AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2016GL069102

Key Points:
- ENSO influence is confined to the North Pacific sector outside of the tropics, while Arctic influence is symmetrical
- In the era of Arctic amplification, Arctic influence on trends in midlatitude circulation and temperatures has exceeded that of ENSO
- In the era of Arctic amplification, temperature variability has increased in the midlatitudes and not decreased as previously argued

Correspondence to:
J. Cohen,
jcohen@aer.com

Citation:
Cohen, J. (2016), An observational analysis: Tropical relative to Arctic influence on midlatitude weather in the era of Arctic amplification, *Geophys. Res. Lett.*, *43*, 5287–5294, doi:10.1002/2016GL069102.

Received 11 APR 2016
Accepted 29 APR 2016
Accepted article online 2 MAY 2016
Published online 17 MAY 2016

An observational analysis: Tropical relative to Arctic influence on midlatitude weather in the era of Arctic amplification

Judah Cohen[1]

[1]Atmospheric and Environmental Research, Inc., Lexington, Massachusetts, USA

Abstract The tropics, in general, and El Niño/Southern Oscillation (ENSO) in particular are almost exclusively relied upon for seasonal forecasting. Much less considered and certainly more controversial is the idea that Arctic variability is influencing midlatitude weather. However, since the late 1980s and early 1990s, the Arctic has undergone the most rapid warming observed globally, referred to as Arctic amplification (AA), which has coincided with an observed increase in extreme weather. Analysis of observed trends in hemispheric circulation over the period of AA more closely resembles variability associated with Arctic boundary forcings than with tropical forcing. Furthermore, analysis of intraseasonal temperature variability shows that the cooling in midlatitude winter temperatures has been accompanied by an increase in temperature variability and not a decrease, popularly referred to as “weather whiplash.”

1. Introduction

The influence of El Niño/Southern Oscillation (ENSO) on global weather patterns is currently the cornerstone of seasonal forecasting [*Barnston et al.*, 2012; *Hoskins*, 2013; *Scaife et al.*, 2014]. In addition, the Madden-Julian Oscillation (MJO) has been shown to influence midlatitude weather [*L'Heureux and Higgins*, 2008; *Johnson et al.*, 2014]. ENSO coupled with the Madden-Julian Oscillation (MJO) establishes the tropics as the most important remote driver on midlatitude weather considered by climate scientists [*Seager et al.*, 2015]. Only recently has the idea been proposed that the Arctic may influence midlatitude weather in a significant and detectable way, but this idea is considered much more controversial [*Kintisch*, 2014]. It has been proposed that Arctic amplification (AA), including melting Arctic sea ice [*Honda et al.*, 2009; *Kim et al.*, 2014; *Mori et al.*, 2014] and/or increasing Eurasian snow cover [*Cohen et al.*, 2013, 2014], is contributing to more extreme weather in winter [*Francis and Vavrus*, 2012; *Cohen et al.*, 2014; *Overland et al.*, 2015] and even possibly in summer [*Coumou et al.*, 2015].

Climate extremes like heat waves and heavy rainfall have been observed to be increasing and are thought to be associated with human-induced global warming [*Coumou and Rahmstorf*, 2012; *Herring et al.*, 2015]. Over the period of AA, climate extremes have even included cold air outbreaks and heavy snowfalls most recently in North America and also in Eurasia over the past two decades [*Cohen et al.*, 2014; *Overland et al.*, 2015]. The streak of cold midlatitude winters has puzzled scientists [*Gramling*, 2015]. The winter cooling trend in the midlatitudes is one reason offered for the global warming hiatus over the past two decades [*Cohen et al.*, 2012a]. Despite this year's El Niño and its associated warming in tropical Pacific sea surface temperatures (SSTs), over the past two decades a cooling trend has been observed in the tropical Pacific SSTs more akin to El Niño's opposite—La Niña. Further, it has been argued that this trend toward La Niña was responsible for the global warming hiatus [*Meehl et al.*, 2011; *Kosaka and Xie*, 2013; *Xie*, 2016]. Whether the hiatus is an artifact of errors in the data or is real has recently become an active topic of debate [*Karl et al.*, 2015; *Fyfe et al.*, 2016]. However, no study disputes the boreal winter midlatitude cooling.

Scientists who focus on the Arctic rather than the tropics have proposed a relatively new idea—Arctic change is driving the winter cooling at midlatitudes [*Cohen et al.*, 2014; *Overland et al.*, 2015]. This idea has been met with much skepticism as tropical variability is considered the main forcing of midlatitude atmospheric circulation other than internal variability and any variability attributable to the Arctic cannot be measured above the noise of the climate system [*Wallace et al.*, 2014].

