The Relationship between Low-Frequency North Atlantic Sea Surface Temperatures and Eastern North American Climate

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1. INTRODUCTION

The expansion of research interest in climate variability, fueled by a great desire to understand the El Niño Southern Oscillation (ENSO), has focused attention on several dominant modes of climate variability. These include, but are not limited to, the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and the Pacific Decadal Oscillation (PDO). These climate oscillations are well known not only for their aperiodic variability along numerous timescales, but also for the climate impacts they impart on their respective regions of influence.

The present study investigates the relation between low-frequency North Atlantic sea surface temperature (SST) anomalies and eastern North American climate. SST's are used because the ocean plays a large role in determining long-term climate fluctuations, given the ocean's large specific heat and inertia. In addition, studies have indicated that the North Atlantic Ocean is a region of intense ocean-atmosphere coupling, particularly during winter (Häkkinen, 2000). Other studies have shown that prescribed North Atlantic SST's in an atmospheric general circulation model (AGCM) can reproduce the low-frequency atmospheric variability characterized by the NAO/AO (Rodwell et al., 1999; Mehta et al, 2000).

The NAO and AO, which are arguably the same phenomenon (Wallace, 2000), are unique because most of the emerging interest in them can be attributed to upward trends in their indices (Wallace and Thompson, 2002). However, the oscillatory components of the AO and NAO are also important, particularly for the forecasting of Northern Hemisphere climate (Higgins et al., 2000). Over the United States and Canada, low-frequency fluctuations in the AO/NAO explain a significant portion of climate variability. During the low-index phases of the AO and NAO, eastern Canada experiences warmer conditions while negative temperature anomalies reside over the eastern United States. The high-index phase brings the opposite dipole pattern in temperature to eastern North America (Thompson and Wallace, 1998; Hurrell, 1995).

2. NORTH ATLANTIC SST VARIABILITY

The North Atlantic Ocean plays an important role in the global ocean-atmosphere system. It is home to the Gulf Stream and a significant branch of the global Thermohaline Circulation. The North Atlantic is also a significant source of deep-water formation. The North Atlantic exhibits numerous modes of low-frequency variability in SST. The dominant mode is multidecadal (Kushnir, 1994; Delworth et al., 1993; Deser and Blackmon, 1993), while significant modes also exist at quasi-decadal (Mizoguchi et al., 1999) and inter-annual timescales (Delworth, 1996).

3. DATA AND METHODS

The data for this project are extracted from four data sets. North Atlantic SSTs are from the Hadley Centre Sea Ice and Sea Surface Temperature Data Set (HadISST). Temperature and Precipitation from select stations in the Eastern United States and Canada are retrieved from the Global Historical Climatology Network (GHCN) data set. In addition, indices of the AO and the NAO are used. Each of the data sets consists of monthly values between 1901 and 1999.

The North Atlantic SST Index (NASSTI) was calculated from data in the HadISST data set. All monthly SST values in the box bounded by 51° N, 65° N, 23° W, and 65°W are averaged, yielding a monthly time series. For simplicity, the grid boxes were not weighted by the cosine of the latitude. Subsequently, the monthly SST series was detrended and the monthly climatology (over the 99-year period) was removed. The time series was then low-pass filtered with a 145-point Gaussian filter, or 72 consecutive 1-2-1 hannings. Following the ENSO convention, the NASSTI is separated into three parts: a warm phase, a neutral phase, and a cold phase. The warm and cold phases represent the top and bottom 20% of the SST anomaly values, respectively. The 20% threshold is selected as a compromise between station data completeness (specifically the data voids in Canada) and a desire to isolate extreme events.

Fifty-one GHCN stations are used for the temperature analysis, whereas 43 stations were utilized in assessing precipitation impacts. The stations were selected with an explicit desire to maximize spatial coherence and data completeness. Total deviations (from neutral) in mean monthly temperature and monthly precipitation are obtained for each station during the warm and cold phases of the NASSTI. Deviations are also evaluated on a monthly basis, reported as three-month seasonal averages. For precipitation, the deviations are also divided by the mean neutral phase value, yielding percent deviations. All comparisons are made with respect to the neutral phase, as opposed to the total mean.

Any patterns that emerged in the analysis were compared to AO/NAO impacts in the region. The AO and NAO series are filtered with the same 145-point filter. For the NAO and AO, we distinguish the extreme phases, the top and bottom 20% of the distributions, as the high polarity phase and the low polarity phase, respectively.

