Atlantic Multidecadal Oscillation and Northern Hemisphere's climate variability

Marcia Glaze Wyatt[1], Sergey Kravtsov[2] and Anastasios A. Tsonis[2]

[1] Department of Geologic Sciences, CIRES/INSTAAR, University of Colorado-Boulder, 2200 Colorado Ave, Boulder, CO 80309-0399

[2] Department of Mathematics, Atmospheric Sciences Group, University of Wisconsin-Milwaukee, P.O. Box 413, Milwaukee, WI 53201

Introduction

Non-uniformity in the global warming trend is usually attributed to corresponding non-uniformities in the external forcing. An alternative hypothesis involves multi-decadal climate oscillations affecting the rate of global temperature change. **We use 20th-century observations of a network of Northern Hemisphere (NH) climate indices to study the effects of the Atlantic Multidecadal Oscillation (*Enfield et al. 2001*; *Knight et al. 2006*) on the NH, as well as the global, climate's variability.**

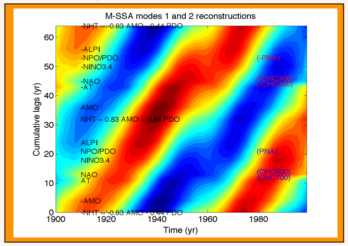

Fig. 1. The Hoffmuller diagram of the "stadium-wave" propagation in the "space" of 15 climate indices. The horizontal cross-sections in locations marked by index acronyms would represent the time series of the corresponding index's reconstruction based on the leading M-SSA pair; these time series are, in fact, plotted for select indices in Fig. 2, and for all indices in Fig. 3 (heavy blue lines). The vertical "distance" between the adjacent indices represents the time lag between their reconstructed time series.

Methodology. We use the Multi-channel Singular Spectrum Analysis (M-SSA; *Ghil et al. 2002*) to identify the dominant multidecadal signal in our climate network, consisting of 15 indices. Choice of indices was guided by our hypothesized hemispheric influence of the AMO; indices considered included those based on SST (sea-surface temperature) anomalies in the North Atlantic (AMO: Atlantic Multidecadal Oscillation) and North Pacific (PDO: Pacific Decadal Oscillation, ENSO: El Niño Southern Oscillation), as well as the "atmospheric" indices – NAO (North Atlantic Oscillation), AT (Air-mass Transfer anomalies), NPO (North Pacific Oscillation), among others. The climate signal is represented by the dominant M-SSA pair, whose reconstruction is visualized in **Fig. 1** (**Fig. 3** [heavy blue lines].)

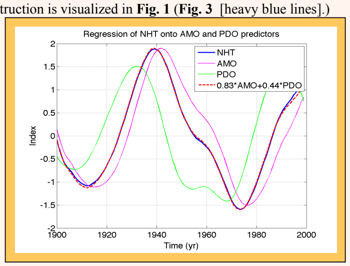

Fig. 2. The M-SSA reconstruction of the NH surface temperature time series can be nearly perfectly represented as a weighted sum of the AMO and PDO reconstructions.

Stadium-wave multidecadal variability

The "stadium-wave" (**Fig. 1**) comprises a collection of atmospheric and lagged oceanic teleconnections, which "propagate" across our climate-index phase space. It describes how the Atlantic-generated climate signal produces hemispheric climate-regime shifts. In particular, a warm (cool) North Atlantic initiates atmospheric teleconnections that generate cool (warm) Pacific circulations within approximately twenty years, culminating in a cooling (warming) hemispheric signal. This hemispheric response is reflected in the Northern Hemispheric surface temperature (NHT, with linear century-scale trend removed); it can be thought of as a weighted sum of the North Atlantic and North Pacific SST anomalies (**Fig. 2**). As the stadium-wave teleconnections evolve, so does the NHT:

+AMO → – AT → –NAO → –NINO3.4 → –NPO/PDO → –ALPI → –NHT → –AMO →+AT → +NAO → +NINO3.4 → +NPO/PDO → +NHT → +AMO…

The AMO signature is present in a wide variety of proxy and instrumental records in the form of a broadband 50–80-yr climate signal across the Northern Hemisphere, with particular presence in the North Atlantic (*Delworth and Mann 2000*). Modeling studies rationalize this variability in terms of the intrinsic dynamics of the North Atlantic Meridional Overturning Circulation (AMOC: *Knight et al. 2005*). AMOC anomalies influence distribution of the North Atlantic SSTs, resulting in a characteristic basin-wide SST-anomaly pattern (*Enfield et al. 2001; Knight et al. 2006*). Initial AMO-related SST anomalies in the North Atlantic Ocean lead to accompanying changes in atmospheric poleward heat-transport (*Marshall et al. 2001*), and cause reorganization of the North Atlantic mid-latitude jet stream and the Atlantic Intertropical Convergence Zone. Through middle and low latitudes, this climate response is communicated to the North Pacific, where local changes may reinforce the Atlantic-born multidecadal signal (*Dong et al. 2006; Zhang and Delworth 2007*).

