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THE INFLUENCE OF CLIMATE TELECONNECTIONS ON WINTER TEMPERATURES IN WESTERN NEW YORK

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ABSTRACT: *Teleconnections are recurring and persistent large-scale patterns of pressure and circulation anomalies that span vast geographical areas. A growing body of evidence suggests that teleconnections influence medium-term temperatures in regions well removed from their place of origin. The objective of the research presented in this article is to identify and quantify the impacts of two large-scale teleconnections - North Atlantic Oscillation (NAO) and El Niño Southern Oscillation (ENSO) - on winter temperature patterns in Western New York (WNY). The NAO and ENSO phases were quantified using the NAO Index and Multivariate ENSO index (MEI), along with monthly temperature values for Buffalo, NY (1950 to 2012), obtained from the Buffalo Forecast Office of the National Weather Service. In WNY, the NAO teleconnection exhibits a stronger impact on winter temperatures than ENSO; the NAO phase exerts its strongest influence on WNY temperatures early in the winter season (up to 4.60°F for November/ December), and under reinforcing conditions, the pairing of NAO and ENSO phases appeared to have a stronger influence on temperatures than either as a singular influence (6.15°F for November/December and 6.42°F for December/January).*

Keywords: *NAO, ENSO, Western New York, Winter Temperatures*

INTRODUCTION

Weather, by definition, refers to atmospheric conditions at a location over a short period of time, and is characterized by a number of atmospheric elements - temperature, atmospheric pressure, humidity, wind and precipitation, to mention a few. The climate of a region is a measure of the aggregate weather over an extended period of time. In turn, climate is partially controlled by latitude, terrain, altitude, and geographic situation (continental or marine) – as an example of what are collectively called 'climate controls'. Given its mid-continent position, Western New York (WNY) experiences a continental-type climate, but as the region is sandwiched between the shores of Lakes Erie and Ontario, there is a maritime influence (Figure1). This 'lake effect' is a contributor to the geographic variability of climate within this region; although Vermette and Orengo (2006) demonstrated that the lake effect is less pronounced in the data record with the move of the Buffalo Weather Office in 1943 from its original downtown location to its current airport location.

A growing body of evidence suggests that teleconnections influence medium-term weather patterns in regions well removed from their place of origin (Hurrell, 1995). Teleconnections are "recurring and persistent large-scale patterns of pressure and circulation anomalies that span vast geographical areas" (CPC, 2008). These naturally occurring teleconnections arise from the internal dynamics of the atmosphere and act as an additional climate control. In their development of a seasonal probability forecast model for WNY, Vermette and Bittner (2010) explored the continuity of seasonal memory, and referred to teleconnections as a possible mechanism to account for this continuity. Hurrell and Van Loon (1997) noted that the study of local climate trends needs to identify the influence of teleconnections.

As part of a larger study examining local climate trends in WNY, the objective of the research presented in this article is to identify and quantify the impacts of two large-scale teleconnections - the North Atlantic Oscillation (NAO) and the El Niño Southern Oscillation (ENSO) - on winter temperature patterns in WNY. As prior research suggests that the North American influence of the NAO and ENSO is thought most pronounced during the winter months, the impact of these teleconnections on WNY's winter months is the main focus of this study.

The two teleconnections of interest to this study (NAO and ENSO) have been shown to impact weather patterns around the world and within the United States (Diaz and Markgraf, 2000; Glantz et al., 2009). The NAO, the first teleconnection considered in this study is measured at two pressure centers located over the Northern Atlantic. A low pressure system is typically located over Iceland, and a high pressure system is typically located over the Azores in the eastern Atlantic Ocean. Periodically, the Icelandic low and the Azores high will strengthen (positive phase NAO or +NAO) resulting in an increased pressure gradient between the two centers. This enhanced difference in pressure strengthens the jet stream, reinforcing zonal flow across eastern North America, while the rotating winds around the Azores high push warm air northward from the tropical Atlantic and Caribbean up along the U.S. East Coast (Weier, 2003). During this positive phase NAO, the Eastern U.S. will typically experience warmer than average temperatures during the winter season (Hurrell, 1995; Weier, 2003; CPC, 2012a).

Figure 1. Location of New York, Western New York (WNY), and the Buffalo, NY Weather Office.

