AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2016GL069024

**Key Points:**
- Arctic sea ice loss is responsible for "Warm Arctic" but not for "Cold Continents"
- Recent "Cold Continents" are an extreme event of natural decadal variability
- Sea ice loss reduces temperature variability and risk of cold extremes in high-latitude continents

**Supporting Information:**
- Supporting Information S1

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**Citation:**
Sun, L., J. Perlwitz, and M. Hoerling (2016), What caused the recent "Warm Arctic, Cold Continents" trend pattern in winter temperatures?, *Geophys. Res. Lett.*, *43*, 5345–5352, doi:10.1002/2016GL069024.

Received 19 FEB 2016
Accepted 6 MAY 2016
Accepted article online 8 MAY 2016
Published online 25 MAY 2016



# What caused the recent "Warm Arctic, Cold Continents" trend pattern in winter temperatures?

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**Abstract** The emergence of rapid Arctic warming in recent decades has coincided with unusually cold winters over Northern Hemisphere continents. It has been speculated that this "Warm Arctic, Cold Continents" trend pattern is due to sea ice loss. Here we use multiple models to examine whether such a pattern is indeed forced by sea ice loss specifically and by anthropogenic forcing in general. While we show much of Arctic amplification in surface warming to result from sea ice loss, we find that neither sea ice loss nor anthropogenic forcing overall yield trends toward colder continental temperatures. An alternate explanation of the cooling is that it represents a strong articulation of internal atmospheric variability, evidence for which is derived from model data, and physical considerations. Sea ice loss impact on weather variability over the high-latitude continents is found, however, to be characterized by reduced daily temperature variability and fewer cold extremes.

## 1. Introduction

Arctic sea ice extent has been declining at an accelerating pace in recent decades [see *Stroeve et al.*, 2012, and references therein]. The sea ice loss is having a profound impact on Arctic climate, including an observed amplification of surface warming (compared to lower latitudes) and an increase in high Arctic precipitation [e.g., *Screen and Simmonds*, 2010; *Deser et al.*, 2010]. Less certain are impacts of Arctic sea ice loss on midlatitudes [*Walsh*, 2014; *Vihma*, 2014; *Cohen et al.*, 2014; *Barnes and Screen*, 2015; *Hoskins and Woollings*, 2015].

Coinciding with the continued Arctic sea ice loss and Arctic amplification, cold winters and cold waves have recently been observed to be more frequent and severe over Europe, Central Asia, and the eastern United States [e.g., *Cohen et al.*, 2014; *Horton et al.*, 2015]. It has been speculated that more cold extremes over midlatitude continents could occur due to impacts of Arctic sea ice loss [*Francis and Vavrus*, 2012, 2015; *Tang et al.*, 2013; *Overland et al.*, 2015; *Overland and Wang*, 2015]. It is surmised that teleconnections like the Arctic Oscillation and other atmospheric patterns are the dynamical conduit linking more extreme temperature variations over midlatitude continents to Arctic change. The pattern of this Northern Hemisphere (NH) temperature signal has been referred to as "Warm Arctic, Cold Continents" with the conjecture that Arctic change is the driver [*Overland et al.*, 2011; *Cohen et al.*, 2013, 2014]. The characteristic structure of this winter temperature trend since 1990/1991 is shown in Figure 1a and consists of cooling centers over central/east Asia and central North America, encircling a strong Arctic warming.

Whereas the directionality toward warming Arctic surface temperatures is well understood to be linked strongly with accelerating sea ice loss, there is neither an established theory nor strong experimental evidence that midlatitude temperature trends having opposite directionality results as a dynamical response. Indeed, the existing body of model simulations indicates that wintertime NH continents experience strong warming as a response to overall anthropogenic driving of climate change [*Intergovernmental Panel on Climate Change*, 2013]. Furthermore, there are alternate explanations for the post-1990 cooling of the continents. For example, *Deser et al.* [2015] show how cooling trends over the North American continent on multidecadal time scales can arise from circulation driven atmospheric variability. This occurs purely due to nonlinear dynamics of a chaotic system, rather than from deterministic forcing. There is still considerable uncertainty among modeling studies of Arctic sea ice loss impacts on atmospheric circulation. Some model simulations find a connection between Arctic sea ice loss and cooling over midlatitude continents [e.g., *Honda et al.*, 2009; *Liu et al.*, 2012; *Mori et al.*, 2014; *Kug et al.*, 2015], while others have found no significant linkages [e.g. *Kumar et al.*, 2010; *Screen et al.*, 2013; *Gerber et al.*, 2014; *Perlwitz et al.*, 2015; *Li et al.*, 2015]. Such disagreement warrants more investigation to understand the nature of Arctic-lower latitude linkages, especially in the framework of the recent "Warm Arctic, Cold Continents" pattern.

