Bimodal behavior in the Northern Hemisphere's zonal-mean zonal flow and its possible association with decadal-scale coupled climate variability

Sergey Kravtsov,[*] A. W. Robertson, M. Ghil, W. K. Dewar, P. Berloff, and J. C. McWilliams

[*]Department of Mathematics, University of Wisconsin-Milwaukee, P.O. Box 413, Milwaukee, WI 53201

Introduction

Spontaneous variability of the climate system on decadal and longer time scales may arise due to interactions between its oceanic and atmospheric components. Such intrinsic coupled climate signals are important to understand and quantify in order to better assess and predict the magnitude of human-induced changes to the Earth's climate and their consequences. An example of observational evidence for this type of behavior is presented in **Fig. 1**.

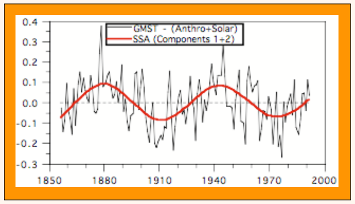


Fig. 1. The residual (solid black line — in °C) between observed global mean surface temperature (GMST), and an estimate of GMST variations due to combined anthropogenic and solar forcing (Marcus et al. 1999). Heavy red line shows reconstruction by singular spectral analysis (SSA; Ghil et al. 2002); this multi-decadal signal, unexplained by the external forcing evolution, might be due to intrinsic climate variability.

An intriguing example of decadal ocean–atmosphere co-variability involves spatial patterns associated with the North Atlantic Oscillation and the North Atlantic sea-surface temperature (SST) tripole (**Fig. 2**). **A major ambiguity in ascribing this dependence to coupled dynamics lies in the lack of robust atmospheric response to such SST anomalies in atmospheric general circulation models.**

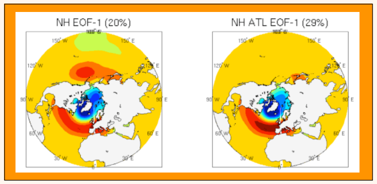
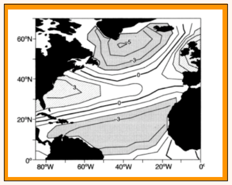


Fig. 2. Evolution associated with the Arctic Oscillation (AO; upper left) and North Atlantic Oscillation (NAO; upper right) teleconnection patterns dominates atmospheric low-frequency variability in the Northern Hemisphere's mid-latitudes. The corresponding SST signal in the Atlantic Ocean (bottom) has a tripolar pattern (Marshall et al. 2001).



Data, models, and results

In this study, we have supported our statistical analysis of NCEP/NCAR reanalysis of the Northern Hemisphere's wintertime zonal wind and geopotential height data sets (Kalnay et al. 1996), as well as SST data set (Kaplan et al. 1998), with dynamical insights obtained from two different idealized coupled models. The atmospheric components of both models were identical and represented by a baroclinic beta-channel quasi-geostrophic module, which has a reasonable degree of realism in representing the mid-latitude atmospheric jet stream (**Fig. 3**).

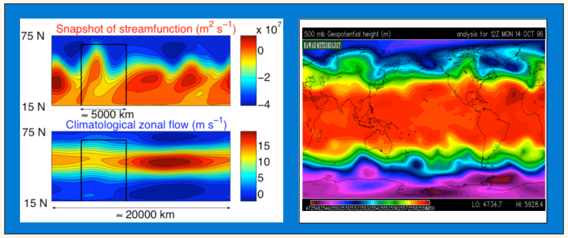
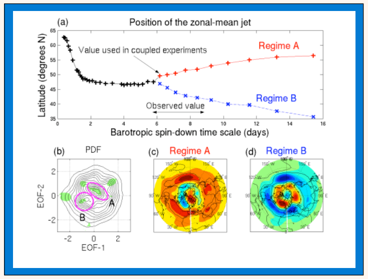


Fig. 3. Snapshot of streamfunction (upper left) and time-mean zonal velocity (lower left) of the simulated atmospheric flow. Right panel: snapshot of the observed geopotential height (reanalysis).

Fig. 4. Atmospheric bimodality: Results from our atmospheric model appear in (a), showing zonally averaged jet latitudes versus atmospheric bottom drag. (b) A phase-space plot of the principle components of the first two EOFs of the zonally averaged NH jet. Departures from gaussianity are indicative of bimodality. The 250-mb spatial patterns associated with the two regimes "A" and "B" appear in (c) and (d).