With the Arctic at record warm levels, the 9 years between 2007 and 2015 have exhibited the lowest minimum sea ice extents recorded in September since satellite observations began, with an all-time record low

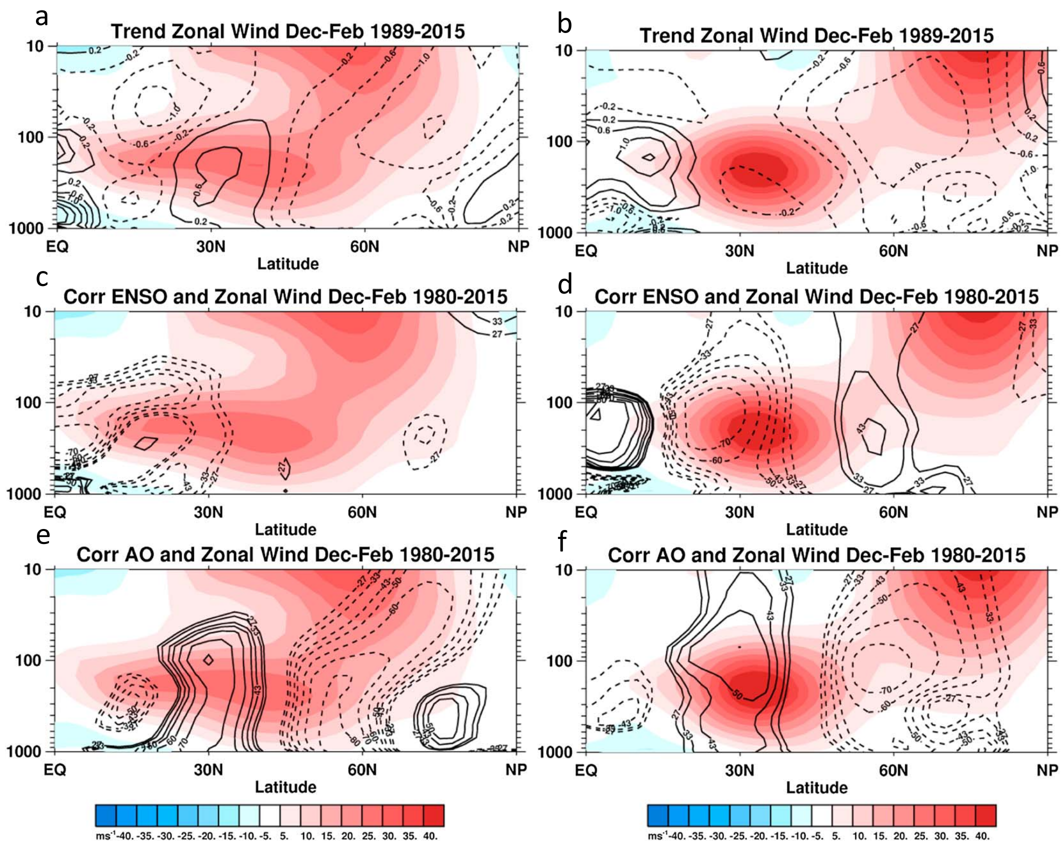

Figure 1. (a) Zonal mean zonal wind (shading) and trend in the zonal mean zonal wind (contours; m s^{-1}) over the North Atlantic sector from 1000 to 10 hPa for December, January, and February (DJF) winters 1988/1989–2014/2015. (b) Same as Figure 1a except for the North Pacific sector. (c) Correlation (×100) of ENSO index (DJF Niño 3.4 multiplied by −1) with zonal mean zonal wind (contours) and zonal mean zonal wind (shading) over the North Atlantic sector for winters 1979/1980–2014/2015. (d) Same as Figure 1c except for the North Pacific sector. (e) Correlation (×100) of AO index (DJF multiplied by −1) with zonal mean zonal wind (contours) and zonal mean zonal wind (shading) over the North Atlantic sector for winters 1979/1980–2014/2015. (f) Same as Figure 1e except for the North Pacific sector. In all correlation plots, first, second, and third contours represent 90, 95, and 99% statistical significance, respectively. Symbols in all color bars are just intended to represent the variable analyzed. Values shown are consistent with the negative phase of the AO and for La Niña to best match recent decadal trends with both climate modes.

in 2007 followed by another in 2012. Several of these seven winters following the low sea ice minima have been unusually cold across the Northern Hemisphere (NH) extratropical landmasses [*Kosaka and Xie*, 2013; *Cohen et al*., 2013, 2014]. Numerous compelling hypotheses linking changes in the Arctic to recent severe weather have been presented [*Cohen et al*., 2014; *Overland et al*., 2015]. The most highly publicized proposed theory is that a warming Arctic results in a wavier polar vortex, leading to enhanced atmospheric blocking that often spawns extreme weather events [*Francis and Vavrus*, 2012].

In contrast to declining sea ice, continental snow cover in the fall has been increasing, especially across Eurasia [*Cohen et al*., 2012b]. It has been shown that above normal snow cover across Eurasia in the fall leads to a negative Arctic Oscillation (AO) and cold temperatures across the eastern United States and northern Eurasia in winter [*Cohen and Entekhabi*, 1999; *Allen and Zender*, 2010]. Therefore, it has been argued that a significant portion of the wintertime temperature trend is driven by dynamical interactions between October Eurasian snow cover and the large-scale NH extratropical circulation in the late fall and winter. So while the Arctic continues to warm, NH continental winters have recently grown more extreme across the major industrialized centers.