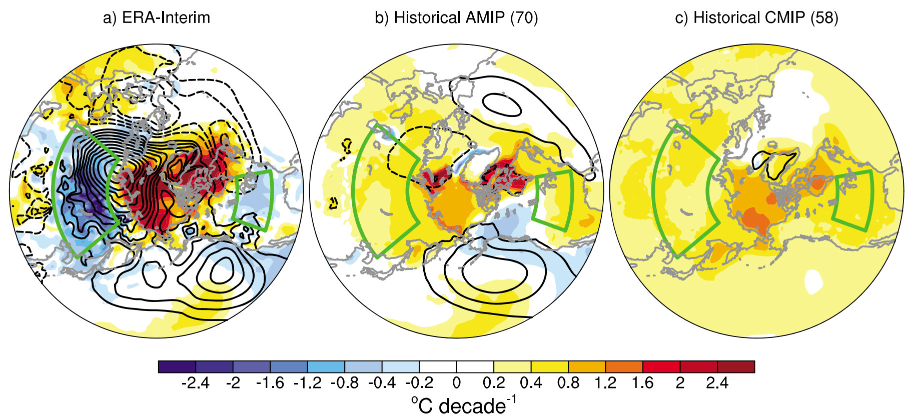


**Figure 1.** The 1990/1991–2013/2014 winter surface air temperature trend (shading) and the corresponding sea level pressure trend (contours) in (a) ERA-Interim, (b) 70-member ensemble-mean of Historical AMIP, and (c) 58-member ensemble-mean of Historical CMIP. The contour interval is 0.5 hPa decade$^{-1}$, and zero line is omitted. The two green sectors denote the observed cooling trend regions in central/east Asia (40–65°N, 50–130°E) and central North America (35–50°N, 80–110°W).

In this paper we analyze a large multimodel ensemble, using both coupled and uncoupled global models, to diagnose factors responsible for the observed linear trends in NH temperatures over the 1990/1991–2013/2014 period.

## 2. Analysis Approach and Model Experiments

We compare 1990/1991–2013/2014 winter (December to February) trends of surface air temperature (SAT) and sea level pressure (SLP) between Reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim (ERA-Interim) project [*Dee et al.*, 2011] and historical climate simulations. The 1990/1991–2013/2014 period is chosen because it exhibits a strongly pronounced "Warm Arctic, Cold Continents" trend pattern of wintertime near-surface temperatures (*Cohen et al.* [2014], also see our Figure 1a). By diagnosing the statistical significance and end-point sensitivity of the regional temperature trends (Figures S1 and S2 in supporting information) we found that the Arctic warming trend is statistically significant above the 95% level, and the trend is robust when adding one or two more recent years consistent with the ongoing strong sea ice forcing of the Arctic warming. In contrast, continental temperatures are strongly affected by interannual variability. In consequence, the central/east Asian cooling trend exhibits large end-point sensitivity with adding one or two recent years reducing its magnitude by roughly 30% and 50%, respectively. Central North American cooling is not statistically significant independent of record length.

We utilize two sets of experiments carried out with the National Center for Atmospheric Research (NCAR) community climate model, details of which are listed in Table S1 in the supporting information. The first set of experiments is denoted *Historical AMIP* (Atmospheric Model Intercomparison Project) and consists of atmosphere-only model simulations forced by observed/projected radiative forcing, observed monthly sea surface temperature (SST) and sea ice concentrations [*Hurrell et al.*, 2008]. We construct a multimodel average using a 20-member ensemble in which the atmospheric model is the Community Atmosphere Model Version 4 [*Neale et al.*, 2013] and a 50-member ensemble based on the Community Atmosphere Model Version 5 [*Neale et al.*, 2012] from the Climate of the Twentieth Century Plus (C20+) Detection and Attribution Project [*Folland et al.*, 2014]. We note that these models have realistic wintertime surface temperature variability (Figure S3).