4. RESULTS

Surface temperature deviations from neutral during the NASSTI's warm phase reveal a general warming over much of eastern North America. Seasonal composites indicate that this pattern is most intense during winter. Positive temperature anomalies first appear in the Ohio River Valley and the Great Lakes region in the fall. During DJF, the largest deviations have shifted to eastern Canada, but the vast majority of our study region is blanketed in warm anomalies (Figure 1). By early spring (FMA), the temperature anomalies in the Ohio River Valley and Great Lakes region have disappeared, while the withdrawal of the eastern Canadian anomalies has commenced. Animations confirm the existence of a propagating signal in temperature anomalies from southwest to northeast during the warm phase of the NASSTI. This propagation can also be seen using a seasonal Hovmöller diagram (Figure 2).

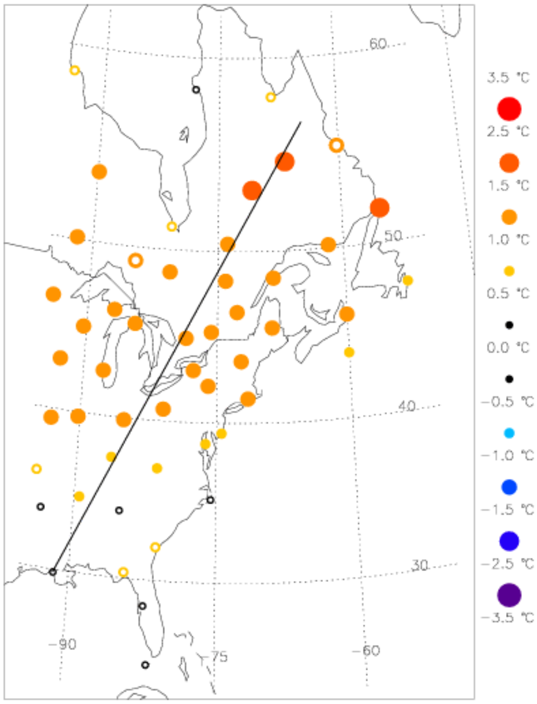

Figure 1. Warm-Neutral NASSTI temperature deviations during DJF. The line is the propagation axis used for Figure 2. Completely filled circles have passed a non-simultaneous t-means test at 95%.

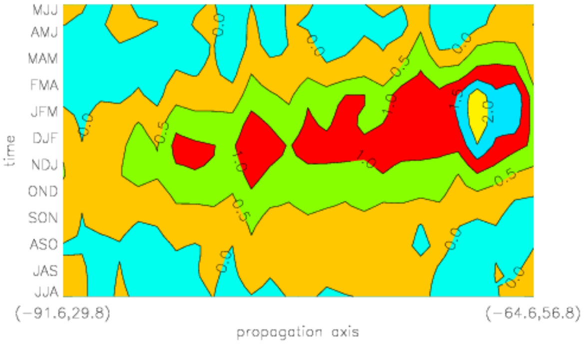

Figure 2. Hovmöller diagram of NASSTI warm-neutral temperature deviations.

During the cold phase, a dipole-like pattern exists. Eastern Canada, which borders the SST domain, experiences colder than neutral conditions, while most of the eastern U.S. experiences warm anomalies (Figure 3). The amplitudes of the anomalies once again peak during the winter. The gradient pattern appears to be stationary, with both poles amplifying from fall to winter and fading as spring arrives. It is important to note that the cold phase and warm phase deviations are not converse patterns.

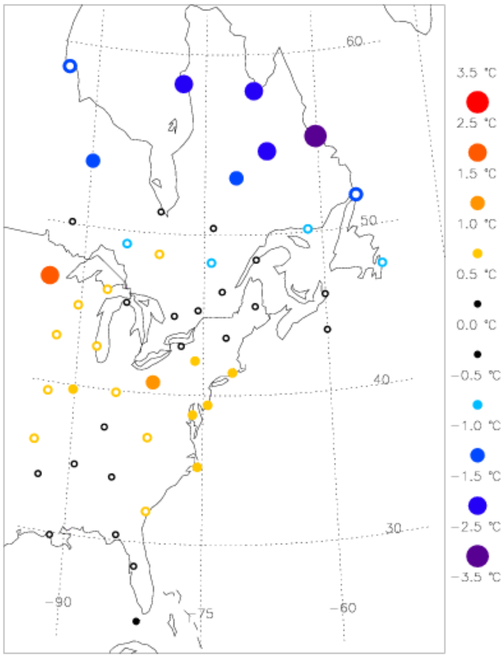

Figure 3. Cold-Neutral NASSTI temperature deviations during DJF.

