

Atlantic Decadal Variability: Combining observations and models to investigate predictability

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Estimating the state of the Earth System is critical for monitoring our planet's climate and for predicting changes to it on time scales from months to decades. Toward these ends, the vast number of atmospheric observations and the growing number of ocean observations must be combined with model estimates of the state of the Earth System by means of data assimilation systems. This study explores the development of new data assimilation techniques using state-of-the-art *coupled* climate models (CM2) and applies these techniques to detecting climate change, improving forecasts on seasonal to interannual time scales while providing estimates of their uncertainty, and improving our understanding of predictability at decadal time scales in order to provide a foundation for the development of a NOAA capability for decadal forecasts. This capability will provide the Nation's decision and policy makers with the best possible climate information on critical problems such as abrupt climate change, changes in hurricane activity, drought, and sea-level rise.

A fully coupled data assimilation (CDA) system, consisting of an Ensemble Kalman Filter applied to CM2, has been developed to facilitate the detection and prediction of seasonal-to-multidecadal climate variability and climate trends (Zhang et al. 2007). The assimilation provides a self-consistent, temporally continuous estimate of the coupled model state and its uncertainty, in the form of discrete ensemble members, which can be used directly to initialize probabilistic climate forecasts.

The assimilation system has been evaluated using one CM2.1 simulation of the 20th century as "truth", and assimilating "observations" from that "truth" experiment into a second, independent experiment. "Observations" are taken from the model at places and times where real observations were taken. These observations are then assimilated into a coupled model ensemble that is subjected only to preindustrial forcings. These experiments constitute a observing system simulation experiments (OSSE). By examining how well this analysis ensemble reproduces the "truth", the skill of the analysis system in recovering anthropogenically forced trends and natural variability is assessed, given the historical observing network. The assimilation is able to successfully reconstruct twentieth-century ocean heat content variability and trends in most locations (Fig.1). The experiments highlight the importance of maintaining key physical relationships among model fields, which are associated with water masses in the ocean and geostrophy in the atmosphere.

The experiments described above indicate that the Atlantic meridional overturning circulation is difficult to constrain using the twentieth-century observational network, but can successfully be reproduced when Argo measurements are available, thereby constraining ocean salinity and density. This preliminary work on assessing the capability of the CDA and ocean observing systems suggests that Argo profiles will be critical for developing a nowcasting capability for the AMOC (Fig.1). Using the CDA system a twenty-five year ocean analysis, for the period 1979-2006, was produced, using XBT, CTD, and Argo observations. The historic ocean state estimation has been extensively analyzed in term of mean and variability. This pioneering fully coupled analysis was then

used to initialize a set of retrospective seasonal/interannual twelve-month forecasts. It was found that the CDA system showed significantly improved ENSO forecast skill over the previous 3DVar scheme demonstrating the improvement in the initialization scheme.

