Correlation of Sea Surface Temperature in the Gulf Stream Extension with the Northern Hemisphere Annular Mode

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Abstract

The Northern Hemisphere annual mode (NAM, also known as the Arctic Oscillation) has been identified as the dominant mode of extratropical atmospheric variability in the Northern Hemisphere. Contrary to conventional wisdom suggesting a one-way forcing of midlatitude sea surface temperature (SST) anomalies by atmospheric variability, an empirical correlation has been found to suggest that small changes in SST in the Gulf Stream Extension region of the North Atlantic may precede the NAM on intraseasonal timescales. An investigation of this finding using the same SST dataset as well as a new higher-resolution SST dataset yields similar results but at significantly reduced amplitudes and correlation values.

1. Introduction

The climate of the Northern Hemisphere often exhibits an out-of-phase relationship between temperatures in Greenland and Northern Europe. It has long been observed that Greenland tends to experience milder winter conditions when Northern Europe experiences particularly harsh ones (and vice versa). An account from Gronau (1881; reproduced in van Loon and Rogers 1978) shows this tendency was observed during a dozen winters in the 1700s.

This relationship, the North Atlantic Oscillation (NAO), has been studied more closely in the last 100 years. The NAO was defined on the basis of surface pressures exhibiting a seesaw of atmospheric mass between the Atlantic and the Arctic, and an index was formed based on the difference in sea level pressure (SLP) between the Azores (or Portugal) and Iceland (Hurrell 1995). However, Thompson and Wallace (1998) used empirical orthogonal function (EOF) analysis to define a broader hemispheric phenomenon, related to the NAO, which they called the Arctic Oscillation (AO). The positive AO phase is defined to be the circumstance of lower than normal pressures over the pole and higher than normal pressures in the midlatitudes, while the negative phase is defined to be the opposite situation. The AO is also referred to as the Northern Hemisphere annular mode (NAM) to reflect its zonal symmetry, which increases with height in the atmosphere (Thompson and Wallace 2000). This paper will employ the NAM terminology.

Ciasto and Thompson (2004, hereafter CT) present evidence that variability in sea surface temperature (SST) in the Gulf Stream Extension region of the North Atlantic precedes the NAM's signature of atmospheric anomalies. CT found that conditions reflecting the positive phase of the NAM (lower atmospheric pressures in the Arctic, higher pressures over the North Atlantic and North Pacific , and a strengthening of the westerlies around 55° N) appeared to follow two weeks after lower than normal SST anomalies in the Gulf Stream Extension near Grand Banks.

The CT findings merit further study for a few reasons. First, conventional wisdom holds that midlatitude SST anomalies are forced by atmospheric variability and not the other way around. Secondly, the correlation is an empirical finding not accompanied by a well-understood physical mechanism. Thirdly, CT suggest that large-scale climate variability in the Northern Hemisphere may be caused by surprisingly small (around 0.25° C) intraseasonal SST changes in a relatively small region. One possible explanation for the suggested effect of these small SST anomalies on hemispheric atmospheric variability is that actual SST fluctuations in the Gulf Stream region are under-represented in the data used by CT. The goal of this research project is to investigate the findings by recreating some of their analysis using new higher-resolution SST fields.

This paper is composed of five sections. Section 2 describes the SLP data used in this project and the process used to derive a NAM index. Section 3 describes the SST datasets used in this project and discusses the regression maps formed by regressing intraseasonal SST anomalies onto the NAM index at various lags. In the final phase of this project, time series were formed by projecting intraseasonal SST anomalies onto these regression maps, and Section 4 details the results of lagged correlations of these time series with the NAM index. Section 5 summarizes the outcome of this project in comparison to CT's results.