The second set of experiments is denoted *Historical CMIP* (Coupled Model Intercomparison Project) and consists of coupled atmosphere-ocean climate model simulations forced by observed/projected radiative forcing. We again construct a multimodel average using a 20-member ensemble carried out with the Community Climate System Model version 4 [*Gent et al.*, 2011] and a 38-member ensemble based on NCAR's large-ensemble project [*Kay et al.*, 2015] carried out with the Community Earth System Model version 1.

To isolate the impact of recent Arctic sea ice loss, we utilize two sets of AMIP-style simulations (Table S1) previously analyzed by *Perlwitz et al.* [2015] for the fall season. The first set consists of Historical AMIP simulations described above. The second set is denoted *CLIM_POLAR AMIP* and is forced by SST and radiative forcings that are identical to the Historical AMIP runs but replaces the observed sea ice concentrations (SIC) with a repeating climatological seasonal cycle of SIC for 1979–1989. In addition, each grid box that is partially covered by sea ice has SSTs set to the 1979–1989 climatological values (see *Perlwitz et al.* [2015] for more details). For this analysis, we combine 20-member experiments with the CAM4 and 30-member experiments with the fifth generation of the atmospheric general circulation model ECHAM (ECHAM5) [*Roeckner et al*., 2003]. The trend difference between the 50-member ensembles of Historical AMIP and CLIM_POLAR AMIP, denoted as *ΔICE*, can be solely attributed to the impact of sea ice loss.

## 3. Results

### 3.1. Trend Comparison Between Observations and Model Simulations

Figure 1 shows the 1990/1991–2013/2014 winter (December–February) SAT and SLP trend for ERA-Interim (left), Historical AMIP (center), and Historical CMIP (right) simulations. Continental regions experiencing cooling trends in observations are identified by green boxes. Reanalysis data indicate strong Arctic warming, accompanied by cooling over central/east Asia and central North America. Both AMIP and CMIP ensemble means show strong Arctic warming as observed, while continental temperatures also warm in the simulations, opposite to observations.

Inspection of SLP trends (contours in Figure 1) indicates that the pattern of observed continental cooling is associated with large-scale dynamical changes in atmospheric circulation. Noteworthy is the observed trend toward higher surface pressure over northern Eurasia, indicative of a strengthened Siberian High. In striking contrast, no appreciable SLP trends occur over continents due to forcing alone in either AMIP or CMIP simulations. The only appreciable forced signal of atmospheric circulation change during 1990/1991–2013/2014 is found over the North Pacific in the AMIP simulations. There a simulated trend toward higher pressure is indicative of Aleutian low weakening, as observed and which is related to a cooling trend in the tropical Pacific Ocean during this period [*Perlwitz et al*., 2015].

Overall, Figure 1 indicates that the observed cold continent pattern of recent wintertime surface temperature trends is not a signal of forced change. Neither radiative forcing alone nor the additional effects on the atmosphere by the particular trajectory of the observed SSTs and sea ice histories induces continental cooling. Rather, the forced signal of the 24 year temperature changes during 1990/1991–2013/2014 is best described as "Warm Arctic, Warm Continents", rather than "Warm Arctic, Cold Continents" even though the observed continental cooling trend can still appear in some individual model ensembles (Figures S4 and S5).

What physical processes caused the recent cooling trend over midlatitude continents? The observed cooling pattern was intimately tied to the trends in SLP, implying that atmospheric driven fluctuations in circulation may be the primary factor. Given that we find no appreciable forced component to such atmospheric circulation trends (see Figure 1), our conjecture is that purely internally driven fluctuations are mainly responsible. To test that theory, we diagnose samples of individual model temperature trends that ranked within the coldest and warmest quintiles of 1990/1991–2013/2014 surface temperature trends over the green box regions of Figure 1. Composites of the corresponding SLP trends for those situations (cooling minus warming trends) were constructed (Figure 2). Since the temperature trends in Asian and North American sectors are largely uncorrelated (Figure S6), we make the composite separately for these two regions.