A negative phase NAO (or -NAO) indicates a weakening of both the low pressure center over Iceland and the high pressure over the Azores, resulting in a decreased pressure gradient between these two centers. The lower pressure gradient weakens the westerlies, promotes greater amplitude or meridional flow of the jet stream, which in turn allows cold air to build up over Canada and to migrate south into the eastern United States. Below average temperatures are typical during winter when the NAO is negative (Hurrell, 1995; Weier, 2003).

The second teleconnection considered in this study is the El Niño Southern Oscillation (ENSO). The ENSO pattern involves a fluctuation in sea surface temperatures (SST's) and atmospheric pressures in the equatorial Pacific. These fluctuations have been shown to cause variations in regional weather patterns extent beyond the Pacific Ocean. The two extreme phases of ENSO are termed 'El Niño' and 'La Niña' (CPC, 2012b; CPC, 2012c).

The El Niño phase occurs in conjunction with the warming of the SST's of the central and eastern equatorial Pacific, as well as is an oscillation in pressure across the Pacific (increasing in the west Pacific and decreasing in the east Pacific). The increased ocean temperatures typically seen during the El Niño phase enhance convection in the Northern Hemisphere. This phase typically has four changes in atmospheric flow. The first change is an eastward shift of the East Asian jet stream; the second is a more west-to-east flow of the jet stream winds across the United States; the third is a southward shift of the storm tracks from the Northern U.S. to the Southern U.S.; and the fourth is a southward and eastward shift in the main cyclone forming region. These effects result in a cooler than normal winter across the south and a warmer than normal winter across the northern plain states (CPC, 2005).

The La Niña phase is essentially the opposite that of El Niño. The SST's of the central and eastern equatorial Pacific are cooler than normal. There are three changes to atmospheric flow during this phase. The first change is the amplification of the jet stream, resulting in increased meridional flow across the United States; the second is increased blocking activity over the high latitudes of the Northern Pacific that leads to the third change as seen in the highly variable strength of the jet stream over the eastern North Pacific. These changes position the jet stream to enter the

United States further north than usual, resulting in colder air outbreaks than normal to the Northern states. In the Southern states, temperatures are typically warmer than normal (CPC, 2005).

An unpublished presentation by Hamilton (2004) showed that the occurrence of above normal temperatures in WNY can be related to both El Niño and La Niña episodes, with the warming most pronounced during strong ENSO phases. With regard to NAO, Hamilton (2004) noted only very weak month to month temperature correlations, strengthened only slightly for significant events. Correlations improving from 'weak' to 'moderate' suggest that specific phases of NAO and ENSO occurring in concert created more dramatic and conclusive temperature anomalies in WNY. For example, the effects of ENSO (both El Niño and La Niña) combined with a +NAO raised temperatures 2.3ºF above normal, as compared to 1.4ºF and 0.94ºF, respectively for El Niño and La Niña alone.

METHODS

The NAO and ENSO phases were quantified using the NAO Index (NCDC 2014) and Multivariate ENSO index (MEI) (ESRL, 2014). Both indices are available in a bimonthly (two-month) format beginning with 1950, thereby determining the timeline of this study. Both indices are based on a sliding numeric scale ranging between positive and negative values; the further the value from zero, the stronger the teleconnection. In the case of the NAO and ENSO, a strong positive value indicates a positive phase NAO (+NAO) and an El Niño event respectively, whereas a strong negative value indicates a negative phase NAO (-NAO) and a La Niña event, respectively. This study assigned an arbitrary index value of 1.0 or higher as a positive phase NAO (+NAO) and El Niño and -1.0 and lower as a negative phase NAO (-NAO) or La Niña. Intermediate values were considered neutral.

Monthly temperature values for Buffalo, NY (1950 to 2012), obtained from the Buffalo Forecast Office of the National Weather Service (NWS, 2014), were paired with NAO and ENSO events. An Excel spreadsheet was used to collate, sort and graph data, and to perform statistical analyses.

Correlation analyses were performed using bi-monthly (November/December, December/January, January/February, and February/March) temperature and teleconnection indices from 1950 to 2012. The data were plotted as a scatter plot and a linear regression was applied to the data. Comparison of temperature and teleconnection indices for positive, neutral, and negative NAO events, as well as for positive (El Niño), neutral, and negative (La Niña) ENSO events was made for the bi-monthly combinations, and displayed as box-and-whisker plots (mean, 25th and 75th percentiles, and data range). A Student's t-Test was employed to evaluate whether the mean monthly temperature differences linked to specific NAO or ENSO events were statistically significant ($p \leq 0.05$).