2. NAM Index

This project uses daily 2.5° NCEP-NCAR Reanalysis SLP data for the years 1981-2006 (Kistler et al. 2001). SLP anomalies were formed by removing the annual plus semi-annual seasonal cycle derived from regression onto sine and cosine functions. Year-round monthly mean Northern Hemisphere (poleward of 20° N) SLP anomalies were weighted by the square root of the cosine of latitude so that equal areas were given equal weight, and EOF analysis of the unstandardized covariance matrix was performed to determine the leading modes of the variance. The first EOF (Fig. 1) was found to account for 17.9% of the variability over the time period 1981-2006. This is somewhat lower than the 20% reported by Thompson and Wallace (2000, their table 2) for the longer time period 1958-1997. Thompson and Wallace (2000, their Fig. 1d) depict a map of year-round monthly anomaly SLP (expressed as 1000-hPa geopotential height using the relationship, $Z_{1000} = 8(\text{SLP} - 1000\text{ hPa})$) regressed onto the time series of the first EOF. The same procedure was performed to produce the highly similar regression map in Fig. 2.

Weekly mean SLP anomalies were formed for the winters 1985-2006. The selected years match the overlapping time period for which data are available from both SST datasets described in Section 3, and identical weekly averaging periods were also used. Winter is defined here as the 23 weeks beginning with the first week in November through the end of March. A standardized weekly wintertime NAM index is formed by projecting these SLP anomalies onto the spatial pattern of Fig. 1 and then dividing the resulting time series by its own standard deviation. CT created a similar weekly winter time series by averaging daily values of a NAM index described by Thompson and Wallace (2001), which was formed from 40 years of 2.5° SLP data from 1958 to 1997.

3. Lagged Regression Maps

The two SST datasets used in this project are the weekly 1° Reynolds SST analyses data (Reynolds et al. 2001) that were used by CT and newer daily 0.25° SST reanalyses data (Reynolds et al. 2007) (hereafter old SST and new SST respectively). This project uses 1985-2006 data from each dataset to form weekly 1° SST averages centered on Sundays through 1989 and Wednesdays thereafter. The change in center dates was dictated by the center dates of the old SST. Northern Hemisphere intraseasonal winter SST anomalies (old SST_{is} and new SST_{is}) were formed following methods similar to those of CT. The annual plus semi-annual seasonal cycle was removed at each grid point and then each winter's mean over the time period November-March was removed from the weeks of that winter.

Fig. 3 shows old SST_{is} regressed onto the NAM index at lags of 0, ±2 and ±4 weeks. At zero and positive lags, the regression maps (Fig. 3c,d,e) show a tripole pattern of intraseasonal SST anomalies that are lower than normal south of Greenland, higher than normal to the east of the United States, and lower than normal off the western coast of Africa. At negative lags (Fig. 3a,b) a simpler structure emerges that is dominated by an area of lower than normal SST anomalies off the coast of eastern Canada in the Gulf Stream Extension.

Though quite similar in overall structure to CT's regression maps (their Fig. 1), a significant difference in amplitude can be seen in the regression maps where SST leads the NAM index (negative lags). In particular, CT's pattern at -2 weeks lag is a prominent structure of amplitude -0.25° C, while the corresponding pattern in Fig. 3b shows a weaker structure of amplitude -0.05° C. Additionally, at zero and positive lags (SST lags the NAM index) the lower-than-normal SST structure seen in CT off the west coast of Africa is less evident.

Regressions of new SST_{is} onto the NAM index at the same lags (Fig. 4) show generally good agreement with old SST_{is}. The increase in smaller scale structures as compared to Fig. 3 reflect the enhanced resolution (and possibly additional noise) of the newer dataset. In particular, the pattern emerging from regressing new SST_{is} onto the NAM index at a lag of -2 weeks (Fig. 4b) shows somewhat greater similarity to CT's corresponding pattern in both overall structure and amplitude.

