Decadal variability in regional and global mean sea level and its causes

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Outline

Topic: Determination and understanding of regional and global sea level decadal change in relation to the ocean circulation and its temperature (T), salinity (S), and mass fields

Issues: Need accurate estimates of the variable ocean circulation and atmospheric surface forcing fields, including global mean quantities such as net heat and freshwater input into the oceans

Approach: Fit a state-of-the-art ocean model to most ocean observations in a constrained least-squares procedure to produce dynamically consistent 4-dimensional "optimal" estimates of ocean state, including sea level and related fields

Present Analyses:
- based on MIT-AER constrained solutions produced as part of the ECCO-GODAE (Estimating the Circulation and Climate of the Ocean-Global Ocean Data Assimilation Experiment) project
- version 3, iteration 73: interim solution, optimization on-going, constrained by several hundred million data points, including all the altimetry and modern hydrography, sea surface temperature, scatterometer winds, GRACE geoid and more
- differences with version 2: version 3 includes coupled sea-ice model, adjustments to surface atmospheric state (wind, temperature, humidity, short wave radiation) rather than fluxes, covers longer period through the end of 2007, uses more data

Sea Level Trends (1993-2007)

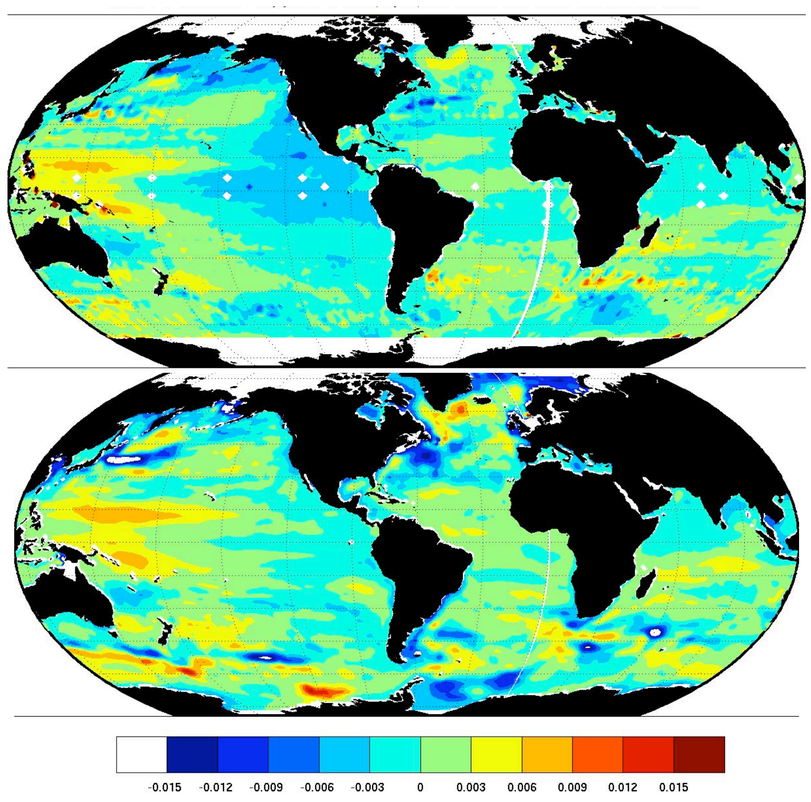

Figure 1. Regional sea level trends from *(top)* altimeter RADS data and *(bottom)* optimized solution. Units are m/yr. The spatial mean of 0.0031 m/yr, which is removed from the data, is a small residual of a noisy inhomogeneous field.

Things to note:
- solution patterns close to the data but details differ, particularly in western boundary regions where altimeter constraints less efficient due to enhanced "eddy" noise
- local decadal variability large compared to expected long-term trends in global mean sea level

Density & Mass Trends (1993-2007)