A second round of comparisons and t-tests was conducted with temperature data paired with various NAO and ENSO combinations (e.g. temperatures linked to a positive NAO and strong ENSO vs. temperatures linked to negative NAO and a weak ENSO). These combinations resulted in a smaller N value, typically under 10 pairings. As with the previous comparisons, the pairings were plotted as box-and whisker plots, and statistically evaluated using a Student's t-Test ($p \leq 0.05$).

RESULTS AND DISCUSSION

NAO

NAO/temperature scatter plots exhibit a trend of cooling temperatures associated with –NAO events and warmer temperatures associated with +NAO events, however, the correlations ranged from weak to insignificant. The strongest correlation (R^2 = 0.236) occurred in November / December (Figure 2). As the winter progressed, the correlation weakened and the slope flattened out. It should be noted that bi-monthly dominant phases of the NAO are difficult to quantify, as the positive and negative phases of the NAO occur in short time periods (varying from week to week) than our bi-monthly time frame and this likely accounts for the weak correlations.

Temperatures associated with a strong +NAO, as compared to a strong -NAO are shown in Figures 3 - 6. A statistically significant positive difference, with temperature differences ranging between 2.91ºF and 4.60ºF for the period November through February (Table 1). The temperature difference was greatest (4.60ºF) for November/December (Figure 3) and dropped to 0.49ºF (not significant) for February/March (Figure 6). When compared to a neutral condition for November/December, a significant temperature difference of 2.17ºF (warming) is exhibited when compared to a strong +NAO, and a significant temperature difference of -2.42ºF (cooling) is exhibited when compared to a strong -NAO. The remaining monthly pairs show no significant difference in temperatures (Table 1). The short time frame of the NAO phases may in relation to the bi-monthly data also account for the otherwise insignificant statistical findings reported for later in the winter season. Notwithstanding this timing, Buffalo's winter temperatures are clearly influenced by the phase of the NAO. A strong +NAO brings warmer than normal temperatures, while a strong -NAO brings colder than normal temperatures. It appears that the impact of a strong NAO (+ or -) on WNY's temperatures is best manifested at the onset of winter, as the impact of the NAO on temperatures appears to lessen as the winter season progresses.

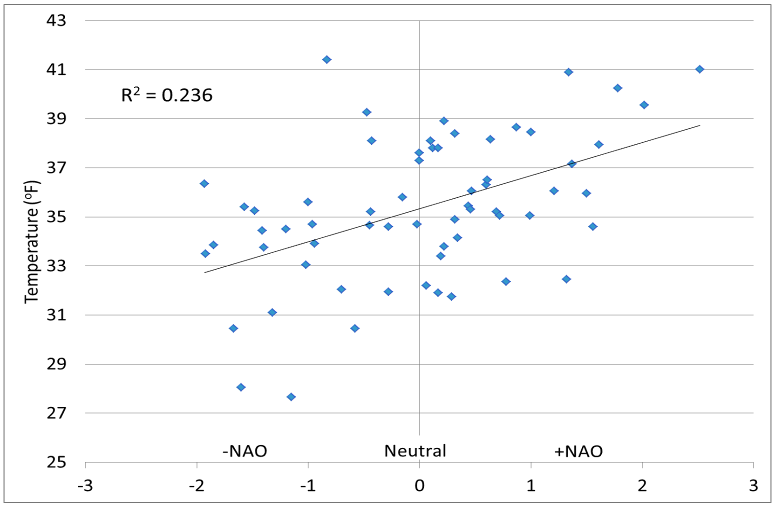

Figure 2. November/December mean temperatures associated with NAO phases.

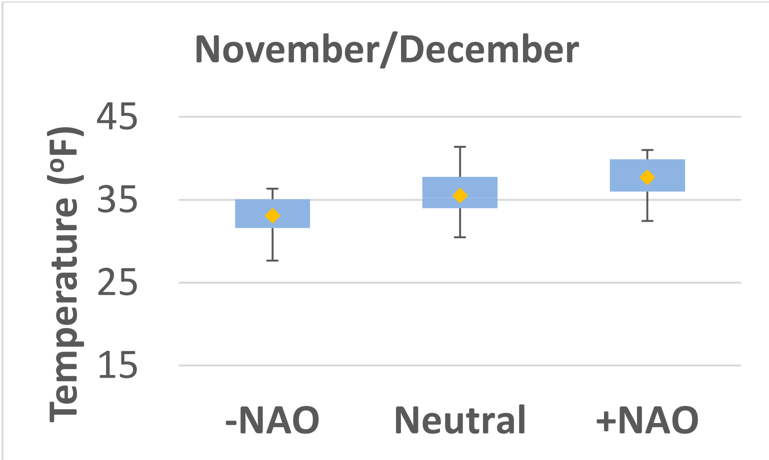

Figure 3. November/December mean temperatures associated with NAO phases.

