Atlantic MOC Observing System Studies Using Adjoint Models

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LONG-TERM GOALS

To understand, with a comprehensive data set and a state-of-the-art ocean model, the nature of the North Atlantic ocean circulation, with a particular emphasis on its long term variability and climate consequences.

OBJECTIVES

The so-called meridional overturning circulation (MOC) is a simplified schematic of the complex North Atlantic Ocean circulation that is believed important to the climate system. As such, it is a useful shorthand for the description of changes, past, ongoing, and possibly in the future that could have serious consequences.

APPROACH AND WORK PLAN Adjoint models are used to study the MOC in two distinct, but nonetheless, overlapping ways. In one approach, the adjoint is used as a numerical tool for fitting a general circulation model to a great variety of oceanic observations. Approach 2 exploits explicitly the mathematical result that the adjoint solution (the Lagrange multipliers) are the sensitivity of an arbitrarily chosen cost-function to almost any perturbation in the model or its external constraints (initial and boundary conditions).

WORK COMPLETED

Wunsch and Heimbach (2009) discuss trends in the global (not just the North Atlantic) meridional overturning circulation, and showed that whatever changes were taking place were largely confined to low latitudes and the deep Southern Ocean. Beyond a general tendency for the upper ocean to be warming, no large scale trends were apparent. An example of the first empirical orthogonal function of the global meridional flow field is shown in Fig. 1.

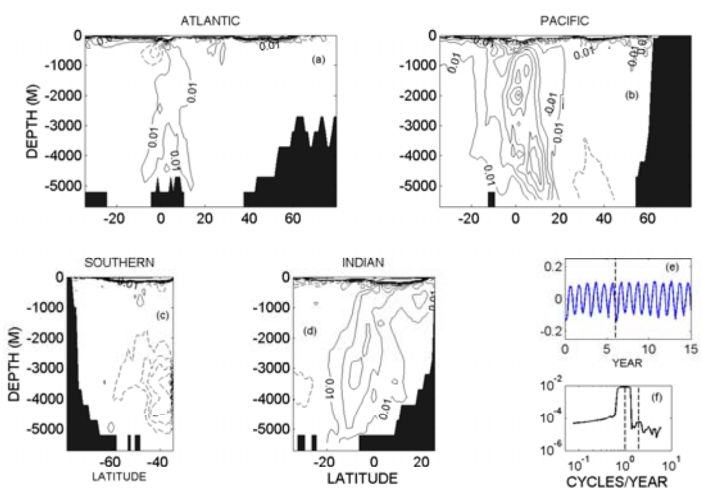

Figure 1 First global volume transport variability EOF (singular vector), u_1, using monthly means, with about 44% of the total variance displayed in each ocean basin (a-d). Dashed contours are negative. This mode evidently represents the predominant and strong annual cycle in volume transport, and like most of the variability seen is largely tropical and dominated by the Pacific and Indian Oceans. Little North Atlantic response is visible (only contours with magntiude greater than or equal to 0.01 are shown). Consistent with linear theory, the Pacific response has a somewhat barotropic nature below the very surface layers. Panel (e) displays $v_1(t)$ and its power spectral density estimate, with the first two years omitted from the analysis here and in the other plots. A hint of an ENSO response is visible (vertical dashed line in the plot of v_1) is the 1997-1998 transition time. Vertical dashed lines on the spectral density of $v_1(t)$ (f) denote the annual and semiannual periods. (Wunsch and Heimbach, 2009)

RESULTS

The application of the adjoint solution as a direct sensitivity measure is illustrated in Fig. 2, showing the sensitivity of the heat transport across 25°N to perturbations in oceanic temperature remote in time and space from that location. Similar figures exist for the global version of this sensitivity, and they can be computed for any parameter effecting the oceanic state. Particular attention is being paid to the effects of sea ice changes on the circulation. These and other results are part of the white paper prepared for the OceanObs2009 meeting in Venice,