2. Data and Methods

For Figures 1–4 I used the daily fields from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis [*Kalnay et al*., 1996] to compute seasonal means for the

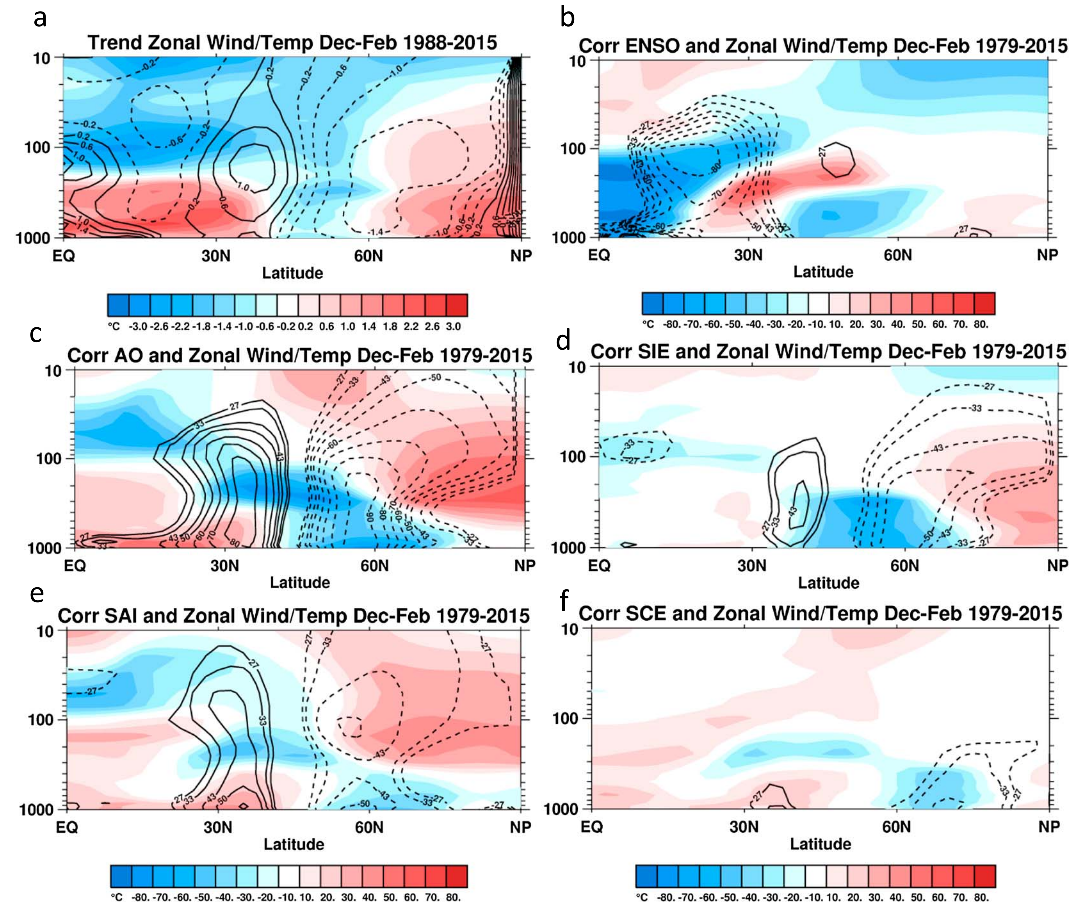

Figure 2. (a) Trend in the zonal mean zonal wind (contours; m s^{-1}) and zonal mean air temperature (shading; °C) from 1000 to 10 hPa for December, January, and February (DJF) winters 1988/1989–2014/2015. (b) Correlation (×100) of ENSO index (DJF Niño 3.4 DJF multiplied by −1) with zonal mean zonal wind (contours) and zonal mean air temperature (shading) for winters 1979/1980–2014/2015. (c) Correlation (×100) of AO index with zonal mean zonal wind (contours) and zonal mean air temperature (shading) for winters 1979/1980–2014/2015. (d) Correlation (×100) of November sea ice concentration index (multiplied by −1) in the Barents-Kara Seas with zonal mean zonal wind (contours) and zonal mean air temperature (shading) for winters 1979/1980–2014/2015. (e) Correlation (×100) of October snow advance index for Eurasia with zonal mean zonal wind (contours) and zonal mean air temperature (shading) for winters 1979/1980–2014/2015. (f) Correlation (×100) of October snow cover extent for Eurasia with zonal mean zonal wind (contours) and zonal mean air temperature (shading) for winters 1979/1980–2014/2015. Wind averaged over all longitudes but temperature averaged over longitudes from 0 to 130°E and 75 to 120°W.

period December 1979 to February 2015. These data were averaged around circles of latitude. Standard seasonal means were computed and used. I estimated trends using least squares linear regression. The linear trends are calculated based on December, January, and February (DJF) values during the period 1988/1989–2014/2015. This period has been used in previous related studies [*Cohen et al.*, 2012a, 2012b] and matches the full period of AA [*Cohen et al.*, 2014]. Using different start years did not significantly change the results. For correlations, I detrended all the original time series by subtracting the long-term trend, which focuses more on the year-to-year variability. However, there may be other sources of long-term variability that is not removed by simply removing the linear trend. From this detrended signal, seasonal normalized standard deviations are calculated using the 1979–2014 period. The statistical significances of the correlations were calculated from a two-tailed Student's *t* test. The 90, 95, and 99% significance are represented by first, second, and third contours in all correlation plots.

