Atlantic MOC Observing System Studies Using Adjoint Models

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Award Number: *NNX08AV89G*
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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 circulation changes (past, ongoing, and possibly in the future) that can have serious climate implications and consequences for society in general.

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 scalar-function, for example, climate metrics that capture Atlantic transport and heat content variability, to almost any perturbation in the model or its external constraints (initial and boundary conditions).

WORK COMPLETED

In previously published work, 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.

Extensions of the study of the North Atlantic circulation and its variability are now described in a paper submitted to the special issue of Deep-Sea Research by Heimbach et al. (2009). In addition, a major effort went toward producing results and recommendations for the OceanObs2009 Conference (Heimbach et al., 2010; Wunsch, 2010).

In related work, now being prepared for publication, the sensitivity of major elements of the ocean circulation in the North Atlantic has been undertaken. These particularly focus on the socially important meridional heat transport and sea level changes.

RESULTS

Apart from the results discussed at length in the above papers, a major effort has gone towards using the adjoint model (Lagrange multipliers) of the ECCO-GODAE effort, to understand the factors controlling the North Atlantic circulation, and in particular, the controls on sea level change. As one example, Fig. 1 shows response magnitudes of sea level anomalies near the US East Coast to temperature perturbations of sizes comparable to local variability estimates at 222 m depth, 15 years back in time. A positive value at a specific location implies US East coast sea level increases 15 years after a unit temperature increase at that location. The results were obtained for an optimized ECCO-GODAE solution, so-called version 3, iteration 73. The influence of remote regions is clearly visible.

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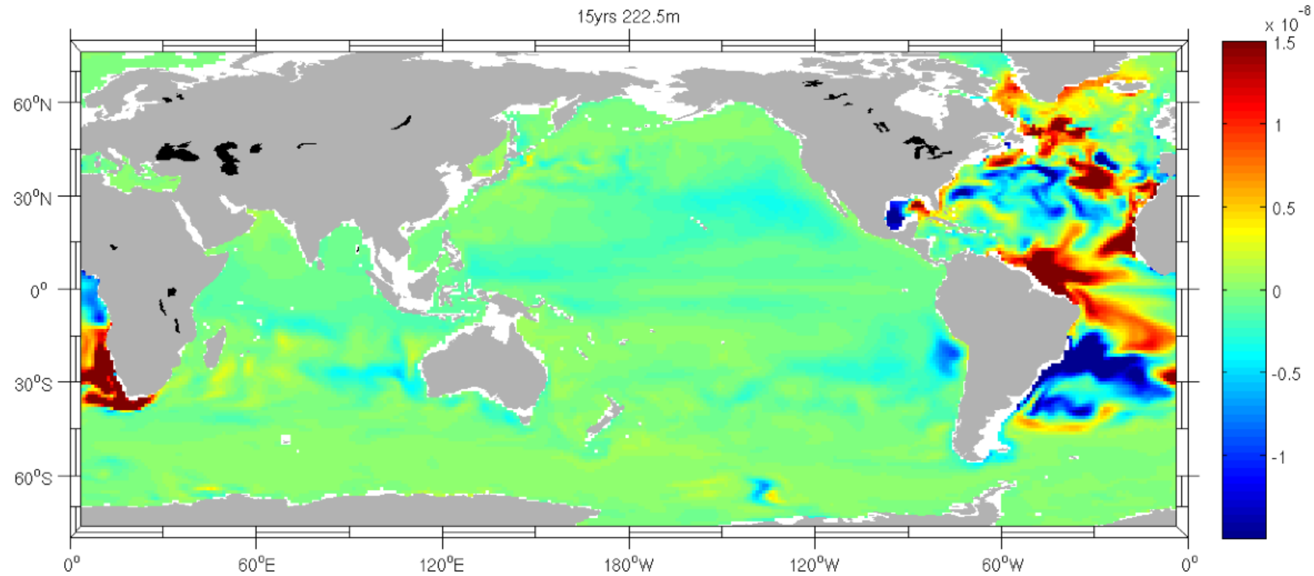

Figure 1 Estimate of the sensitivity of the sea level change along the US east coast to temperature anomalies 15 years prior, at a depth of 222 m. Maps such as these show the challenge of designing observing systems for understanding and prediction.

Another area of focus has been the assessment of temperature and salinity variability in ocean layers below approximately 2000 m, which are not now sampled by the Argo observing system. Analyses of adjoint-based state estimates that dynamically interpolate the very sparse hydrographic data available at depth show substantial temporal variability in deep steric height fields (see example in Figure 2). Implications for future observing system design are being worked out as part of the ongoing work.

