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Max-Planck-Institut für Meteorologie
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Simulated Ocean Thermal Expansion, Mass Load Changes, and Length-of-Day

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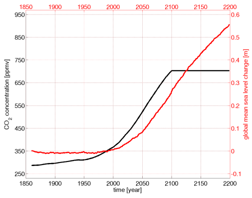
Steric sea level changes due to heat uptake do not alter the mean global ocean water mass, but a mass redistribution within the global ocean basins can occur. Here, we diagnose these bottom pressure changes from a global warming simulation performed with the Max Planck Institute for Meteorology coupled Atmosphere Ocean General Circulation Model ECHAM5/MPI-OM. Generally, bottom pressure increases over shallow areas, and decreases over deep ocean areas. We present a simple conceptual model that directly links bottom pressure changes as a function of depth and ocean thermal expansion. Additionally, we find that an ocean thermal expansion of 0.5 m can be associated with a decrease in the length-of-day of about 0.1 ms.

1. The Model and the Experiment

- ECHAM5 atmosphere model T63L31, coupled to MPI-OM ocean model with 1.5°x1.5 ° resolution and 40 levels
- 1860 - 2000: observed forcing (GHG)
- 2001 - 2099: IPCC-A1B scenario with increasing GHGs
- 2100 - 2199: constant GHGs concentration at 2099 level (703 ppmv)



2. Bottom pressure changes

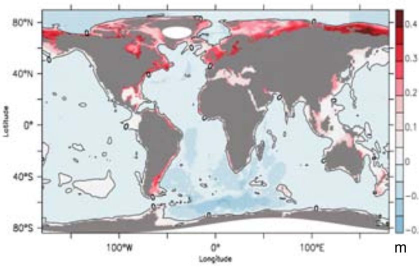
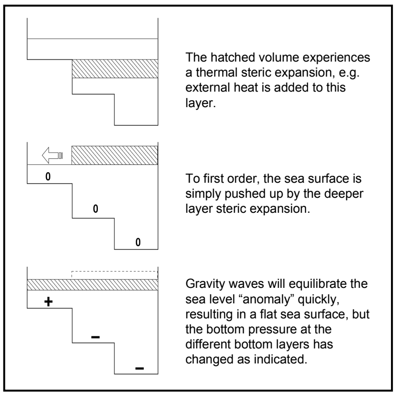


Figure 2: Bottom pressure (or, equivalently, mass load) changes for the period 2090-2099 relative to an unperturbed simulation. All bottom pressure changes occur solely due to mass redistribution within the global ocean. Most prominently, all shelf regions experience an additional mass loading of up to 0.45 m. Note that the mean global ocean mass is conserved.

3. Conceptual Model



The hatched volume experiences a thermal steric expansion, e.g. external heat is added to this layer.

To first order, the sea surface is simply pushed up by the deeper layer steric expansion.

Gravity waves will equilibrate the sea level "anomaly" quickly, resulting in a flat sea surface, but the bottom pressure at the different bottom layers has changed as indicated.

Figure 3: The areal extent *A* of different depth layers *z* is not constant, so that a deep steric expansion will result in a mean sea level change at the surface scaling with *A(z)/A(surface)*. While the global ocean mass is thus not changed, mass loading anomalies Δp_b do occur depending on the actual bottom depth and the steric anomalies for the individual depth layers. With this conceptual model, we can estimate mean bottom pressure changes *as a function of topographic depth* induced by ocean warming.

4. Estimation of Global Mean Bottom Pressure Changes over Time

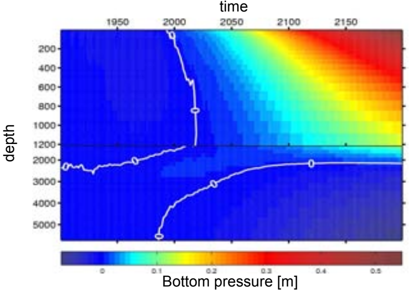


Figure 4: Employing the conceptual model (Fig.3) to all depth layers in the coupled model, we calculate the temporal evolution of bottom pressure changes in the IPCC-A1B scenario. A positive anomaly propagates downward to about 2000 m depth. Deep bottom pressures decrease, as is expected from the conceptual model (Fig. 3).