The ENSO index used is the DJF Niño 3.4 index downloaded from the NOAA Climate Prediction Center (CPC) website ftp.cpc.ncep.noaa.gov. The AO index was also downloaded from NOAA CPC website http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index. The sea ice extent is the November anomaly in

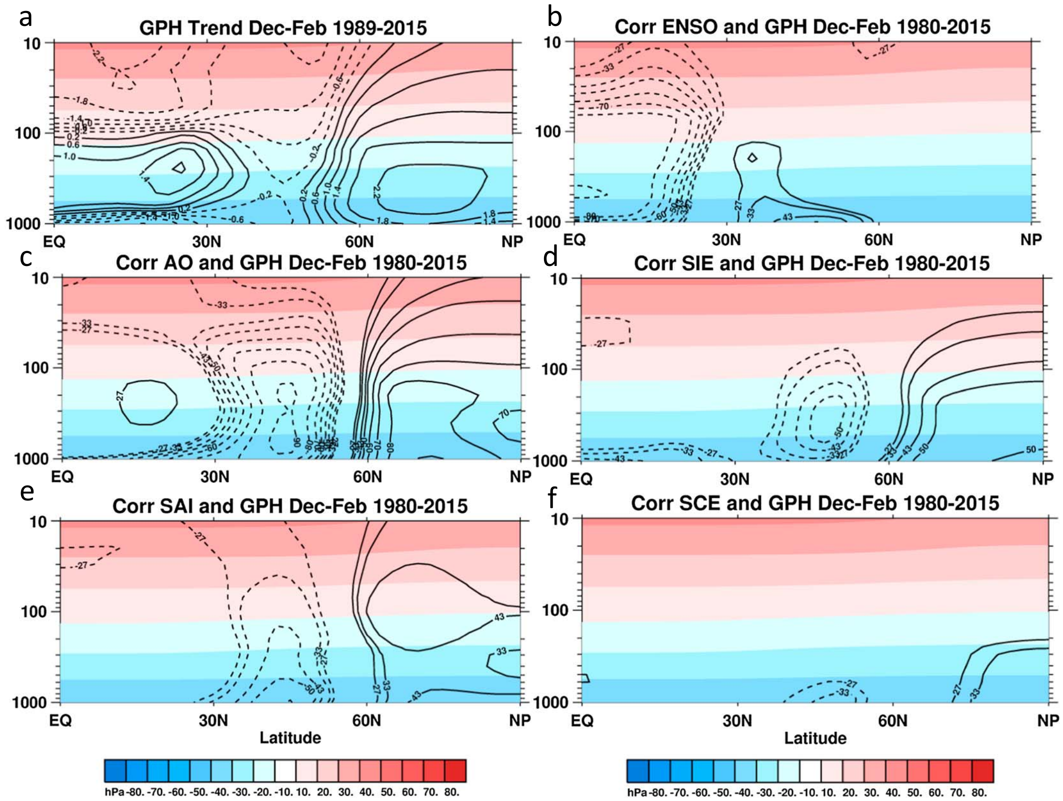

Figure 3. (a) Zonal mean geopotential height climatology (shading) and trend (contours; m s^{-1}) from 1000 to 10 hPa for December, January, and February (DJF) winters 1988/1989–2014/2015. (b) Correlation (×100) of ENSO index (DJF Niño 3.4 multiplied by −1) with zonal mean geopotential height (contours) for winters 1979/1980–2014/2015. (c) Correlation (×100) of AO index (DJF multiplied by −1) with zonal mean geopotential height (contours) for winters 1979/1980–2014/2015. (d) Correlation (×100) of November sea ice concentration index in the Barents-Kara Seas (multiplied by −1) with zonal mean geopotential height (contours) for winters 1979/1980–2014/2015. (e) Correlation (×100) of October snow advance index for Eurasia with zonal mean geopotential height (contours) for winters 1979/1980–2014/2015. (f) Correlation (×100) of October snow cover extent for Eurasia with zonal mean geopotential height (contours) for winters 1979/1980–2014/2015. Shading in all panels represent climatology of zonal mean geopotential height.

Barents-Kara sea ice concentration computed from the Met Office Hadley Centre's sea ice and sea surface temperature (SST) data set, HadISST [*Rayner et al.*, 2003]. I defined the Barents-Kara se ice region bounded by 65–80°N and 10–100°E. Two snow cover indices are used. The first is the October Snow Advance Index (SAI). The SAI is computed at all longitudes across Eurasia but only for latitudes ≤60°N. I used a merged weekly and daily October SAI as described in *Cohen and Jones* [2011]. The second index is the October anomaly in Eurasian snow cover extent (SCE) computed from Rutgers Snow Lab data [*Estilow et al.*, 2015]. The SCE is computed at all longitudes and longitudes across Eurasia. In computing all correlations and regressions, atmospheric data and boundary forcing indices are detrended prior to statistical analysis.