Using both the old and new SST datasets, this project found that the pattern in weekly wintertime intraseasonal SST regressed onto the NAM index at negative lags is distinct from the tripole structure found at zero and positive lags. These finding are consistent with the results presented in CT, and, using their definitions, the patterns in Figs. 3b and 4b are hereafter referred to as G patterns and those in Figs. 3d and 4d as Tripole patterns.

4. Lagged Correlations

Weekly time series were formed by projecting old and new SST_{is} onto the Tripole and G patterns, and lagged correlations were performed between the NAM index and these time series from -6 to 6 weeks (Figs. 5 and 6). Lagged correlations between the NAM index and Tripole time series (Figs. 5 and 6 top) exhibit highest correlations when the NAM index leads by 1-3 weeks. By contrast, lagged correlations between the NAM index and G time series (Figs. 5 and 6 bottom) peak when the NAM index lags by 1-3 weeks. This result mirrors CT, with the notable exception that their correlation values were about 0.1 higher both between the NAM index and the Tripole and between the NAM index and the G time series. Switching to the newer SST dataset appears to have little effect, with each Tripole and G time series peaking at about same value and showing very similar shapes regardless of the dataset.

5. Conclusion

The results of this project do not contradict the findings of CT, which imply that small changes in SST anomalies in the North Atlantic may lead changes in the NAM by a couple of weeks. However, though able to reproduce the general structure of CT's regression maps and lagged correlations, this project resulted in substantially lower amplitudes and correlation values. These dissimilarities may result from the different time span of SLP dataset used in this project, as noted above. Furthermore, while this project endeavored to closely reproduce CT's research process, differences also may arise from inevitable small variations in data processing and analysis.

Alternatively, the findings of this project may be an indication of lack of robustness of the CT results. The difference in magnitude of the SST precursor to NAM variability found in this study is especially noteworthy. Whereas CT found that SST variations with a small magnitude of 0.25° C lead the NAM variability by 2 weeks, this project resulted in an even smaller magnitude of only 0.05° C. The indication that the NAM may be responding to small SST fluctuations in the Gulf Stream Extension is not conclusive, and the concerns discussed in Section 1 remain. Use of the newer SST dataset did not reveal a higher correlation due to better resolved SST fluctuations. One is left with an interesting but small empirical correlation unaccompanied by a well-understood physical mechanism.

Acknowledgements

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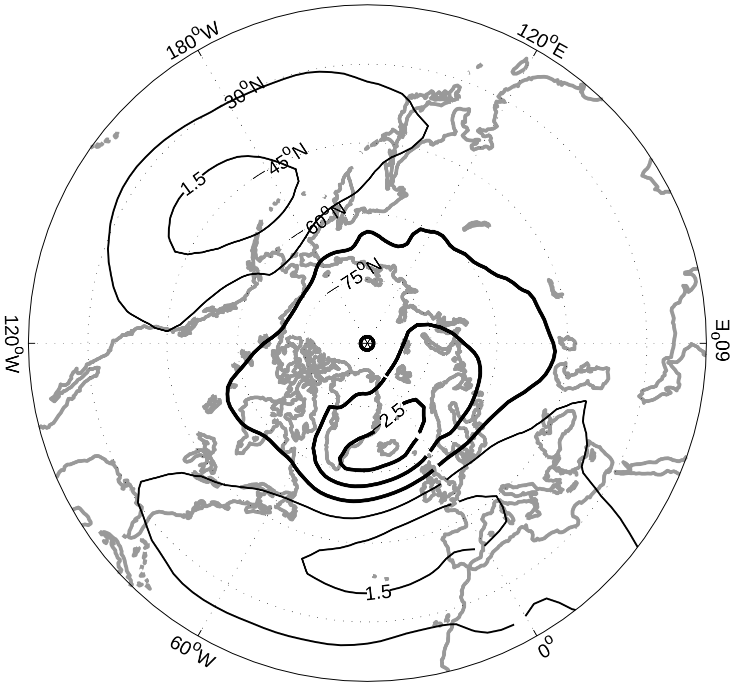


FIG. 1. Spatial pattern associated with the first EOF of Northern Hemisphere monthly year-round SLP anomalies. Positive (negative) contours are denoted by thin (thick) lines and are drawn at -0.5, 0.5, 1.5 hPa, … etc.