Figure 2a shows these composite over central/east Asia (green sector) based on the AMIP simulations. We find similar results when forming composites with the CMIP ensemble members (Figure S7). As in observations (see Figure 1a), wintertime cooling trends over Eurasia are accompanied by an intensification of the Siberian High in the model. Such a relationship is well known, the physics of which involves meridional air mass exchange from the Arctic to the continent [e.g., *Mori et al*., 2014; *Kug et al*., 2015]. The structure of the SLP anomaly trend pattern in observations and the model composite resembles the third empirical orthogonal teleconnection (EOT) mode of NH SLP variability and is the dominant mode of wintertime circulation variability over Eurasia continent [*Smoliak and Wallace*, 2015], a feature that is well reproduced in our models (Figure S8). Our results thus indicate that a decadal fluctuation in the statistics of the leading pattern of

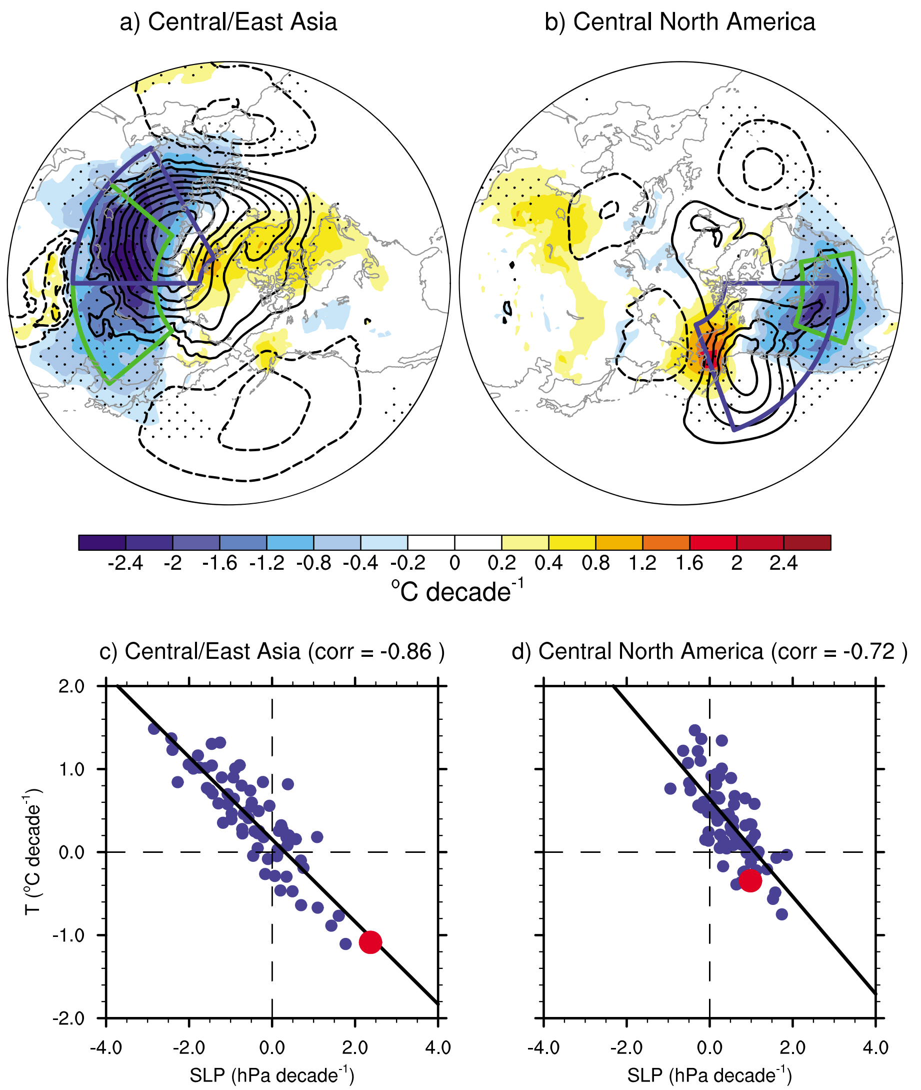


**Figure 2.** (a) Surface air temperature and sea level pressure trend composite in Historical AMIP for the difference between 14-sample lowest quintile and 14-sample highest quintile surface air temperature trend over central/east Asia. (b) As in Figure 2a but for the difference over central North America. The green sectors in Figures 2a and 2b denote the cooling trend regions in central/east Asia (40–65°N, 50–130°E) and central North America (40–65°N, 50–130°E), respectively. The blue sectors in Figures 2a and 2b denote the main circulation region responsible for the cooling trend in Eurasia (40–80°N, 30–90°E) and North Pacific/west North America (40–80°N, 30–90°E). The stippling in Figures 2a and 2b denotes the 95% statistical significance based on two-sided student *t* test. (c) Scatter plot of the sea level pressure trend averaged over blue sector and surface air temperature trend averaged over green sector in Figure 2a. (d) As in Figure 2c but for the scatter plot in Figure 2b. The red dot denotes the ERA-Interim result.

Eurasian wintertime SLP variability has occurred during 1990/1991–2013/2014, evolving independently from effects of long-term anthropogenic climate change.