3. Results and Discussion

The two dominant modes of climate variability are ENSO in the tropics and AO in the boreal extratropics. To first order, changes in global weather patterns are controlled by changes in the global jet streams. The zonal mean zonal wind, the trend in the zonal wind, and correlations with both ENSO and the AO and for both ocean basins separately are shown in Figure 1. The trend in the North Atlantic shows a dipole structure with weakening of the zonal wind on the poleward side of the jet but a strengthening on the equatorward side of the jet. In contrast, in the North Pacific a weakening of the zonal wind is observed throughout the entire extratropics. ENSO (shown for La Niña state to match the negative ENSO or La Niña trend observed over the period of AA) is related to a strengthening of the poleward side of the jet and a weakening on the equatorward side in the North Pacific, but in the North Atlantic ENSO has almost no influence in the extratropics

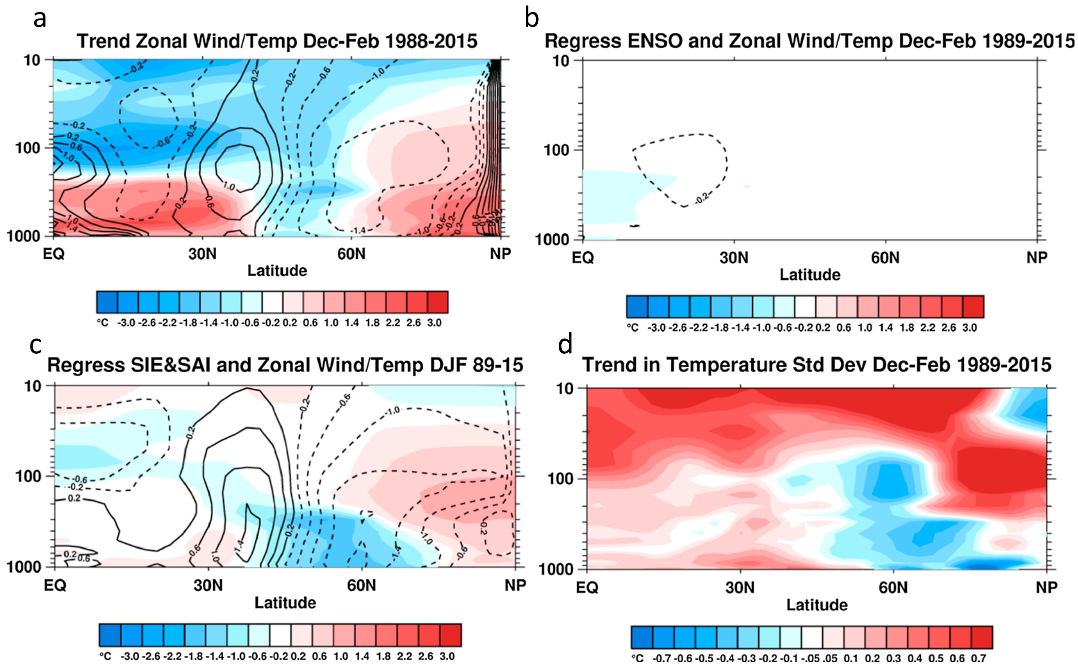

Figure 4. (a) Trend in the zonal mean zonal wind (contours; m s^{-1}) and zonal mean air temperature (shading; °C) from 1000 to 10 hPa for December, January, and February (DJF) winters 1988/1989–2014/2015 (same as Figure 2a). (b) Regression of trend in ENSO index (DJF Niño 3.4) from 1988/1989 to 2014/2015 with zonal mean zonal wind (contours) and zonal mean air temperature (shading). (c) Multiple regression of trend in November sea ice concentration index in the Barents-Kara Seas and the October snow advance index for Eurasia from 1988/1989 to 2014/2015 with zonal mean zonal wind (contours) and zonal mean air temperature (shading). (d) Zonal mean of trend of intra-annual standard deviation of air temperatures at each grid point for December, January, and February (DJF) winters 1988/1989–2014/2015.

but is related to a weakening of the zonal wind in the tropics. In contrast, variability associated with the AO (shown for the negative phase) is symmetrical about both ocean basins and is related to a weakening of the zonal wind on the poleward side of the jet but a strengthening on the equatorward side of the jet and is consistent with recent trends, especially in the North Atlantic. Variability in the zonal wind associated with the negative phase of the AO better matches the trends in the zonal wind than does the variability in the zonal wind associated with La Niña in the North Atlantic but not necessarily in the North Pacific. The trends in the North Pacific seem to be a superposition or combination of the variability in both the AO and ENSO, and the negative trends in the North Pacific midlatitudes are more consistent with La Niña than the negative AO.

In Figure 2, variability is again shown for the zonal wind but this time over the entire hemisphere and for air temperatures focused over the midlatitude continents. Figure 2a represents the trend in the zonal wind (contours) and air temperature (shading). In the midlatitudes the dominant trend has been a dipole in the zonal winds with strengthening equatorward of 40°N and weakening poleward of 40°N. The weakening of zonal winds extends all the way up to the polar stratosphere and is consistent with the reporting of a weakening of the polar vortex that is attributed to an increase in severe winter weather [*Cohen et al.*, 2014]. Comparing Figure 2a with Figures 1a and 1b, trends in the North Atlantic zonal winds contribute more strongly to the hemispheric trends than the tends in the North Pacific. Also shown in the figure is the trend in air temperatures. The greatest anomaly is the strong warming trend in the polar latitudes that extends from the surface all the way into the stratosphere, consistent with expected AA [*Overland et al.*, 2015; *Screen and Simmonds*, 2010]. It has been argued that the greater warming at the colder latitudes results not only in a weakened longitudinal temperature gradient but also in a weaker jet stream in the midlatitudes [*Francis and Vavrus*, 2012], which is consistent with the figure. A warming trend can also be seen in the lower latitudes of the tropics and the subtropics of the troposphere. However, throughout the atmospheric column of the midlatitudes from 40 to 65°N, a weak cooling trend is observed, which is surprising and not predicted by the global climate models used for long-range projections [*Cohen et al.*, 2012a]. Together, the temperature anomalies from equator to pole form a tripole. The tripole pattern in zonal temperature trends is consistent with similar analysis performed with ERA-Interim and different start and end dates [*Cohen et al*., 2014].