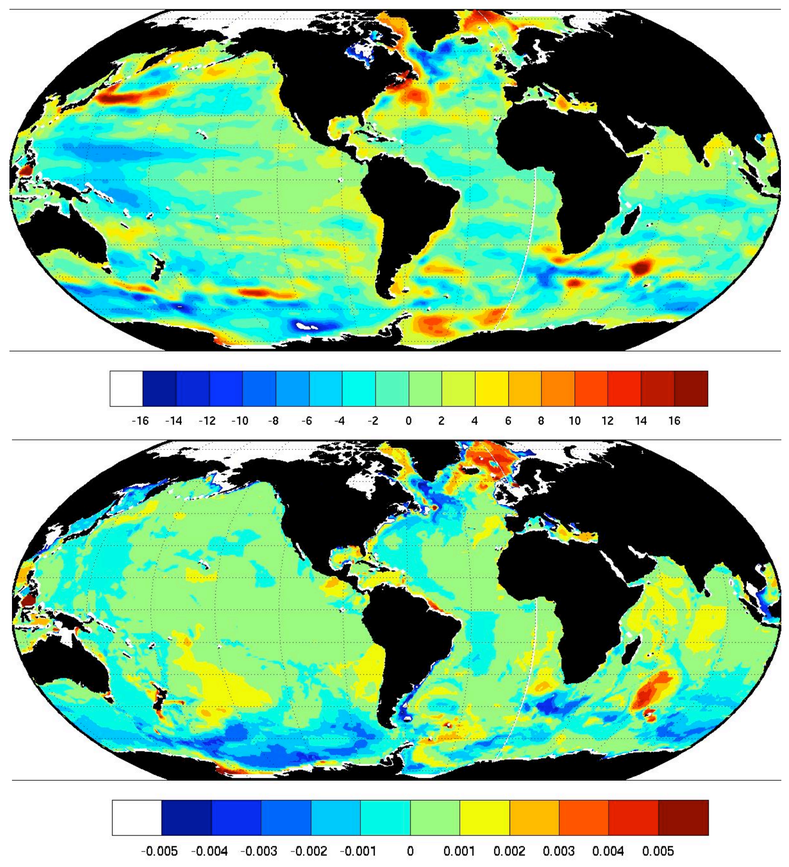

Figure 2. Vertically-integrated regional trends in *(top)* density (units of kg/m^2/yr, very close to mm/yr) and *(bottom)* bottom pressure (m/yr). Note that decreasing density means warming and/or freshening of the water column, which implies increasing steric levels.

Things to note:
- most sea level trends are associated with density (steric) effects
- changes in bottom pressure (total mass) weaker but not negligible in general

T & S Trends (1993-2007)

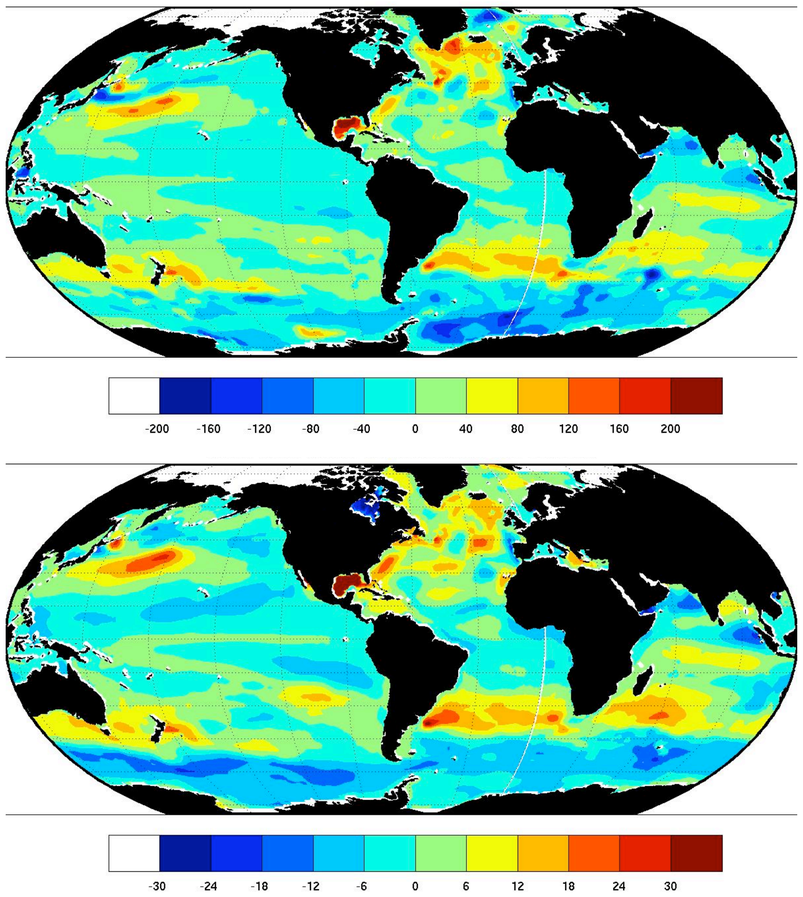

Figure 3. Vertically-integrated regional trends in *(top)* T (°C m/yr) and *(bottom)* S (m/yr), with spatial means removed.