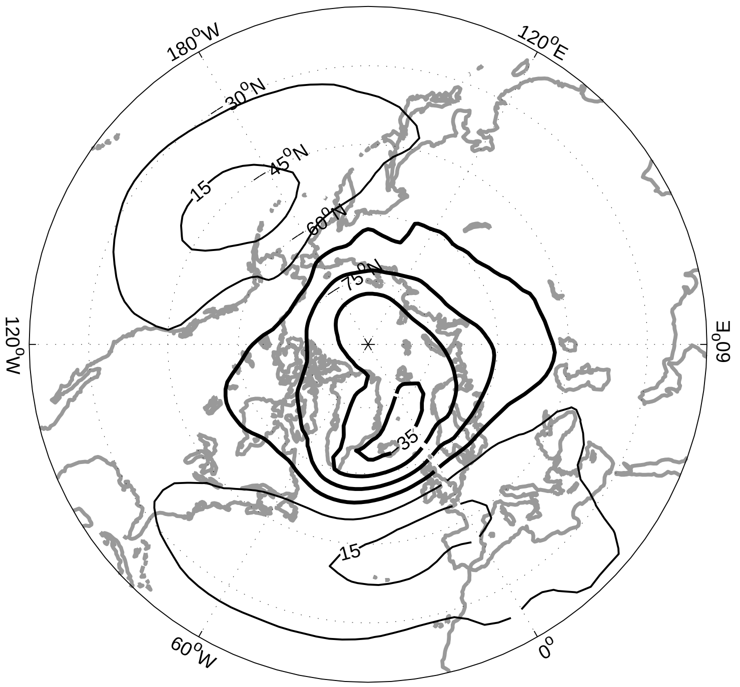
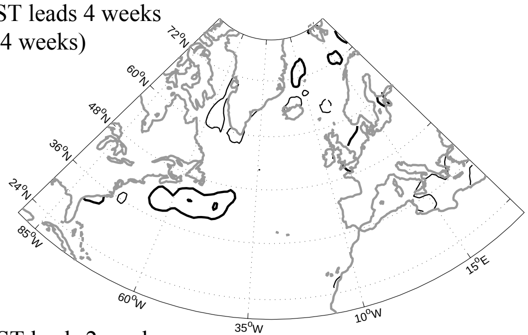
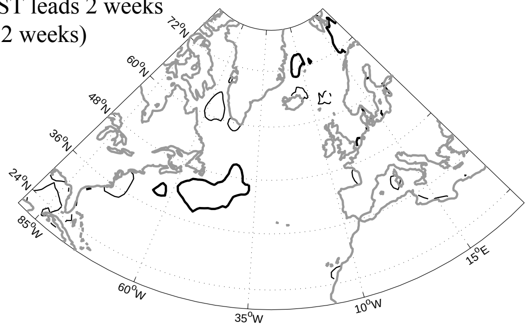


FIG. 2. Year-round monthly Northern Hemisphere SLP anomalies expressed as geopotential heights and regressed onto their standardized leading EOF time series. Positive (negative) contours are denoted by thin (thick) lines and are drawn at -15, -5, 5 m, … etc.

