2012 Project Summary

Sensitivity Patterns of Atlantic Meridional Overturning and Related Climate Diagnostics over the Instrumental Period

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The long-term goals are 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 decadal variability and climate consequences. 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.

Adjoint models, which provide comprehensive sensitivities, are used to study the MOC in four 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). Approach 3 extends the adjoint application through formulating an optimality problem in which initial conditions are sought which lead to maximum transient amplification of climate-related norms, such as the MOC. From approach 1, we obtain estimates of the North Atlantic time-varying three-dimensional ocean state as a subcomponent consistent with the global-scale ocean. That estimate can be used to study the behavior of the MOC directly (Approach 4).

Recent Results

(1) Approach 1: Preliminary results are now available for a new-generation decadal fully global state estimate with an extended adjoint model (ECCO version 4), and which resolves Arctic/Atlantic subpolar gyre water mass exchanges. Fidelity of the solution in the Atlantic and variability of the estimated Atlantic circulation are presented in Wunsch and Heimbach, 2012 (see also Forget and Heimbach, 2012). On regional scales, Fenty et al. (2012a/b) undertook a detailed regional coupled ocean-sea ice state estimation study of the Labrador Sea, which is one of the key sites in the North Atlantic for deep convection and the vertical branch of the MOC.

(2) Approach 2: A detailed adjoint sensitivity study of the North Atlantic circulation and its variability was performed by Heimbach et al. (2011). In addition, a major effort went toward producing results and recommendations for the OceanObs2009 Conference (Heimbach et al., 2010; Wunsch, 2010). Similar calculations, but targeting regional sea level sensitivity patterns in the North Atlantic are under way.

(3) Approach 3: Extensions of the adjoint-based sensitivity calculations use formal methods to study linear predictability of the AMOC. In the first set of studies, Zanna et al. (2011/12) infer optimal patterns leading to non-normal amplification of the strength of the AMOC on sub-decadal timescales, with implications for limits of predictability and observing system requirements. A related approach of linear prediction theory was adopted by Wunsch (2012), who found that there is predictive skill in some parts of the system out to about 5 years.

(4) Approach 4: A review of major issues associated with measurements and analyses of oceanic temperature and heat content was provided by Ponte (2011). In related work (Piecuch and Ponte, 2012) the sensitivity of major elements of the ocean circulation in the North Atlantic has been undertaken. These focus on the socially important meridional heat transport and sea level changes. One important aspect is how the heat content variability in the North Atlantic relates to the meridional overturning circulation, as well as to other circulations and to direct exchanges with the atmosphere, The results indicate a complex, regionally-dependent behavior, with several factors contributing to heat content variability at seasonal and inter-annual timescales. For example, shallow overturning circulations dominate at low latitudes but zonally-asymmetric (gyre) components become important at higher latitudes. Oceanic advection is generally important, but temperature variability (not just velocity variability) can contribute to variable heat transports at high latitudes. Wunsch (2011) analyzed the same ECCO state estimate for the degree to which it appears to be in equilibrium with the wind field.

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