In Figure 2b the correlations or the variability associated with the negative phase of ENSO are plotted. Despite that, recent cooling trends have been attributed to negative trends in ENSO [*Meehl et al*., 2011; *Kosaka and Xie*, 2013; *Xie*, 2016]. Figures 2a and 2b have little in common. The main impact of ENSO on the atmospheric circulation is at lower latitudes with a decrease in the wind speeds of the subtropical jet stream during La Niña, and there is only weak variability in the jet associated with ENSO in the midlatitudes to high latitudes. The largest variability in air temperatures associated with La Niña is cooling in the tropics with alternating warming and cooling of weakening amplitude advancing poleward. The temperature anomalies associated with La Niña in the troposphere poleward of 40°N do match the observed temperature trends albeit weak. Still, it is a challenge to argue that a trend toward La Niña could be forcing observed hemispheric temperature trends when the strongest anomaly of cooling in the tropics is opposite to the observed tropical warming trend and the hemispheric trend does not match the tripole in the observed trend.

For comparison, in Figure 2c the variability in the zonal winds and temperatures associated with the negative AO is shown. The variability associated with the AO nicely matches that of the observed trends. A dipole is observed in the zonal wind with a strengthening of the subtropical jet but a weakening of the polar jet that extends into the stratospheric polar vortex. In the temperature anomalies, a tripole is observed with warming at high and low latitudes but cooling in the midlatitudes. The temperature variability associated with the AO does not explain the entire observed temperature trends, e.g., the warming in the Arctic lower troposphere. However, this panel is consistent with the argument that recent NH winter trends are in large part related to trends in the AO [*Cohen et al*., 2012a].

The AO is but an index and cannot force observed trends. Instead, Arctic change, including melting Arctic sea ice and increasing Eurasian snow cover, has been proposed as forcing winter trends [*Cohen et al*., 2014; *Overland et al*., 2015]. Variability in the zonal wind and air temperatures associated with sea ice and snow cover variability are plotted in Figures 2d–2f. Both decreased sea ice and increased snow cover are associated with the dipole in zonal wind, with weakening on the poleward side of the jet and the tripole in air temperatures with warming at high and low latitudes and cooling in the midlatitudes. Of all the variables shown, sea ice best explains the observed warming in the Arctic lower troposphere. What is forcing the sea ice to melt remains an open question. One argument is that forcing from the tropics is contributing to sea ice melt [*Ding et al*., 2014; *Lee et al*., 2011] that in turn could be forcing the negative AO. Still, in the analysis presented, the variability in atmospheric circulation associated with trends in sea ice and snow cover best matches not only the variability associated with the AO but also the observed trends including the cooling in the midlatitudes. And of the three boundary forcings presented, variability associated with low sea ice most strongly resembles observed trends.

Similar analysis was performed for the zonal mean geopotential height. Increases in the geopotential height at high latitudes are indicative of a weakened polar vortex, increased high-latitude blocking, and more extreme weather across the midlatitudes, while decreases are associated with the opposite [*Screen and Simmonds*, 2013; *Hassanzadeh and Kuang*, 2015]. In Figure 3a the trends in geopotential height show increasing geopotential heights in the high latitudes throughout the troposphere and stratosphere consistent with a weakening polar vortex, decreasing geopotential heights in the midlatitudes throughout the troposphere and stratosphere and more mixed in the tropics. La Niña (Figure 3b) is related to little change in the high latitudes, increased geopotential heights in the midlatitude troposphere, and decreased geopotential heights in the tropics. ENSO variability does not match trends in the extratropics and is even mixed in the tropics. Meanwhile, the negative AO (shown in Figure 3c), low sea ice (shown in Figure 3d) and high snow cover (shown in Figures 3e and 3f) are all related to a dipole in the geopotential heights with increased geopotential heights in the high latitudes throughout the troposphere and stratosphere and decreased geopotential heights in the midlatitudes, matching the trends in the boreal extratropics (Figure 3a).

In Figure 4, I regressed the trend in ENSO, sea ice, and snow cover onto temperatures and zonal wind over the period of AA. Trends in ENSO have contributed little to zonal wind and air temperatures over this period, with any changes confined to the tropics and temperature changes are even of opposite sign of the observed temperature trends. In contrast, combined trends in fall Arctic sea ice and Eurasian snow cover project more strongly onto hemispheric trends in the zonal wind and air temperatures matching the dipole structure in the observed winds and tripole structure in temperatures and with the largest changes observed in the midlatitudes to high latitudes. ENSO is just one climate mode of tropical variability, and others exist. For example, *Ding et al*. [2014] showed that a mode of tropical variability other than ENSO has been in an upward trend over this period as well. This mode is characterized by above normal SSTs in the central tropical Pacific, which can generate a Rossby wave train that forces both warming in the Arctic and a negative AO. In this Letter, however, I have exclusively focused on ENSO.