Variations in precipitation are not as clearly defined. Unlike air temperature, which tends to be spatially coherent, precipitation is highly dependent on local effects. In general, the stations tend to be slightly wetter than neutral during the NASSTI's warm phase, although a small concentration of New England stations exhibits somewhat drier conditions. During the cold phase, the northeastern United States and southern Canada tend to receive a little more precipitation than normal. The neutral phase anomalies are marginally drier than mean conditions. In general, there is no consistent temporal or spatial coordination between the anomalies. Due to the lack of a robust precipitation signal, only temperature will be considered from this point forward.

Comparing NASSTI temperature deviations during winter to AO/NAO impacts reveals an interesting relation. The wintertime cold-neutral pattern is virtually identical to the high-neutral temperature patterns in this region of the AO and NAO (Figure 4). The low-neutral AO/NAO temperature anomalies show the reverse pattern, with warm anomalies in eastern Canada and cooler conditions in the eastern United States (Figure 5). This does not match up with the Warm-neutral pattern of warm anomalies everywhere.

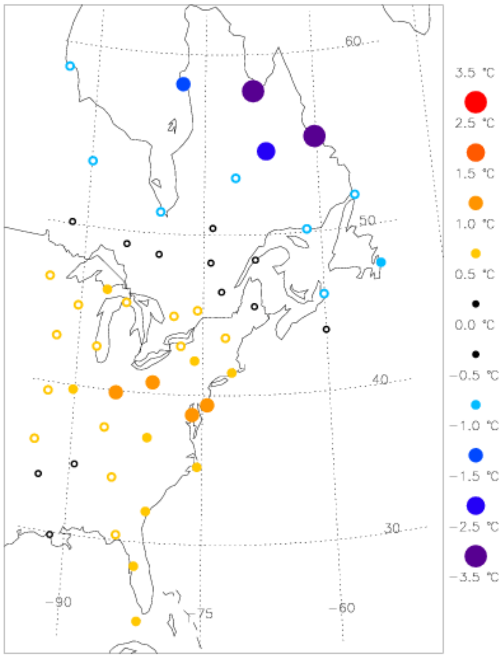

Figure 4. High-Neutral AO temperature deviations during DJF.

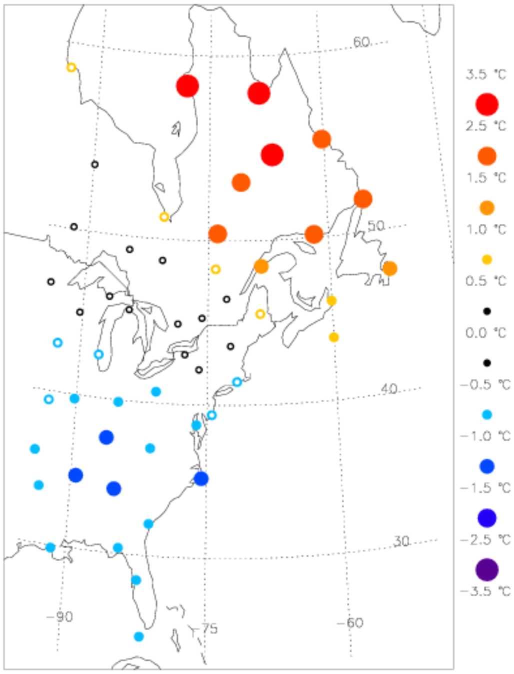

Figure 5. Low-Neutral AO temperature deviations during JFM.

If we only consider eastern Canada, however, the AO/NAO fingerprint here matches up well with the NASSTI patterns. This fact is encouraging, considering eastern Canada borders the NASSTI's domain. The warm-neutral signal corresponds to the low-neutral pattern. During these phases, the AO/NAO is associated with a weaker Icelandic Low during winter, and thus weaker westerlies on its southern flank. SST anomalies between Canada and Iceland tend to be warmer, perhaps due to heat flux anomalies. Anomalously weaker northerlies reside on the western flank of the Icelandic Low, which may be responsible for the warm anomalies in eastern Canada because of reduced advection of cold, polar air.