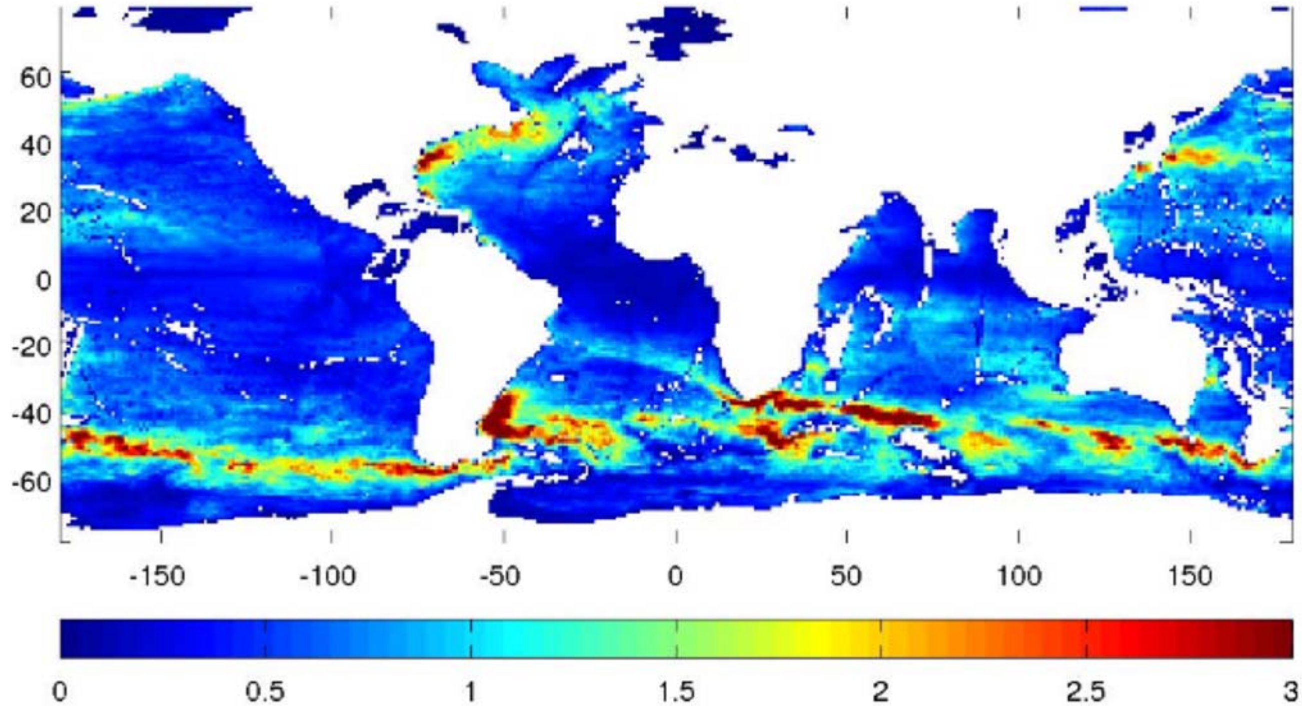

Figure 2 **Standard deviation of steric height (cm) integrated over depths below 1700 m and based on 14 years of monthly temperature and salinity fields from an eddy-permitting estimate of the global ocean circulation. A linear trend and mean seasonal cycle are removed from the time series prior to the calculations.**

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.

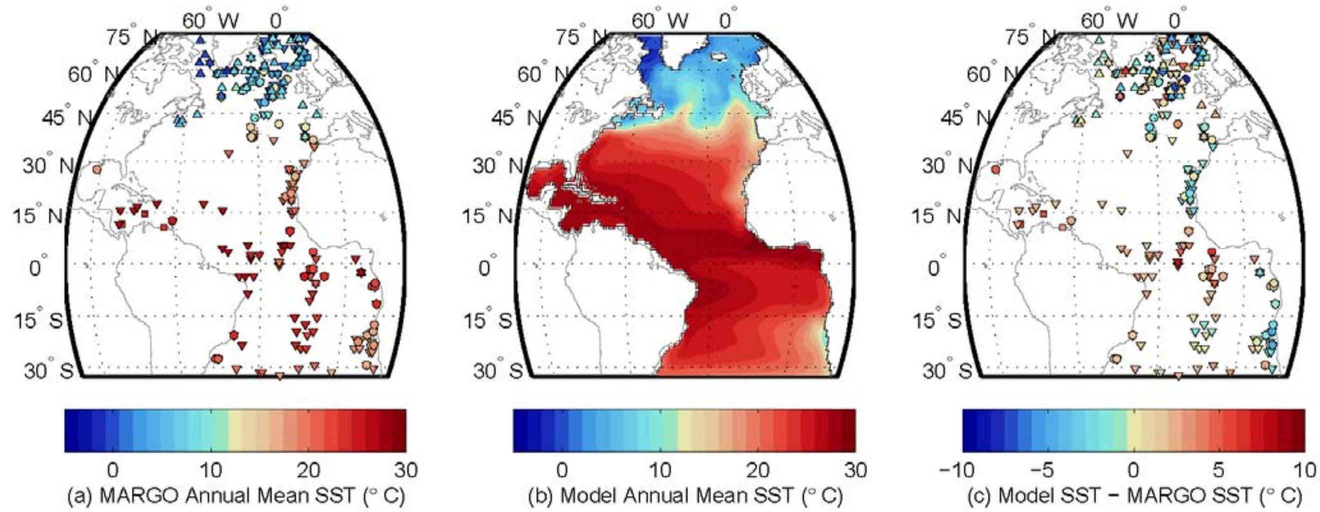

Figure 3 Left panel shows the so-called MARGO estimate of sea surface temperature durnig the LGM. The center panel shows that of the ECCO model optimized (preliminary solution) to those data, and the right panel the difference---showing the remaining misfits. (From PhD thesis, H. Dail, in preparation, 2010.)

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 mentioned 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. Because the North Atlantic is widely thought to be important to climate change on all time scales, the work on this project has implications for, and is symbiotic with, many other studies. As one example, with partial funding also from the National Science Foundation, graduate student Holly Dail is using the same model to study the circulation during the Last Glacial Maximum (LGM; see Fig.3).

PUBLICATIONS

Heimbach, P., C. Wunsch, R. M. Ponte, G. Forget, C. Hill and J. Utke, 2010. Timescales and regions of the sensitivity of Atlantic meridional volume and heat transport magnitudes: toward observing system design. Deep-Sea Research, Submitted. .

Heimbach, P., G. Forget, R. Ponte, C. Wunsch, et al., 2010. Observational Requirements for Global-scale Ocean Climate Analysis: Lessons from Ocean State Estimation. In Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306.

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. In press, 2010.