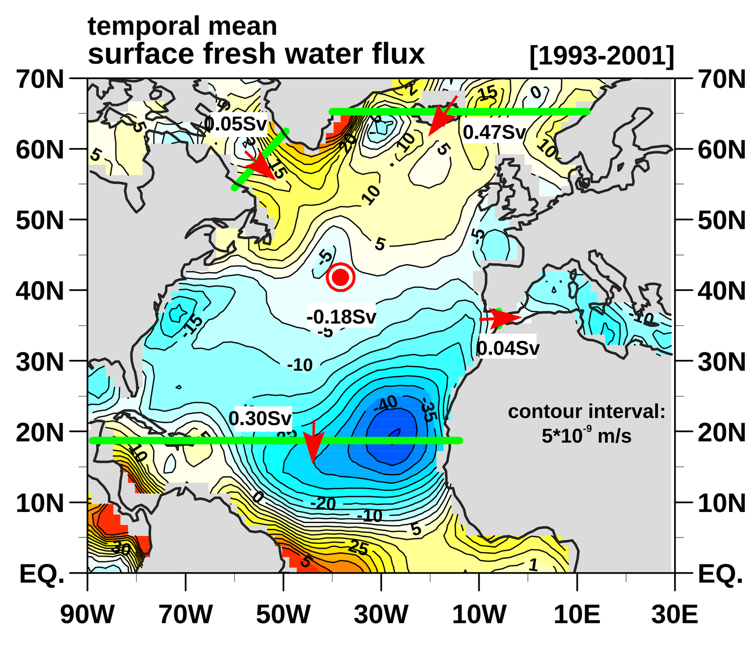
For the North Atlantic part of the world ocean the three plates on the right show from top to undermost: the bottom pressures linear trend as well as the amplitude and the phase of the mean annual cycle. The bottom pressure trend is decorrelated from the sea level trend and cannot be observed by altimetry. It varies substantially locally with an increase in mass in the subtropical gyre and a decrease in the Labrador Sea. Such large scale model predictions should be detectable by the **GRACE** satellites once the measurements have been fully analysed. The annual cycle of the bottom pressure is fairly coherent over the North Atlantic basin. Its maximum is in August and the highest amplitudes are found along the North American coastline.

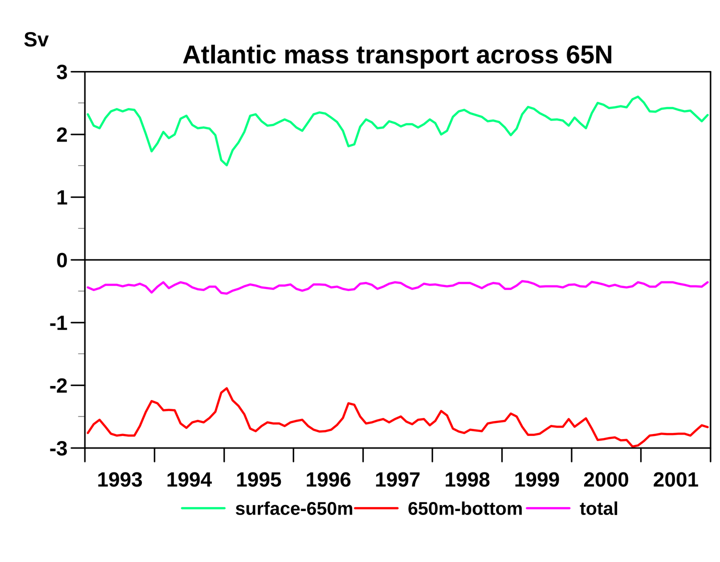


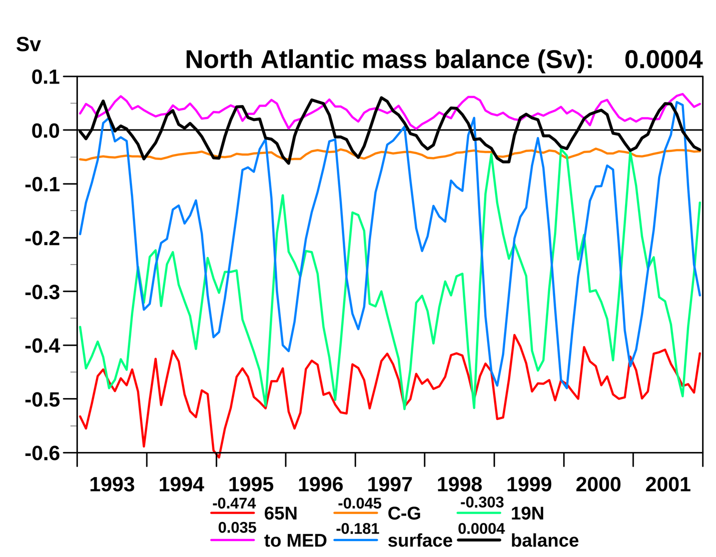


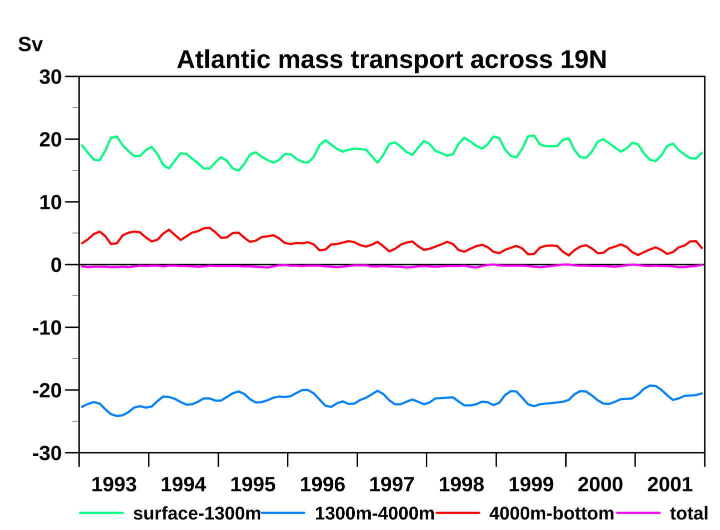


North Atlantic Mass Balance









In the nine year mean the mass balance of the North Atlantic between 19^{o}N and 65^{o}N is closed (upper left figure). The net inflow across 65^{o}N is balanced mainly by the net outflow across 19^{o}N and the mass loss by evaporation. The inflow through the Canadian Archipelago and the loss to the Mediterranean Sea give only minor contributions to the balance. Nevertheless the total mass of the North Atlantic is not constant. There is a seasonal cycle in the balance with an amplitude of about 0.05 Sv (lower left figure, black curve).

The temporal variability of the mass flux through the surface (lower left figure, blue curve) is highly anti-correlated with the North Atlantic horizontal transport divergence ($r = -0.98$). For the single contributions of the total mass balance the correlation is highest (by absolut value) between the surface flux and the total transport across 19^{o}N (green curve, $r = -0.86$), while there is no correlation between the Denmark Strait overflow (upper right figure, red curve) and the mid-depth outflow across 19^{o}N (blue curve in lower right figure, $r = 0.01$).

Summary / Conclusion

The mass budget of the North Atlantic is closed for the period 1993 – 2001. This is distinctly different from the volume budget that exhibits a positiv trend mainly due to halosteric effects (salt export from the North Atlantic).