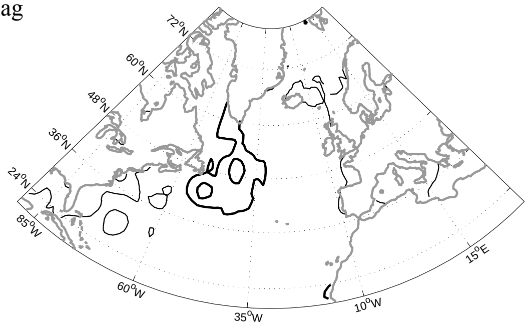
(a) SST leads 4 weeks
(-4 weeks)



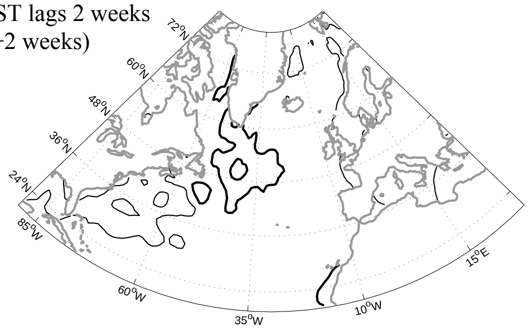
(b) SST leads 2 weeks
(-2 weeks)



(c) 0 lag



(d) SST lags 2 weeks
(+2 weeks)



(e) SST lags 4 weeks
(+4 weeks)

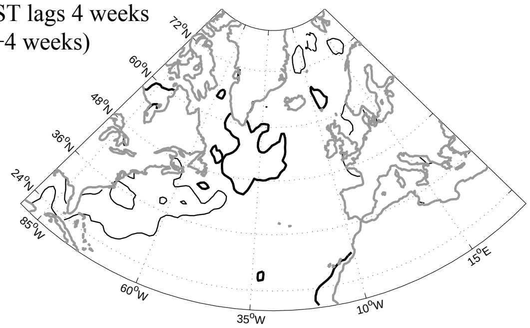
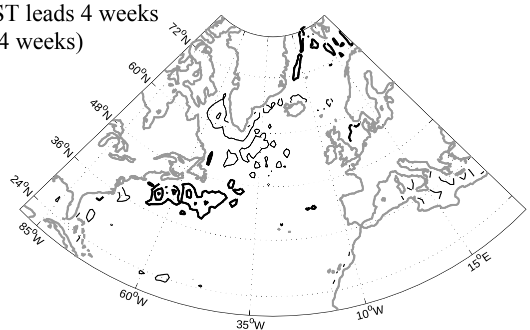
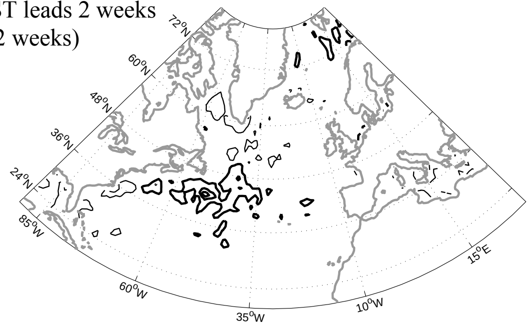


FIG. 3. Weekly winter intraseasonal **old** SST anomalies regressed onto the NAM index at various lags. Positive (negative) contours are denoted by thin (thick) lines and are drawn at -0.05, -0.05, 0.15° C, … etc.

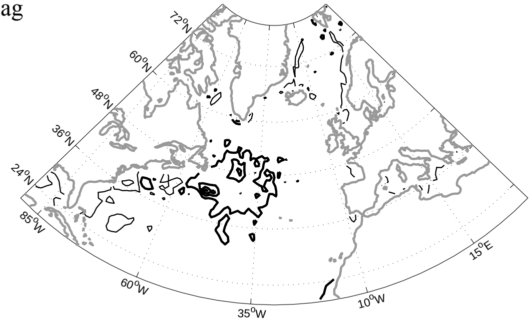
(a) SST leads 4 weeks
(-4 weeks)



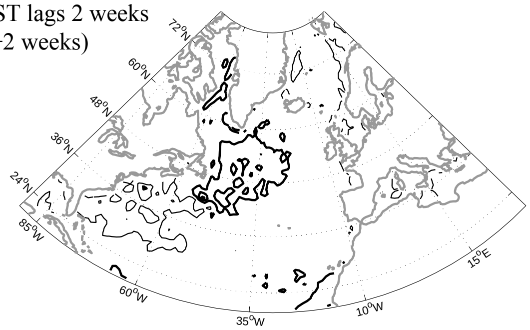
(b) SST leads 2 weeks
(-2 weeks)