Stadium-wave effects on shorter-term variability

M-SSA analysis provides an objective decomposition of our climate-network members into the AMO-related multidecadal signal (**Fig. 3**, heavy blue lines), and shorter-term, decadal-to-interdecadal variability (Fig. 3, red lines), which permits further analysis of possible connections between them. In particular, the 1939 to 1976 period, characterized by the negative phase of multidecadal (Atlantic-induced) stadium-wave signal in the AT and NAO indices (see Figs. 1 and 3), was also a period during which ENSO and NAO variability was substantially reduced compared to surrounding periods (**Fig. 4**; see also *Dong et al.* 2006).

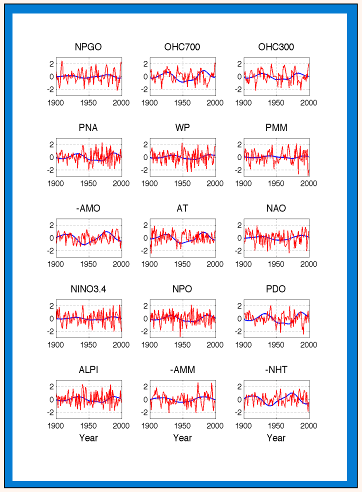

Fig. 3. The decomposition of each of 15 climate indices into the leading M-SSA mode (heavy blue lines) and the residual, shorter-term variability (red lines). The sum of the two components gives the raw index time series (which was linearly detrended and normalized to unit variance prior to the analysis).

Furthermore, *Tsonis et al.* (2007) tagged the years 1939 and 1976 as those of abnormal zero-lag synchronization; that is, phase and frequency locking in short intervals of multiple climate-index time series. Using the concepts of network theory, these authors connected major hemispheric climate-regime shifts to bifurcations rooted in collective behavior of individual climate oscillators.

We have extended the *Tsonis et al.* analysis to our larger climate network by identifying periods of abnormally large statistically significant cross-correlations between subnetworks of climate indices, confirming *Tsonis et al.*'s results (**Fig. 5**), while obtaining a more detailed picture of the two synchronization episodes, in terms of identification of primary indices involved in each case, as well as the time scale and relative phasing of the synchronized teleconnections.

The above matching of synchronization episodes with initiation/termination of the stadium-wave phases suggests an interpretation in which the AMO forcing serves as a primary agent of interannual synchronizations. It is also possible that under certain conditions (see *Tsonis et al.* 2007) higher-frequency synchronizations are actively involved in inducing the lower-frequency hemispheric climate-regime shifts – to be addressed in future work.

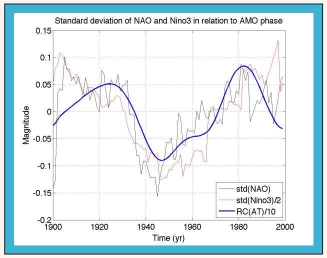

Fig. 4. Anomalies of NAO and Nino3 standard deviations (STD; light lines), along with the stadium-wave multi-decadal signal in the AT index (scaled by 0.1). The Nino3 STD was scaled by 0.5. The STDs were computed over the 31-yr-wide sliding window.

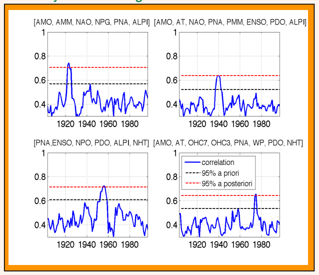

Fig. 5. The objectively defined index subnetworks exhibiting cross-correlations that exceed the climatological cross-correlations at the 5% *a posteriori* significance level). The quantity plotted is the leading singular value of the cross-correlation matrix computed over the 7-yr sliding window.

Discussion

Traditional interpretation of the decreasing global-mean surface temperature during the period of 1940–1970 is that it is due to tropospheric aerosols' cooling effect overweighting greenhouse-gas induced warming. While this anthropogenic influence may have played a role mid-century, the spatiotemporal sequence of the AMO teleconnections identified by our stadium-wave analysis suggests a significant role for natural variability in this phenomenon.

The decadal large-scale teleconnections comprising the stadium wave imply potential gains in the decadal climate predictability via improved initialization of global climate models, using information about the phase of the observed multidecadal signal. Additional predictability may be associated with possible relationships between multidecadal hemispheric climate-regime shifts and interannual-interdecadal synchronization episodes. Both these possibilities are currently being investigated.

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For further information

Please contact *marciawyatt@earthlink.com* or *kravtsov@uwm.edu*.

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UNIVERSITY of WISCONSIN UWMILWAUKEE
College of Letters and Science
ATMOSPHERIC SCIENCE
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