Finally, climate change modeling simulations project that variability in midlatitude lower troposphere temperatures should decrease with AA [*Screen*, 2014]. In Figure 4d, trends in the standard deviation of temperatures are computed. In the lower troposphere, temperature variability has decreased in the Arctic consistent with sea ice melt and strong warming that reduces the probability of extreme cold anomalies in the region. However, in the midlatitudes, temperature variability has increased over the period of AA contrary to expectations. This analysis supports the idea that temperature swings across the midlatitudes have become more extreme, popularly referred to as "weather whiplash." Temperature variability has increased even more strongly in the stratosphere. It is beyond the scope of this paper to investigate why, but it is consistent with conflicting forcings of radiative cooling due to increased greenhouse gases [*Clough and Iacono*, 1995] and dynamical warming due to increased sudden stratospheric warmings [*Cohen et al*., 2009]. The analysis is suggestive of a possible link between the increased variability in the tropospheric midlatitudes and in the region of the stratosphere dominated by the polar vortex.

The idea that the tropics, in general, and ENSO, in particular, influence midlatitude weather across the NH is universally accepted, and for at least the past three decades the tropics are almost exclusively used in generating seasonal forecasts. A more recent and less accepted theory is that the Arctic influences midlatitude weather as well. A simple diagnostic supports that ENSO influences midlatitude weather in the North Pacific sector but is less clear in the North Atlantic sector. In contrast, the analysis supports that Arctic influence is symmetric about the hemisphere. Furthermore, decadal trends better match variability in the Arctic represented by the AO and are associated with low sea ice and high snow cover. In addition, the observational analysis compellingly suggests that not only is Arctic influence on the large-scale midlatitude circulation comparable to that of its larger sibling, the tropics, but also that AA has made a greater contribution to midlatitude-high-latitude circulation trends than ENSO (and possibly the tropics as a whole) during the era of AA. For a more accurate understanding and prediction (projection) of seasonal (decadal) climate variability, Arctic influence should no longer be ignored. However, it remains an open question what is forcing changes in Arctic sea ice and Eurasian snow cover and more observational analysis and modeling experiments are required to fully understand the two-way coupling between the Arctic and lower latitudes. Further, as briefly discussed above, AO variability may not be independent of ENSO, which cannot be quantified using linear statistics.

Acknowledgments
J.C. is supported by the National Science Foundation grants AGS-1303647 and PLR-1504361.

References

Allen, R. J., and C. S. Zender (2010), Effects of continental-scale snow albedo anomalies on the wintertime Arctic oscillation, *J. Geophys. Res.*, *115*, D23105, doi:10.1029/2010JD014490.

Barnston, A. G., M. K. Tippett, M. L. L'Heureux, S. Li, and D. G. DeWitt (2012), Skill of real-time seasonal ENSO model predictions during 2002–11: Is our capability increasing?, *Bull. Am. Meteorol. Soc.*, *93*, 631–651.

Clough, S. A., and M. J. Iacono (1995), Line-by-line calculation of atmospheric fluxes and cooling rates: 2. Application to carbon dioxide, ozone, methane, nitrous oxide and the halocarbons, *J. Geophys. Res.*, *100*, 16,519–16,535, doi:10.1029/95JD01386.

Cohen, J., and D. Entekhabi (1999), Eurasian snow cover variability and Northern Hemisphere climate predictability, *Geophys. Res. Lett.*, *26*, 345–348, doi:10.1029/1998GL900321.

Cohen, J., and J. Jones (2011), A new index for more accurate winter predictions, *Geophys. Res. Lett.*, *38*, L21701, doi:10.1029/2011GL049626.

Cohen, J., M. Barlow, and K. Saito (2009), Decadal fluctuations in planetary wave forcing modulate global warming in late boreal winter, *J. Clim.*, *22*, 4418–4426.

Cohen, J., J. Furtado, M. Barlow, V. Alexeev, and J. Cherry (2012b), Arctic warming, increasing fall snow cover and widespread boreal winter cooling, *Environ. Res. Lett.*, *7*, 014007, doi:10.1088/1748-9326/7/1/014007.

Cohen, J., J. Jones, J. C. Furtado, and E. Tziperman (2013), Warm Arctic, cold continents: A common pattern related to Arctic sea ice melt, snow advance, and extreme winter weather, *Oceanography*, *26*, 150–160.

Cohen, J., et al. (2014), Arctic amplification and extreme mid-latitude weather, *Nat. Geosci.*, *7*, 627–637.

Cohen, J. L., J. C. Furtado, M. Barlow, V. A. Alexeev, and J. E. Cherry (2012a), Asymmetric seasonal temperature trends, *Geophys. Res. Lett.*, *39*, L04705, doi:10.1029/2011GL050582.

Coumou, D., and S. Rahmstorf (2012), A decade of weather extremes, *Nat. Clim. Change*, *2*, 491–496.

Coumou, D., J. Lehmann, and J. Beckmann (2015), The weakening summer circulation in the Northern Hemisphere mid-latitudes, *Science*, *17*, 324–327.

Ding, Q., J. M. Wallace, D. S. Battisti, E. J. Steig, A. E. Gallant, H.-J. Kim, and L. Geng (2014), Tropical forcing of the recent rapid Arctic warming in northeastern Canada and Greenland, *Nature*, *509*, 209–212.