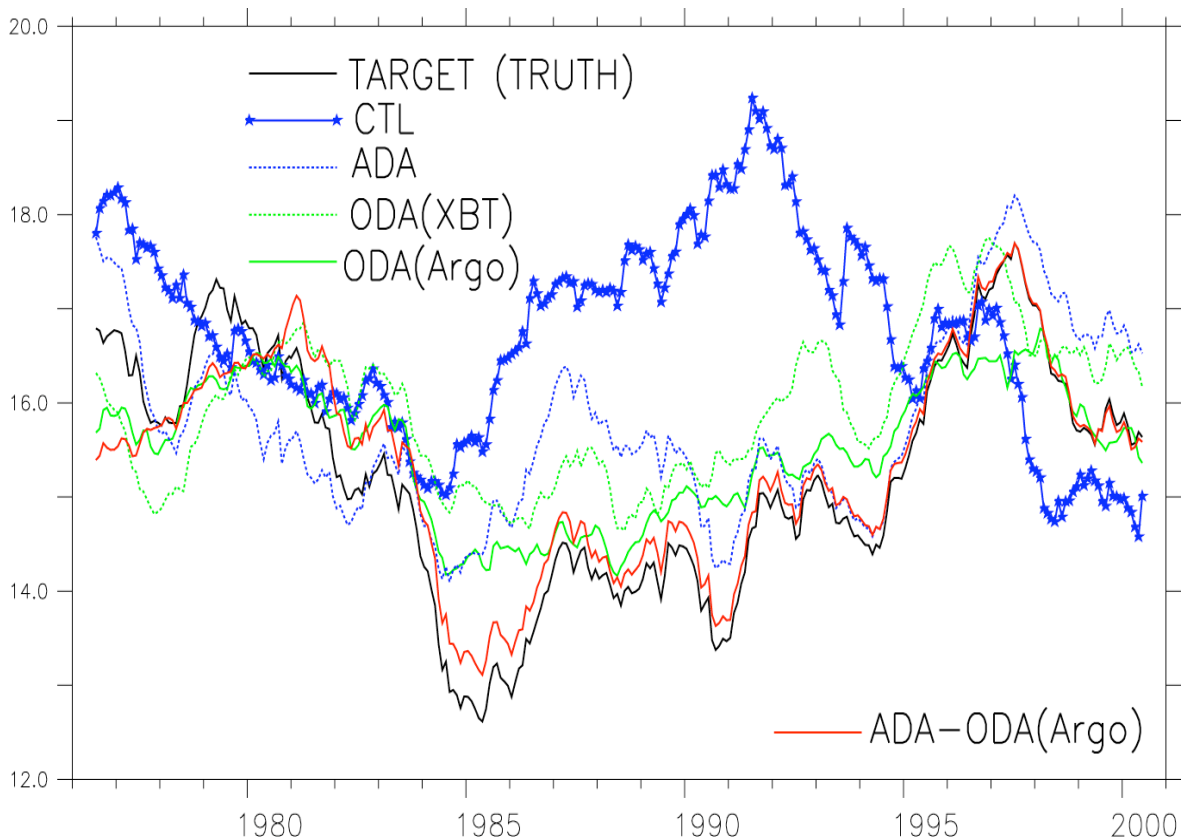


Figure 1 Perfect model studies of the capability of the CDA and observing systems to analyze the AMOC are being carried out at GFDL. The black curve represents a solution from a model simulation. The blue curve represents an independent simulation from which the CDA was initialized. The ADA curve represents only atmospheric data assimilation; the ODA curves represent only ocean data assimilation using the XBT network and the Argo network. The red curve is the coupled ADA and ODA(Argo) and shows the CDA fully recovers the targeted AMOC variability. The y-axis represents AMOC in Sv and x-axis is time in years.

Some new and exciting work has begun on a multi-model ensemble assimilation scheme. Both GFDL's CM2.0 and CM2.1 coupled models are used in a unified ensemble system in which the filtering process is based on the error statistics from both models' ensemble integrations. The system construction is complete but the analysis is ongoing. The idea here is that often the ensemble forecasts tend to look more like each other than reality.

The goal is that the ensemble spread should span the possible solution space and to include the true solution. Some initial OSSE imperfect twin studies using this system uncovered some inconsistent constraints in the upper and deep ocean due to model biases and the nature of the low frequency of the deep ocean circulation. Although this issue may not be important for seasonal initialization it will most likely be for decadal initialization.

Publications

Zhang, S., M.J. Harrison, A. Rosati, and A. Wittenberg, 2007: System Design and Evaluation of Coupled Ensemble Data Assimilation for Global Oceanic Studies. *Mon. Wea. Rev.*, 135, 3541-3564.

Zhang, S., A. Rosati and M.J. Harrison, 2007: Detection of Multi-Decadal Oceanic Variability within a Coupled Ensemble Data Assimilation System. Accepted *JGR Oceans*.