Final Technical Report on DOE DESC0001660 (08/01/2009 – 07/31/2012)

Project Title: Dynamics of Arctic and Sub-Arctic Climate and Atmospheric Circulation: Diagnosis of Mechanisms and Model Biases Using data Assimilation

Publications

1. Nigam, S., B. Guan, and A.Ruiz-Barradas (2011), Key role of theAtlanticMultidecadal Oscillation in 20th century drought and wet periods over the Great Plains, Geophys. Res. Lett., 38, L16713, doi:10.1029/2011GL048650.

The Great Plains of North America are susceptible to multi-year droughts, such as the 1930s 'Dust Bowl'. The droughts have been linked to SST variability in the Pacific and Atlantic basins. This observationally rooted analysis shows the SST influence in multi-year droughts and wet episodes over the Great Plains to be significantly more extensive than previously indicated. The remarkable statistical reconstruction of the major hydroclimate episodes attests to the extent of the SST influence in nature, and facilitated evaluation of the basin contributions. We find the Atlantic SSTs to be especially influential in forcing multi-year droughts; often, more than the Pacific ones. The Atlantic Multidecadal Oscillation (AMO), in particular, contributed the most in two of the four reconstructed episodes (Dust Bowl Spring, 1980s fall wetness), accounting for almost half the precipitation signal in each case. The AMO influence on continental precipitation was provided circulation context from analysis of NOAA's 20th Century Atmospheric Reanalysis.

A hypothesis for how the AMO atmospheric circulation anomalies are generated from AMO SSTs is proposed to advance discussion of the influence pathways of the mid-to-high latitude SST anomalies. Our analysis suggests that the La Nina–US Drought paradigm, operative on interannual timescales, has been conferred excessive relevance on decadal timescales in the recent literature.

2. Baxter, S., and S. Nigam, 2013: A Sub-Seasonal Teleconnection Analysis: PNA Development and Its Relationship to the NAO. *J. Climate* (Acceptance pending minor revisions).

The Pacific-North American (PNA) teleconnection is a major mode of Northern Hemisphere wintertime climate variability, with well-known impacts on North American temperature and precipitation. In order to assess whether the PNA teleconnection has extended predictability, comprehensive data analysis is conducted to elucidate PNA evolution, with an emphasis on patterns of PNA development and decay. These patterns are identified using extended empirical orthogonal function (EEOF) and linear regression analyses on pentad-resolution atmospheric circulation data from the new Climate Forecast System Reanalysis (CFSR). Additionally, dynamical links between the PNA and another important mode of wintertime variability, the North Atlantic Oscillation (NAO), are analyzed both in the presence and absence of notable tropical convection, e.g., the Madden-Julian Oscillation (MJO); the latter is known to be influential on both. The relationship is analyzed using EEOF and regression techniques.

It is shown that the PNA structure is similar in both space and time when the MJO is linearly removed from the dataset. Furthermore, there is small but significant lag between the NAO and PNA, with the NAO leading a PNA of opposite phase on timescales of one to three pentads. It is suggested from barotropic vorticity analysis that this relationship may result in part from excitation of Rossby waves by the NAO in the Asian waveguide.

3. Kavvada, A., A. Ruiz-Barradas, and S. Nigam, 2013: AMO's Structure and Climate Footprint in Observations and IPCC AR5 Climate Simulations. *Climate Dynamics* (Acceptance pending minor revisions)

This study aims to characterize the spatiotemporal features of the low frequency Atlantic Multidecadal Oscillation (AMO), its oceanic and atmospheric footprint and its associated hydroclimate impact. To accomplish this, we compare and evaluate the representation of AMO-related features both in observations and in *historical* simulations of the 20th century climate from models participating in the IPCC's CMIP5 project. Climate models from international leading research institutions are chosen -CCSM4, GFDL-CM3, UKMO-HadCM3 and ECHAM6/MPI-ESM-LR. Each model employed includes at least three and as many as nine ensemble members. Our analysis suggests that the four models underestimate the characteristic period of the AMO, as well as its temporal variability. This is associated with an underestimation/overestimation of spectral peaks in the 70-80yr/10-20 yr range. The four models manifest the mid-latitude focus of the AMO-related SST anomalies, as well as certain features of its subsurface heat content signal. However, they are limited when it comes to simulating some of the key oceanic and atmospheric footprints of the phenomenon, such as its signature on subsurface salinity, oceanic heat content and geopotential height anomalies. Thus, it is not surprising that the models are unable to capture the majority of the associated hydroclimate impact on the neighboring continents, including underestimation of the surface warming that is linked to the positive phase of the AMO and is critical for the models to be trusted on projections of future climate and decadal predictions.