5. Deviation from the Global Mean

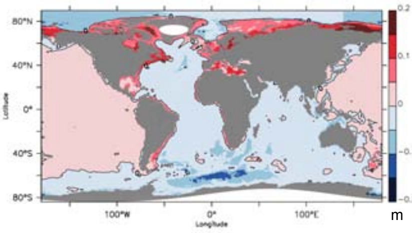


Figure 5a: The true bottom pressure changes (Fig. 2) deviate from the global mean bottom pressure changes (Fig. 4), because the vertical distribution of the steric anomalies is very different between ocean basins (anomalies for the years 2090-2099).

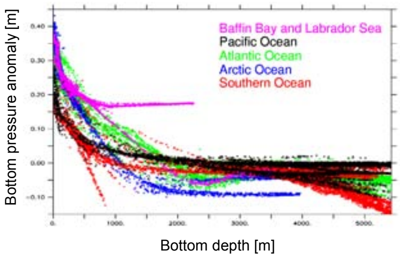


Figure 5b: Scatter plot of bottom pressure changes for the years 2090-2099. Color coding is for different regions. Steric changes (through temperature and salinity) and circulation changes lead to a distinct Δp_b fingerprint for different regions.

6. Implications for C_{20} and Length-of-Day

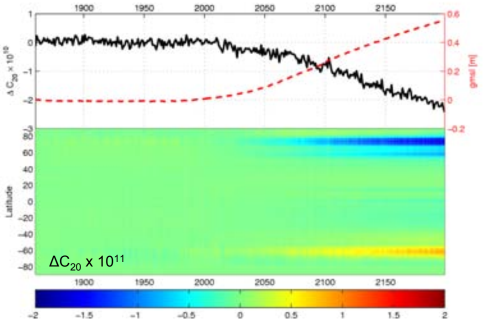


Figure 6a: We use annual means of the simulated bottom pressure anomalies (Fig. 2) to calculate the changes in the C_{20} Stokes gravity field coefficient, which is related to the Earth's moment of inertia. The largest zonal contribution to the C_{20} integral comes from the latitude band between 60°N and 80°N.

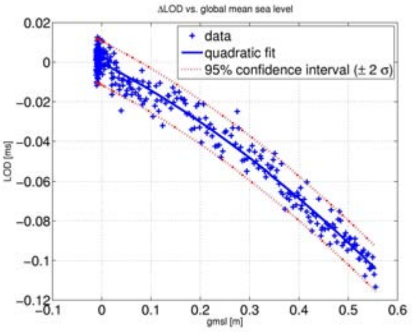


Figure 6b: From the C_{20} Stokes coefficient, we calculate the effective length-of-day changes due to the mass redistribution (Fig. 2). ΔLOD reduces on the order of 0.1 ms per 0.5 m sea level rise through ocean thermal expansion. Almost all data points fall within the 95% confidence interval of a quadratic fit.

Conclusions:

- Ocean thermal expansion causes secular oceanic mass load anomalies. Mass is moved from low to high northern latitudes.
- Shelf areas experience additional mass loading, while deep ocean areas show a decrease. The Arctic Ocean shelf mass load increases strongest.
- Ocean thermal expansion decreases the effective length-of-day by about 0.1 ms per 0.5 m thermosteric sea level rise.
- Mass load changes are highly asymmetric between the Atlantic and Pacific Ocean. Thus, as a next step, we will analyze the equatorial components of the angular momentum.

Reference: Landerer, F., Jungclaus, J. and Marotzke, J., 2006, Length-of-Day changes due to ocean warming, manuscript in preparation.