The cold-neutral and high-neutral patterns exhibit the opposite configuration. Between Canada and Iceland, cooler SSTs are accompanied by anomalously strong westerlies. The Icelandic low is more intense than normal and is associated with stronger northerly winds on its western periphery. These strong winds on its western flank may be responsible for increased penetration of cold air into eastern Canada during winter.

The above considerations for the eastern Canadian anomalies fail to explain why the warm-neutral pattern originates in the Ohio River Valley. The 'dipole' patterns of cold-neutral, high-neutral, and low-neutral also implicate variability in the polar front position as a possible mechanism. In removing high-frequency fluctuations from the AO, NAO, and NASSTI, we did not distinguish between the low-frequency modes that were retained. The patterns we have found may thus be the interaction of several low-frequency signals. Future work may involve recasting the experiment to isolate the various low-frequency impacts over eastern North America. Furthermore, it is quite possible that the AO and NAO are not stationary features. They are typically calculated using EOF-based techniques that only identify stationary patterns. Future work may also include calculating the AO/NAO using complex or cyclo-stationary EOF's and reanalyzing their impacts over eastern North America.

It must be emphasized that the warm-neutral and cold-neutral patterns were found using solely SST as an indicator. The similarity of these two patterns to the high-neutral and low-neutral signals of the AO/NAO, which are the dominant modes of Northern Hemisphere variability, is a testament to the strong coupling of the ocean and atmosphere in the North Atlantic during winter. Häkkinen (2000) also emphasized the importance of air-sea interactions in low-frequency modes, proposing the existence of a coupled system in the North Atlantic in which the quasi-decadal SST variability could be reproduced with knowledge of surface heat fluxes. It is clear that the North Atlantic Ocean actively communicates with the atmosphere above it, and that this relation involves the AO/NAO system (Häkkinen, 2000). A more complete understanding of this communication is necessary to better comprehend low-frequency signals in eastern North America.

5. REFERENCES

Delworth, T. L., 1996: North Atlantic Interannual Variability in a Coupled Ocean-Atmosphere Model. *Journal of Climate*, **9**, 2356-2375.

Delworth, T. L., S. Manabe, and R. J. Stouffer, 1993: Interdecadal variations of the thermohaline circulation in a coupled ocean-atmosphere model. *Journal of Climate*, **6**, 1993-2011.

Deser, C. and M. L. Blackmon, 1993: Surface climate variations over the North Atlantic Ocean during winter: 1900-1989. *Journal of Climate*, **6**, 1743-1753.

Häkkinen, S., 2000: Decadal Air-Sea Interaction in the North Atlantic Based on Observations and Modeling Results. *Journal of Climate*, **13**, 1195-1219.

Higgins, R. W., A. Leetma, Y. Xue, and A. Barnston, 2000: Dominant Factors Influencing the Seasonal Predictability of U.S. Precipitation and Surface Air Temperature. *Journal of Climate*, **13**, 3994-4017.

Hurrell, J. W., 1995: Decadal trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. *Science*, **269**, 676-679.

Kushnir, Y., 1994: Interdecadal variations in North Atlantic sea surface temperature and associated atmospheric conditions. *Journal of Climate*, **7**, 141-157.

Mehta, V., M. Suarez, J. V. Manganello, and T. D. Delworth, 2000: Oceanic influence on the North Atlantic Oscillation and associated Northern Hemisphere climate variations: 1959-1993. *Geophysical Research Letters*, **27** (1), 121-124.

Mizoguchi, K., S. D. Meyers, S. Basu, and J. J. O'Brien, 1999: Multi- and Quasi-Decadal Variations of Sea Surface Temperature in the North Atlantic. *Journal of Physical Oceanography*, **29**, 3133-3144.

Rodwell, M. J., D. P. Powell, and C. K. Folland, 1999: Oceanic forcing of the wintertime North Atlantic Oscillation and European climate. *Nature*, **398**, 320-323.

Thompson, D. W. J. and J. M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geophysical Research Letters,* **25** (9), 1297-1300.

Wallace, J. M., 2000: North Atlantic Oscillation/Northern Hemisphere annular mode: One Phenomenon, two paradigms. Quarterly Journal of the Royal Meteorological Society, 126, 791-805.

Wallace, J. M. and D. W. J. Thompson, 2002: Annular Modes and Climate Prediction. *Physics Today*, **55** (2), 28-33.