4. Ruiz-Barradas, A., S. Nigam, and A. Kavvada, 2013: The Atlantic Multidecadal Oscillation in 20th Century Climate Simulations: Uneven Progress from CMIP3 to CMIP5. (Being revised for Climate Dynamics)

Decadal variability in the climate system from the Atlantic Multidecadal Oscillation (AMO) is one of the major sources of variability at this temporal scale that climate models must properly incorporate because its surface climate impact on the neighboring continents. The current analysis of historical simulations of the 20th century climate from climate models from the CMIP3 project (CCSM3, GFDL-CM2.1, UKMO-HadCM3, and ECHAM5/MPI-OM) and the CMIP5 project (CCSM4, GFDL-CM3, UKMO-HadGEM2-ES, and MPI-ESM-LR) assesses how these models portray the observed spatiotemporal features of the SST anomalies associated with the AMO. The mature stage of the warm phase of the AMO, as well as its evolution before and after reaching this stage, have evolved from the CMIP3 to the CMIP5 versions but not consistently through the models. While the UKMO-HadGEM2-ES displays the best agreement with observations, and improvements from its CMIP3 version, CCSM4 is the worst; GFDL-CM3 and MPI-ESM-LR are in between. The characteristic period of the AMO is underestimated by the models, except the CMIP5 version of the UKMO model that overestimate it; however, if the period is judged by using the e-folding time of the autocorrelations, all models underestimate the 44-year value from observations by almost 50%. Only the AMO indices from the CMIP5 versions of the GFDL and UKMO models have comparable variability to observations, and are mildly correlated with the observed index. Finally, comparison of the observed spatial variability and correlation of the regressed precipitation and SST anomalies of the AMO indices in summer and fall indicates that models are not up to the task of simulating the AMO impact on the hydroclimate over the neighboring continents. This is in spite that the spatial variability and correlations in the SST anomalies improve from CMIP3 to CMIP5 versions of the MPI and UKMO models; the most successful is the CMIP5 version of the UKMO model in both seasons, and the most degraded is the CMIP5 version of the NCAR model.

5. Grodsky, S., J. Carton, S. Nigam, and Y. Okumura, 2012: Tropical Atlantic Biases in CCSM4. *J. Climate*, 25, 3684-3701.

This paper focuses on diagnosing biases in the seasonal climate of the tropical Atlantic in the twentiethcentury simulation of the Community Climate System Model, version 4 (CCSM4). The biases appear in both atmospheric and oceanic components. Mean sea level pressure is erroneously high by a few millibars in the subtropical highs and erroneously low in the polar lows (similar to CCSM3). As a result, surface winds in the tropics are ;1 m s21 too strong. Excess winds cause excess cooling and depressed SSTs north of the equator. However, south of the equator SST is erroneously high due to the presence of additional warming effects. The region of highest SST bias is close to southern Africa near the mean latitude of the Angola–Benguela Front (ABF). Comparison of CCSM4 to ocean simulations of various resolutions suggests that insufficient horizontal resolution leads to the insufficient northward transport of cool water along this coast and an erroneous southward stretching of the ABF. A similar problem arises in the coupled model if the atmospheric component produces alongshore winds that are too weak. Erroneously warm coastal SSTs spread westward through a combination of advection and positive air–sea feedback involving marine stratocumulus clouds.

This study thus highlights three aspects to improve to reduce bias in coupled simulations of the tropicalAtlantic: 1) large-scale atmospheric pressure fields; 2) the parameterization of stratocumulus clouds; and 3) the processes, including winds and ocean model resolution, that lead to errors in seasonal SST along southwestern Africa. Improvements of the latter require horizontal resolution much finer than the 18 currently used in many climate models.

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