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Lead PI: Grant Branstator
Collaborators: Gerald Meehl (nonfunded), Haiyan Teng (nonfunded), Andrey Gristun (visiting project scientist)

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Project title and PI:
Initial Value Predictability of Intrinsic Oceanic Modes and Implications for Decadal Prediction over North America
Lead PI: Grant Branstator

Final Technical Report

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Project Synopsis:

The overall aim of our project is to quantify and characterize predictability of the climate as it pertains to decadal time scale predictions. By predictability we mean the degree to which a climate forecast can be distinguished from the climate that exists at initial forecast time, taking into consideration the growth of uncertainty that occurs as a result of the climate system being chaotic. In our project we are especially interested in predictability that arises from initializing forecasts from some specific state though we also contrast this predictability with predictability arising from forecasting the reaction of the system to external forcing. Also, we put special emphasis on the predictability of prominent intrinsic modes of the system because they often dominate system behavior.

Primary Research and Development Activities

Most of the research for this project was undertaken during its first three years. Results from that research have been described in detail in the three annual reports that have been previously submitted. Highlights from this work include:

- Development of methods for estimating the initial value predictability of climate models based on analysis of long control integrations.
- Quantification of the initial value predictability limits of ocean heat content and AMOC in many state of the art coupled climate models. These limits varied substantially from model to model but on average were about a decade with North Atlantic heat content tending to be more predictable than North Pacific heat content.
- Comparison of initial value and forced predictability in many climate models leading to the conclusion that information from the reaction to greenhouse gas forcing does not dominate until 5 to 10 years after predictions begin.
- Estimation of tbe predictability of dominant patterns of ocean variability including the PDO, AMOC's leading EOF, and North Atlantic subpolar gyre oscillations.
- Determination of especially predictable structures in the North Atlantic. The most predictable of these retain predictability substantially longer than generic patterns, with some being predictable for two decades.

During the four and final year of the project research concentrated on determining efficient means of forcing large amplitude, long-lasting responses in the North Atlantic via surface fluxes from the atmosphere. This was accomplished by applying the fluctuation dissipation theorem (FDT) to a low-resolution version of CCSM4. FDT enables one to construct a linear operator that gives the response of a dynamical system to an arbitrary forcing, thus making it possible to determine optimal forcing and response patterns. When we used it to find the most efficient means of exciting a response in AMOC through 5-year forcing of surface buoyancy, we found that salinity and heat fluxes in the model's deep convection sites were the best way to forcing the ocean and the optimum response was a single overturning cell that stretches from south of the equator to about 60N. This response pattern is very similar to the leading EOF of year to year AMOC variability. Another key finding was that this pattern is so much more readily excited than other patterns that it is not necessary to force the ocean with special distributions of surface fluxes for it to dominate variability. Even random distributions of buoyancy or wind stress forcing will lead to this being the leading pattern of AMOC variability. On the other hand, the flux pattern that does excite this mode depends sensitively on model dynamics and varies substantially from one model to another. This makes prediction of AMOC variability difficult for models with a poor representation of ocean or atmospheric dynamics.

Project Participants

The project consists of PI, Grant Branstator (NCAR) and nonfunded collaborators Gerald Meehl (NCAR) and Haiyan Teng (NCAR). Also Andrey Gritsun (RAS) participated in the project. For example, during the project's last year he visited NCAR to work on development and application of the FDT.

Publications (*15Sep2010-14Sep2014)*

Branstator, G. and H. Teng, 2010: Two limits of initial-value decadal predictability in a CGCM. *J. Climate,* **23**, 6292-6311.

Teng, H., and G. Branstator, 2011: Initial value predictability in prominent modes of North Pacific subsurface temperature in a coupled GCM. *Clim Dyn*, 36, 1813-1834.

Teng, H., G. Branstator, and G. A. Meehl, 2011: Predictability of the Atlantic Overturning Circulation and associated surface patterns in two CCSM3 climate change ensemble experiments. *J. Climate*, **24,** 6054-6076.

Branstator, G., H. Teng**,** G.A. Meehl, M. Kimoto, J.R. Knight, M. Latif, and A. Rosati, 2012: Systematic estimates of decadal predictability for six AOGCMs. *J. Climate*, **25,** 1827-1846.

Teng, H. and G. Branstator, 2012: A zonal wavenumber-3 pattern of Northern Hemisphere wintertime planetary wave variability at high latitudes. *J. Climate*, 25, 6756-6769.