Estilow, T. W., A. H. Young, and D. A. Robinson (2015), A long-term Northern Hemisphere snow cover extent data record for climate studies and monitoring, *Earth Syst. Sci. Data*, *7*, 137–142, doi:10.5194/essd-7-137-2015.

Francis, J. A., and S. J. Vavrus (2012), Evidence linking Arctic amplification to extreme weather in mid-latitudes, *Geophys. Res. Lett.*, *39*, L06801, doi:10.1029/2012GL051000.

Fyfe, J. C., et al. (2016), Making sense of the early 2000's warming slowdown, *Nat. Clim. Change*, *6*, 224–228.

Gramling, C. (2015), Arctic impact, *Science*, *347*, 818–821.

Hassanzadeh, P., and Z. Kuang (2015), Blocking variability: Arctic Amplification versus Arctic Oscillation, *Geophys. Res. Lett.*, *42*, 8586–8595, doi:10.1002/2015GL065923.

Herring, S. C., M. P. Hoerling, J. P. Kossin, T. C. Peterson, and P. A. Stott (Eds.) (2015), Explaining extreme events of 2014 from a climate perspective, *Bull. Am. Meteorol. Soc.*, *96*, S1–S172.

Honda, M., J. Inue, and S. Yamane (2009), Influence of low Arctic sea-ice minima on anomalously cold Eurasian winters, *Geophys. Res. Lett.*, *36*, L08707, doi:10.1029/2008GL037079.

Hoskins, B. (2013), The potential for skill across the range of the seamless weather-climate prediction problem: A stimulus for our science, *Q. J. R. Meteorol. Soc.*, *139*, 573–584.

Johnson, N. C., D. C. Collins, S. B. Feldstein, M. L. L'Heureux, and E. E. Riddle (2014), Skillful wintertime North American temperature forecasts out to four weeks based on the state of ENSO and the MJO, *Weather Forecasting*, *29*, 23–38.

Kalnay, E., et al. (1996), The NCEP/NCAR 40-Year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471.

Karl, T. R., A. Arguez, B. Huang, H. Jay, J. R. Mcmahon, M. J. Menne, C. Thomas, R. S. Vose, and H.-M. Zhang (2015), Possible artifacts of data biases in the recent global surface warming hiatus, *Science*, *348*, 1469–1472.

Kim, B.-M., S.-W. Son, S.-K. Min, J.-H. Jeong, S.-J. Kim, X. Zhang, T. Shim, and J.-H. Yoon (2014), Weakening of the stratospheric polar vortex by Arctic sea-ice loss, *Nat. Commun.*, *5*, doi:10.1038/ncomms5646.

Kintisch, E. (2014), Into the maelstrom, *Science*, *344*, 250.

Kosaka, Y., and S.-P. Xie (2013), Recent global-warming hiatus tied to equatorial Pacific surface cooling, *Nature*, *501*, 403–407.

Lee, S., T. Gong, N. C. Johnson, S. B. Feldstein, and D. Pollard (2011), On the possible link between tropical convection and the Northern Hemisphere Arctic surface air temperature change between 1958 and 2001, *J. Clim.*, *24*, 4350–4367.

L'Heureux, M. L., and R. W. Higgins (2008), Boreal winter links between the Madden-Julian Oscillation and the Arctic Oscillation, *J. Clim.*, *21*, 3040–3050.

Meehl, G. A., J. M. Arblaster, J. T. Fasullo, A. Hu, and K. E. Trenberth (2011), Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods, *Nat. Clim. Change*, *1*, 360–364.

Mori, M., M. Watanabe, H. Shiogama, J. Inoue, and M. Kimoto (2014), Robust Arctic sea-ice influence on the frequent Eurasian cold winters in past decades, *Nat. Geosci.*, *12*, 869–873.

Overland, J. E., J. Francis, R. Hall, E. Hanna, S.-J. Kim, and T. Vihma (2015), The melting Arctic and mid-latitude weather patterns: Are they connected?, *J. Clim.*, *28*, 7917–7932.

Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan (2003), Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, *J. Geophys. Res.*, *108*(D14), 4407, doi:10.1029/2002JD002670.

Scaife, A. A., et al. (2014), Skillful long-range prediction of European and North American winters, *Geophys. Res. Lett.*, *41*, 2514–2519, doi:10.1002/2014GL059637.

Screen, J. A. (2014), Arctic amplification decreases temperature variance in northern mid- to high-latitudes, *Nat. Clim. Change*, *4*, 577–582, doi:10.1038/nclimate2268.

Screen, J. A., and I. Simmonds (2010), The central role of diminishing sea ice in recent Arctic temperature amplification, *Nature*, *464*, 1334–1337.

Screen, J. A., and I. Simmonds (2013), Exploring links between Arctic amplification and mid-latitude weather, *Geophys. Res. Lett.*, *40*, 959–964, doi:10.1002/grl.50174.

Seager, R., J. C. H. Chiang, and J. Shaman (2015), Do the tropics rule? Assessing the state of tropical climate science, *BAMS*, *96*, ES211–ES214.

Wallace, J. M., I. M. Held, D. W. J. Thompson, K. E. Trenberth, and J. E. Walsh (2014), Global warming and winter weather, *Science*, *343*, 729–730.

Xie, S.-P. (2016), Leading the hiatus research surge, *Nat. Clim. Change*, *6*, 345–346.