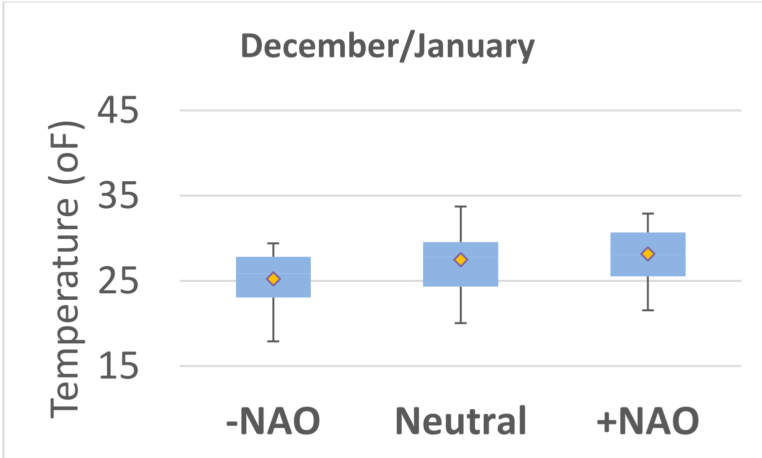

Figure 4. December/January mean temperatures associated with NAO phases.

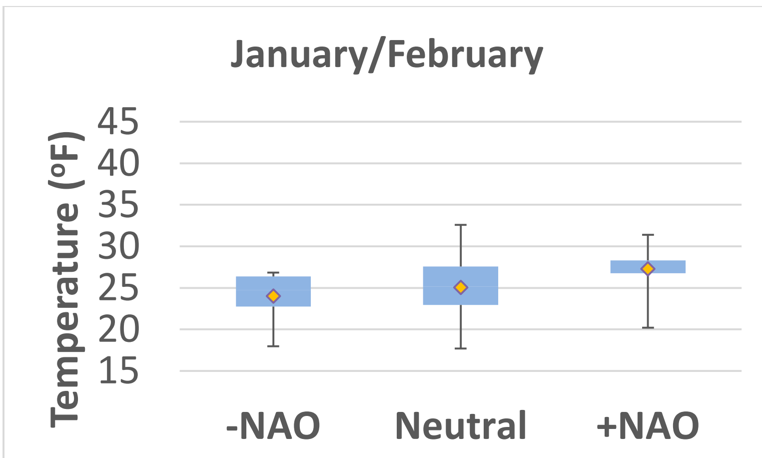

Figure 5. January/February mean temperatures associated with NAO phases.

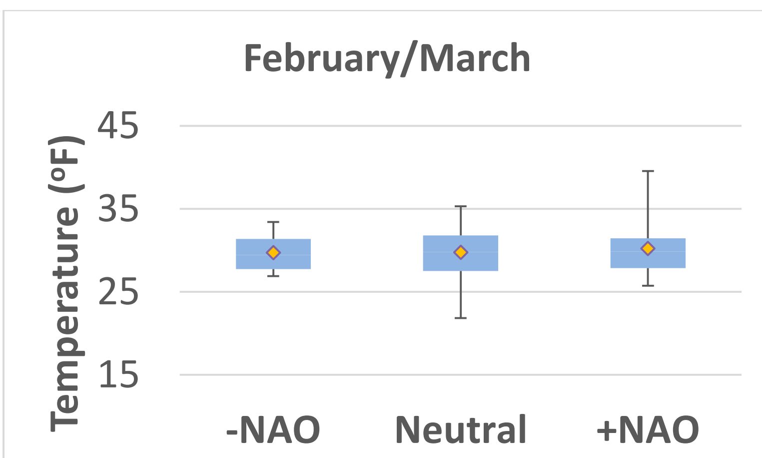

Figure 6. January/February mean temperatures associated with NAO phases.

Table 1. Temperature differences associated with NAO phases.