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Meehl, G., J. Arblaster, and G. Branstator, 2013: Mechanisms contributing to the warming hole and consequent U.S. east-west differential of heat extremes. *J. Climate,* **25***,* 6394-6408.

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Meehl G., L. Goddard, G. Boer, R. Burgman, G. Branstator, and co-authors, 2014: Decadal climate prediction: An update from the trenches. *Bulletin of the American Meteorological Society,* **95**, 243-267.

G. Branstator and H. Teng, 2014: Is AMOC more predictable than North Atlantic heat content? *J. Climate*, **27**, 3537-3550.

Presentations *(15 Sep 2010-14 Sep 2014)*

"Limits of Initial Value Decadal Predictability", WGOMD-GSOP Workshop on Decadal Variability, Predictability and Predictions: Understanding the Role of the Ocean, NCAR, Boulder, 22 September 2010.

“The Response to Time-dependent Tropical Heat Sources”, Mike Wallace Symposium, University of Washington, Seattle, 27 September 2010.

“Two Limits of Decadal Predictability for Two Generations of CCSM”, AMS Conference on Climate Variability and Change, Seattle, 27 January 2011.

“Using the Fluctuation Dissipation Theorem to Examine the Atmospheric Response to Moving Tropical Heat Sources”, European Geophysical Union General Assembly, Vienna, 5 April 2011.

“The Atmospheric Response to Moving Tropical Heat Sources”, Canadian Meteorological and Oceanographic Society Congress, Victoria, 7 June 2011.

“Comparing Decadal Predictability Characteristics of Six CGCMs”, Canadian Meteorological and Oceanographic Society Congress, Victoria, 9 June 2011.

“Contrasting Decadal Variability and Predictability in Six AOGCMs”, Climate Variability Working Group, CESM Workshop, Breckenridge, 22 Jun 2011.

“Comparing Decadal Predictability in Six AOGCMs”, Decadal Prediction Workshop, Aspen Global Change Institute, Aspen, 27 Jun 2011

“The Reliability of AOGCM Decadal Predictability Properties”, WCRP Open Science Conference, Denver, 26 Oct 2011

“Comparing Decadal Predictability in Six AOGCMs”, University of Washington, Seattle, 6 Sep 2011

“Initial Value Decadal Predictability of Climate Modes in Six AOGCMs”, DOE Climate Modeling PI Meeting, Washington, 20 Sep 2011

“Comparing Decadal Predictability in Six AOGCMs”, Goddard Space Flight Center, NASA, Greenbelt, 11 Oct 2011

“CCSM4 Decadal Predictability in a 4XCO2 Climate”, NCAR, Boulder 30 Nov 2011

“Contrasting Initial Value and Forced Decadal Predictability”, International Detection and Attribution Group, Boulder, 2 Feb 2012

“Prominent Interannually Varying Zonal Waves”, Climate Variability and Change Working Group, NCAR, Boulder, 15 Mar 2012

“The remote response to time-dependent tropical heat sources”, Summer Colloquium on the Weather-Climate Intersection: Advances and Challenges, Advanced Studies Program, NCAR, Boulder, 11Jun2012

“Average and optimal AMOC predictability”, CESM Workshop, Breckenridge, 21Jun2012

“Initial value predictability of upper layer temperature and AMOC”, AMOC PI Workshop, Boulder, 15Aug2012

“Using stochastic models to diagnose the origins of leading atmospheric modes”, AIMS Dynamical Systems Conference, Orlando, 2Jul2012

“Predictability of the ocean state on multi-year time scales”, Courant Institute of Mathematical Sciences, New York University, New York, 10Oct2012

“Examples of applying the fluctuation dissipation theorem to the atmosphere/ocean sciences”, Workshop on Stochastic Modeling of the Oceans and Atmosphere, Institute for Mathematics and Its Applications, Minneapolis, 12Mar2013

“Is AMOC more predictable than North Atlantic heat content?”, International workshop on seasonal to decadal prediction, Toulouse, 13May 2013.

“Is Amoc more predictable than North Atlantic heat content?”, US CLIVAR / UK RAPID International Science Meeting, Baltimore, 17Jul2013.

“Optimal excitation of AMOC as estimated via application of the FDT”, US AMOC Science Team Meeting, Seattle, 10Sep14

“ Uncertainty in decadal predictions resulting from imperfect knowledge of the initial conditions”, University of Washington Program on Climate Change Summer Institute, Friday Harbor, 16Sep14