Ocean Heat Uptake And Implications On Sea Level Rise

Analysis with CCSM4 Atmosphere-Ocean General Circulation Model

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Motivation:

- Human influence on the climate system led to an imbalance in the Earth's energy budget. About 90% of the additional energy gets stored in the oceans and leads to sea level rise by thermal expansion (Johnson and Lyman, 2014).

Goal:

- How much contributed thermosteric sea level rise to the global trend since 1993 and where did the extra heat get stored in the ocean? → Analysis of climate model output with Matlab.

Calculation of thermosteric height contribution:

- $\Delta T = ts(T_{2016}) - ts(T_{1993})$ — Temperature trend. Since historical simulation data is only available until 2005, the most likely greenhouse gas emission scenario (i.e. rcp85) was chosen to complete the time series.
- $\alpha_{1993} = f(S_{1993}, T_{1993}, p)$ — Thermal expansion coefficient α as a function of S and T.
- $\Delta h = \frac{V_0 \alpha_{1993} \Delta T}{a}$ — Height anomaly due to thermal expansion.

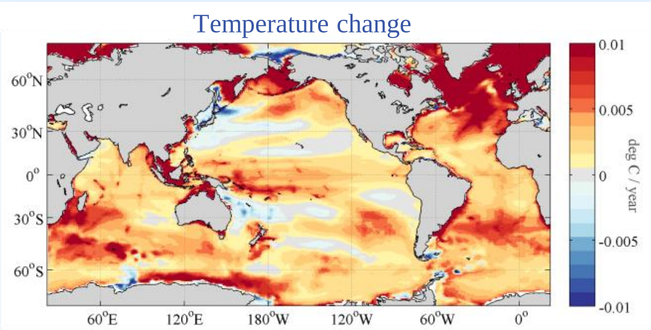

Figure 1: **Modelled total temperature trend 1993 - 2016 over full ocean depth.** The saturated colour bar indicates there are values higher than 0.2 degrees Celsius.

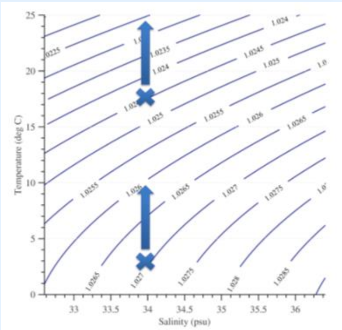

Figure 2: **Temperature - Salinity diagram.** Lines of equal density in g / cm^3.

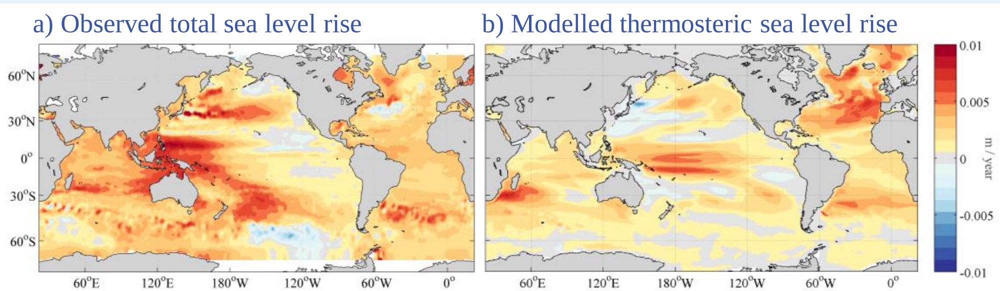

Figure 3: a) **Trend in observed total** and b) **modelled thermosteric sea level rise for the time period 1993 - 2016.** Data in a) provided by the NOAA Laboratory for Satellite Altimetry.

Calculation of heat content anomaly:

- $Q_{1993} = \rho_{1993} c_p V_0 T_{1993}$ — Initial heat content 1993.
- $Q_{2016} = \rho_{2016} c_p V_0 (T_{1993} + \Delta T)$ — Final heat content 2016.
- $\Delta Q = Q_{2016} - Q_{1993}$ — Heat content anomaly.

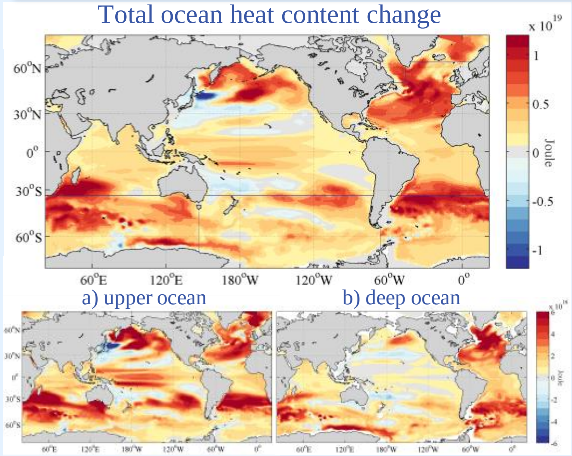

Figure 4: **Modelled total,** a) **upper and** b) **deep ocean heat content change for 1993 - 2016.** Lines in the upper figure indicating ocean basin boundaries.

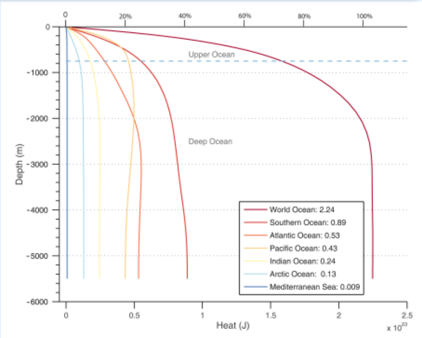

Figure 5: **Modelled cumulative ocean heat content change during 1993 - 2016.** Values inside the box to the lower right indicating total heat uptake for this time period in 10^{23} Joule. Boundary between upper and deep ocean at a depth of - 747 m.

Conclusions:

- The highest ocean temperature change occurs in the subpolar oceans (Fig. 1).
- Warming subpolar water has less impact on density, volume and thus sea level rise than warming tropical water by the same amount (Fig. 2).

Global mean sea level rise trends 1993 - 2016 (Fig. 3):

Observed total:
- 2.8 mm / year.

Modelled thermosteric:
- 1.5 mm / year.

- 70% of the global heat over the modelled 24 year period is stored in the upper ocean (Fig. 4 & 5).
- The Southern Ocean dominates global heat uptake (Frölicher et al., 2015) and storage with 40% despite covering roughly ¼ of the global ocean area. ⅔ of its heat accumulates in the upper 747 m.
- Deep water formation in the Northern Atlantic (30 - 70° N) leads to 50% of this basins accumulation in the upper ocean and 50% in depths from -747 to - 3000 m.
- The strength of the modelled ocean circulation is key in determining heat uptake and distribution.

References:

- Johnson and Lyman. Oceanography: Where's the heat? *Nature Climate Change*, 4(11):956-957, 2014.
- National Oceanic and Atmosphere Administration. http://www.star.nesdis.noaa.gov.
- Frölicher et al. Dominence of the southern ocean in anthropogenic carbon and heat uptake in cmip5 models. *Journal of Climate* , 28(2):862-996, 2015.