Collaborative Research EaSM2: Mechanisms, Predictability, Prediction, and Regional and Societal Impacts of Decadal Climate Variability

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The goals of this interdisciplinary collaborative project are: i) to produce an improved and reliable decadal prediction system within the Community Earth System Model (CESM) framework, including predictive capabilities for marine ecosystems and biogeochemical constituents; and ii) to advance the use of decadal prediction simulations in regional and societal impact studies. In order to achieve these overarching goals, we are engaged in advancing our understanding and technical capabilities in four fundamental areas related to decadal prediction: (1) improving our understanding of intrinsic decadal variability and mechanisms; (2) evaluating the inherent predictability constraints of our forecast model; (3) evaluating practical forecast system design methods; and (4) generating capabilities for incorporating fully-coupled data assimilation and ocean ecosystems and biogeochemistry into our decadal prediction system. We summarize some of our recent progress below and note that several manuscripts are in preparation covering this work.

Recent results

We have investigated the robust and non-robust aspects of the Atlantic Meridional Overturning Circulation (AMOC) variability in the fully-coupled CESM by comparing long (at least 600-year) simulations which differ only in their atmospheric initial conditions, in their atmospheric model resolution, or in their settings for a few loosely-constrained parameters used in various sub-gridscale physics parameterizations in the ocean model. The latter set includes experiments in which parameters in mesoscale and submesoscale mixing of tracers, horizontal viscosity, and vertical mixing are changed in the ocean model. The initial condition and physics perturbation experiments are branched from and compared to a 1500-year pre-industrial coupled control simulation (LE) which uses a version of CESM with nominal 1° configurations of the component models and with the finite volume dynamical core Community Atmospheric Model version 5 (CAM5). We have also analyzed a long control simulation of the last millennium, which uses the 2° configuration of the atmosphere coupled to the 1° ocean model. The power spectra of the AMOC indices obtained in this suite of runs shows a surprising variety of significant spectral peaks (Figure 1). The roughly ~100-year period AMOC variance seen in LE is not replicated in any of the perturbation experiments, which show different concentrations of spectral power at timescales between 10-100 years. Even the simulations, which differ from LE only in terms of a round-off level perturbation to their atmospheric initial conditions (cases 005, 008, and 009), show AMOC spectra, which are distinct from LE. A clear implication is that (600-year) control simulations are much too short to assume that AMOC variability can be described by stationary statistics.

However, more in-depth analysis of this suite of experiments has revealed several aspects of AMOC variability that appear to be quite robust in the CESM framework. In all of the simulations shown in Figure 1, large increases in AMOC are preceded by an enhancement of the Labrador Sea (LS) upper ocean density and deep convection, which are related to positive North Atlantic Oscillation (NAO+) conditions in the atmosphere (Figure 2). The spin up of AMOC is coincident with a strengthened (cyclonic) subpolar gyre transport. The analysis implies that the inverse is also true, i.e., AMOC weakening is preceded by NAO- and reduced deep convection in LS. However, further work is needed to clearly separate the mechanisms associated with AMOC strengthening and weakening, and to explore the extent to which the mechanism is a function of the magnitude of AMOC anomalies.