(c) 0 lag



(d) SST lags 2 weeks
(+2 weeks)



(e) SST lags 4 weeks
(+4 weeks)

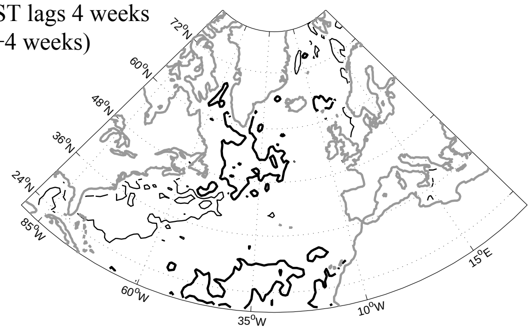


FIG. 4. Weekly winter intraseasonal **new** SST anomalies regressed onto the NAM index at various lags. Positive (negative) contours are denoted by thin (thick) lines and are drawn at -0.05, -0.05, 0.15° C, … etc.

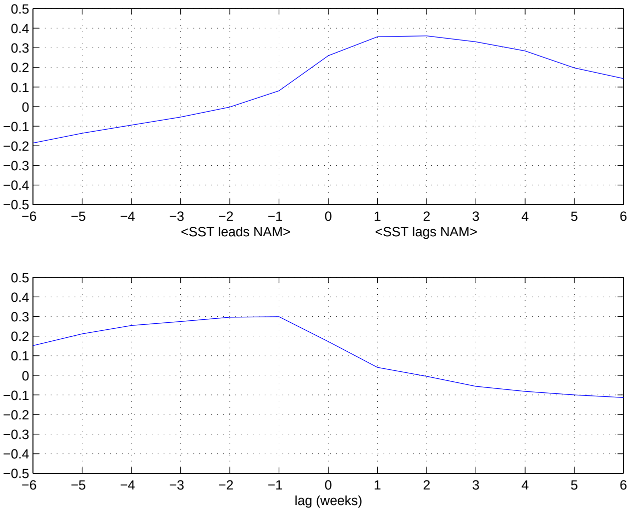


FIG. 5. Lagged correlations between the NAM index and the time series formed by projecting weekly winter intraseasonal **old** SST anomalies onto the patterns in Fig. 3d, the Tripole (top) and 3b, G (bottom).

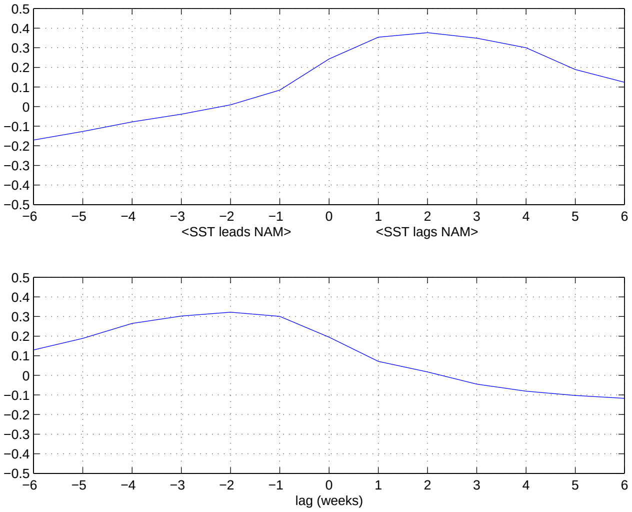


FIG. 6. Lagged correlation between the NAM index and the time series formed by projecting weekly winter intraseasonal **new** SST anomalies onto the patterns in Fig. 3d, the Tripole (top) and 3b, G (bottom).