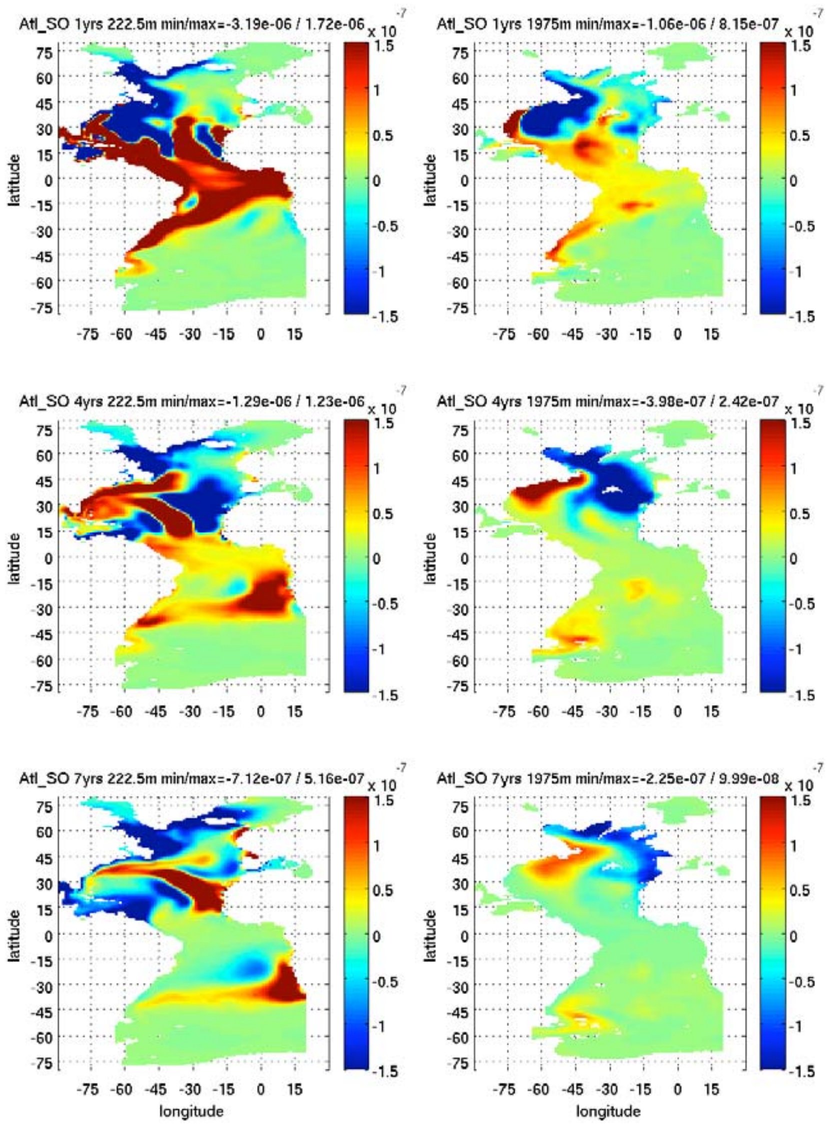

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Figure 2 Sensitivity of J, the meridional enthalpy transport across 25°N, to normalized temperature perturbations 1, 4 and years prior at depths 222.5 and 1975m. (Heimbach et al., 2009)

IMPACT AND APPLICATIONS

National Security

The Defense Department has begun to recognize the threat of climate change to the security of its installations and operations. Atlantic sector changes would influence a number of Naval, Marine and Coastguard bases, and with the potential for human population dislocation in Africa and South America.

Quality of Life

This work is related to the larger problem of understanding ongoing climate change and its implications for human populations.

Science Education and Communication

We teach courses, supervise PhD and master's theses, helping to produce the future generations who will have to live with and understand the changing ocean.

TRANSITIONS

National Security

We are estimating the likelihood of significant changes in coastal areas of the North Atlantic Ocean.

RELATED PROJECTS

This project is closely connected to the ECCO project already noticed above. It is also associated with efforts directed primarily at the use of remote sensing data (altimetry and gravity fields in particular) supported mainly through the National Aeronautics and Space Administration. Some context is provided by a project to understand the same region during the Last Glacial Maximum.

PUBLICATIONS

Heimbach, P., G. Forget, R. Ponte, C. Wunsch, et al., 2009. Observational Requirements for Global-scale Ocean Climate Analysis: Lessons from Ocean State Estimation. Paper prepared for Venice 2009 Ocean Observation Conference, 8pp.

Wunsch, C. and Heimbach, P., 2009. The Global Zonally Integrated Ocean Circulation, 1992-2006: Seasonal and Decadal Variability Journal of Physical Oceanography, 39, 351-368.

Wunsch, C., Observational network design. Prepared for OceanObs09 plenary talk. Submitted, 2009.

OUTREACH MATERIALS FOR NOPP OFFICE *(DELETE THIS SECTION IF THERE ARE NONE)*

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