Teleconnection NAO	**Nov/Dec ∆Temp (°F)**	**Dec/Jan ∆Temp (°F)**	**Jan/Feb ∆Temp (°F)**	**Feb/Mar ∆Temp (°F)**
+NAO vs -NAO	4.60*	2.91*	3.28*	0.49
+NAO vs Neutral	2.17*	0.66	2.23	0.43
-NAO vs Neutral	-2.42*	-2.25	-1.05	-0.06

*$p \leq 0.05$

ENSO

ENSO/temperature scatter plots do not exhibit a significant trend or correlation. The strongest trend and correlation appears for November/December (R^2 = 0.0154), flattening and weakening through the winter (Table 2). While ENSO events (El Niño, neutral, or La Niña) do appear to exhibit a positive increase in WNY temperatures (temperature differences ranging from 0.20ºF to 2.48ºF), as might be expected from the general literature. This increase in winter temperatures is not statistically significant. This lack of correlation and insignificant statistical findings are all the more telling, as ENSO events, unlike the NAO phases, persist for months and should easily be captured within a bi-monthly time frame.

Table 2. Temperature differences associated with ENSO phases.

Teleconnection ENSO	**Nov/Dec ∆Temp (°F)**	**Dec/Jan ∆Temp (°F)**	**Jan/Feb ∆Temp (°F)**	**Feb/Mar ∆Temp (°F)**
El Nino vs La Nina	1.10	1.72	0.04	0.94
El Nino vs Neutral	1.87	2.48	1.21	1.14
La Nina vs Neutral	0.77	0.75	1.17	0.20

*$p \leq 0.05$

NAO and ENSO COMBINATION

While not statistically significant, El Niño and La Niña events do exhibit a positive temperature increase in WNY, as compared to neutral ENSO conditions. Given that NAO or ENSO events manifest themselves independent of one another, the impact on temperature of combined teleconnections was examined. Under reinforcing conditions: a strong +NAO combined with a strong ENSO (expected to bring warming) vs a strong -NAO combined with a neutral ENSO (expected to bring cooling), the temperature difference in WNY is statistically significant (Table 3) in the early winter. The combined effect on WNY's temperatures – temperature differences between 6.15ºF (November/December) and 6.42ºF (December/January) – appears greater than the impact of +NAO vs -NAO events alone (4.56ºF and 2.91ºF, respectively). In other words, reinforcing ENSO events augment the NAO temperature effect. And as with NAO, the combined NAO/ENSO influence on WNY's winter temperatures is best manifested at the onset of the winter season.

Table 3. Temperature differences associated with combined NAO and ENSO phases.

Teleconnection NAO and ENSO	**Nov/Dec ∆Temp (°F)**	**Dec/Jan ∆Temp (°F)**	**Jan/Feb ∆Temp (°F)**	**Feb/Mar ∆Temp (°F)**
+NAO and Strong ENSO vs -NAO and Neutral ENSO	6.15*	6.42*	3.01	-3.2

*$p \leq 0.05$

CONCLUSION

The objective of this study was to identify and quantify the impacts of two large-scale teleconnections (NAO and ENSO) on the winter temperatures of WNY. Winter months, especially early winter (November/December), exhibited significant warming and cooling temperature impacts for both positive and negative NAO phases, ranging from 4.56ºF (+NAO vs -NAO), to 2.17ºF (+NAO vs neutral), to -2.42ºF (-NAO vs neutral). The temperature differences for the months of December/January and January/February were significant only for the +NAO/-NAO comparisons. ENSO events exhibited a warming influence over neutral conditions, but the temperature differences associated with ENSO phases were found not found to be statistically significant. However, under reinforcing conditions, the pairing of NAO and ENSO phases – a strong +NAO combined with a strong ENSO (expected to bring warming) vs a strong -NAO combined with a neutral ENSO (expected to bring cooling) – appeared to have a more significant influence on temperatures, with temperatures differences between phases of warming and cooling of between 6.15ºF and 6.42ºF for November/December and December/January, respectively. As with NAO alone, the paired influences (NAO and ENSO) on temperature lessened later in the winter season, and were not statistically significant.

This research agrees with the early work of Hamilton (2004) with regard to the combined NAO/ENSO effect, but deviates from his work by suggesting that the NAO teleconnection exhibits a stronger impact on winter temperatures than does ENSO events; and that the NAO phase exerts its strongest influence on WNY temperatures early in the winter season.

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