Things to note:

- same sign trends in T and S imply density-compensating patterns as $\Delta\rho = \rho_0(-\alpha\Delta T + \beta\Delta S)$ and point to the role of advection of T and S properties along isopycnals

- changes in sea level associated with lateral shifts of water masses and related dynamic changes in the gyre circulations, rather than with merely passive response to surface atmospheric buoyancy fluxes

- enhanced warming in the northern North Atlantic, mid southern latitudes, enhanced cooling in Southern Ocean

Vertical Distributions

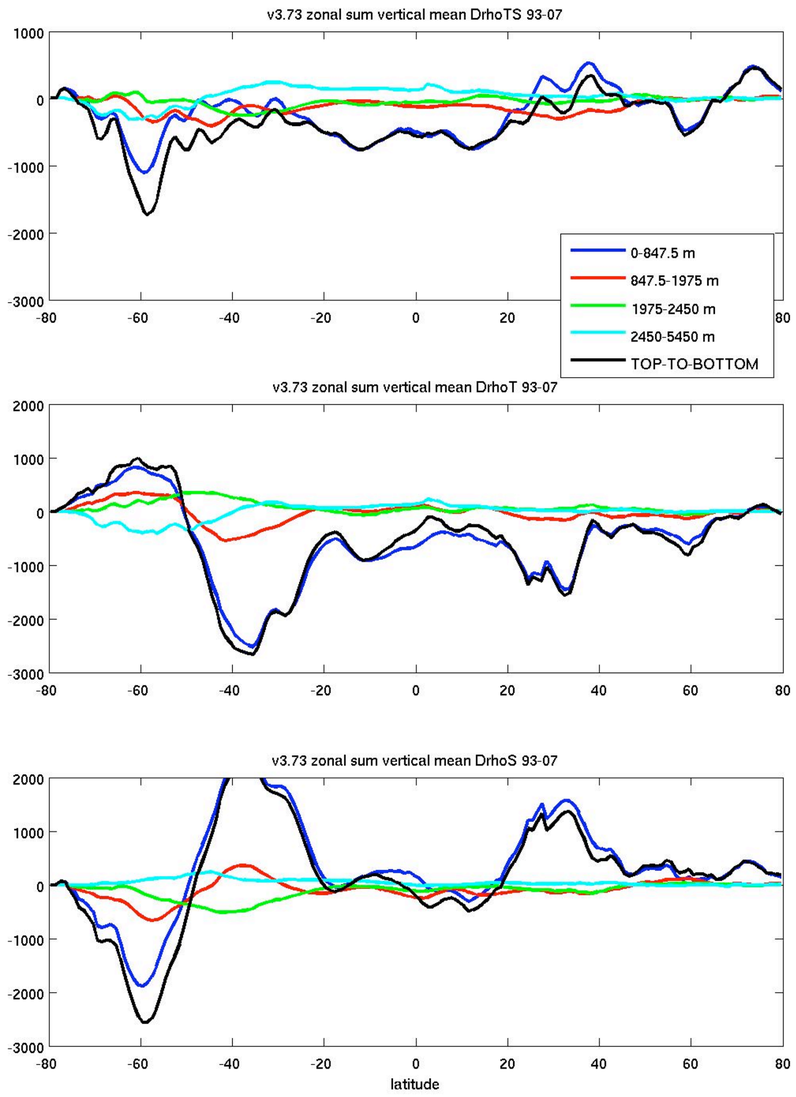

Figure 4. Zonal sums of the trends in vertical integrals of density anomaly in kg/m^2/yr for *(top)* combined T and S effects, *(middle)* only T effects, *(bottom)* only S effects. Various depth ranges are given and spatial means are included here.

Things to note:

- sea level trends mostly related to upper 800 m but measurable contributions from lower layers, especially at mid latitudes and the Southern Ocean
- deep contributions expected to strengthen as time interval lengthens
- mostly warming trends apart from the Southern Ocean
- strong compensation between T and S at latitudes with largest trends

Constraining Global Mean

Problem: there are large global net imbalances in first-guess freshwater and heat flux fields derived from NCEP-NCAR reanalysis product, equivalent to ~3 cm/yr and 3 W/m^2 respectively

Given volume-conserving Boussinesq model, plan currently being implemented is to:

- constrain global mean steric height plus net freshwater flux input to altimeter global mean sea level estimates

- constrain net freshwater flux input and consequent changes in estimated ocean mass to equivalent estimates derived from GRACE data

- ensure consistency between all data constraints (altimetry, hydrography, gravity, sea surface temperature)

References

For more details on a similar analysis, see

Wunsch, C., R. M. Ponte, and P. Heimbach, 2007: Decadal trends in sea level patterns: 1993–2004, *J. Climate*, 20, 5889–5911.

More information on the ECCO-GODAE ocean state estimates, together with a complete list of relevant publications, is available at

http://www.ecco-group.org/