An aspect of atmospheric variability of considerable significance in the present study is the *bimodality* of mid-latitude jets, that is the tendency for the zonally averaged atmospheric jet to be found preferentially and persistently at discrete latitudes. In our atmospheric model, we found that the preferred latitudes of the zonally averaged maximum zonal velocity depended on the bottom drag parameter. Strongly damped solutions had one preferred latitude and weakly damped solutions had two (**Fig. 4a**). Strong observational evidence for bimodality in the Southern Hemisphere zonally averaged jet appeared recently in Koo et al. (2003). Similar analysis for the Northern Hemisphere is shown in **Fig. 4b**: the two regimes, consisting of northward (regime A) and southward (B) shifts relative to the climatological jet position (Fig. 4b); The 250-mb height patterns of these regimes (**Fig. 4c,d**) are not unlike opposite phases of the Arctic Oscillation (cf. **Fig. 2**).



Coupled to the above atmospheric model are *two different ocean models*: (i) three-layer, eddy-resolving quasi-geostrophic (QG) model; and (ii) a coarse-resolution primitive-equation (PE) model of the thermohaline circulation (THC). QG equatioins describe perturbations about pre-specified density field; this basic stratification is set up, implicitly, by THC. On the other hand, the THC is explicitly described by the PE model, but this model's coarse resolution and high horizontal viscosity effectively suppress eddy dynamics.

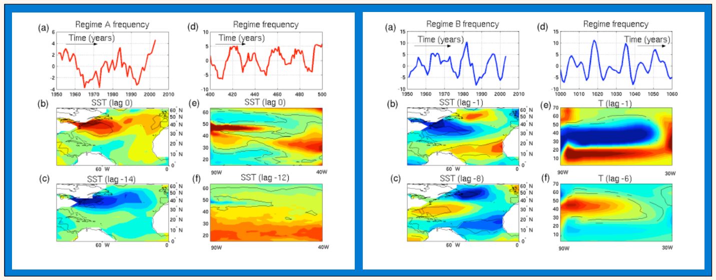


Fig. 5. Left frame: Time series of anomalies of days spent per winter in regime A as computed from reanalysis data appears in (a); it is compared to the same time series of the coupled mode from our process coupled model of the wind-driven circulation in (d). Below are phases of the SST pattern that regresses onto the regime time series from the observations (e) and (f) and from the model (b) and (c). Right frame: the same for regime B and thermohaline circulation model.

In both coupled models, the occupation frequency of atmospheric regimes (number of days spent in a given regime per winter) exhibits tantalizing decadal-to-interdecadal variability (**Fig. 5**). Spatial signatures and time scales of both 21-yr QG and 12-yr THC modes have also been detected in observations. The latter mode has a tripolar SST pattern (cf. **Fig. 2**), while the former is represented by the SST monopole, roughly co-located with the position of the tripole's center lobe. These results suggest that, at the least, part of the observed decadal-to-interdecadal climate variability in middle latitudes can be ascribed to coupled dynamics.

Discussion

Tripolar and monopolar, decadal-to-interdecadal SST patterns have been both observed and simulated in coupled GCMs, as well as in oceanic GCMs forced by observed NAO variability. Largely monopolar SST patterns similar to our Regime A's have usually been associated with the time scales on the order of 60–100 years and have been referred to as the Atlantic Multidecadal Oscillation. Monopolar SST patterns varying on a time scale of 20–30 yr have also been obtained, but the center of action was located, in general, to the north-east of that in **Fig. 5**. Therefore, we claim that while regime-B SST pattern has been seen and interpreted before, regime-A SST pattern represents a novel signal, which has not been previously detected.

Our modeling results shed light on the origin of atmospheric sensitivity to ocean-induced SST anomalies in middle latitudes; namely, long-term ocean–atmosphere heat fluxes associated with either monopolar or tripolar SST patterns affect attraction basins of two distinct anomalously persistent atmospheric "regimes." The associated reorganization of the atmospheric jet feeds back onto ocean currents in a way to support decadal-to-interdecadal variability. The time scale of these signals is set, in each case, by intrinsic oceanic processes.

Selected references

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For further information

Please contact *kravtsov@uwm.edu*. A PDF-version of this poster can be found at *www.uwm.edu/~kravtsov/presentations/EGU2006_poster.pdf*.

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