Figure 2b shows the SLP trend associated with the cooling trend in central North America for Historical AMIP. Similarly, the high-pressure trend in Pacific-North America brings more warm air into the Alaska and adjacent Bering Sea and Chukchi Sea region (note that despite SSTs being fixed, SAT still shows statistically significant warming over the ocean) and more cold air into central North America. The spatial pattern of this SLP trend resembles the circulation anomaly linked to Arctic warming in East Siberian-Chukchi Sea region [*Kug et al.*, 2015, Figure 3b], though our results provide a different interpretation of the cause-effect linkages. Specifically, the results in Figure 2b indicate that the observed recent cooling in central North America likely resulted from

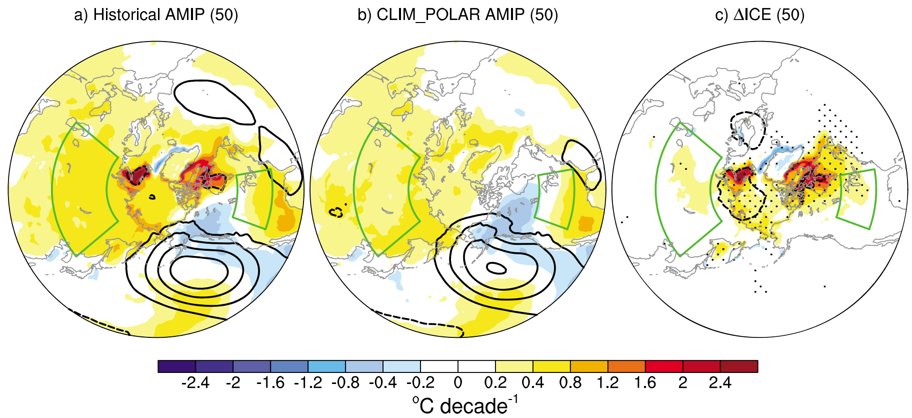


**Figure 3.** (a) The 1990/1991–2013/2014 winter surface air temperature trend (shading) and the corresponding sea level pressure trend (contours) in a 50-member Historical AMIP. (b) As in Figure 3a but for the CLIM_POLAR AMIP in which Arctic sea ice concentrations are substituted with 1979–1989 climatology. (c) The difference between Figures 3a and 3b. The two-sided student's *t* test is calculated in Figure 3c with the sample size of 50. The stippling in Figure 3c denotes the 95% statistical significance. The two green sectors denote the observed cooling trend regions in central/east Asia (40–65°N, 50–130°E) and central North America (35–50°N, 80–110°W).

a mode of circulation variability that is symptomatic of internal dynamics, rather than being a symptom of sea ice forcing due to effects of Arctic amplification overall.

We also construct a "combined composite" by considering those ensemble members whose 1990/1991-2013/2014 temperature trends reside in the lowest/highest quintile (Figure S9), which resembles the combination of Figure 2a or 2b. Collectively, these results indicate that the models used in this study are capable of generating the physical processes and dynamical mechanisms through which such cold continental regimes can occur. As such, the lack of a cold continent signal in the forced solution of the Historical AMIP and CMIP ensemble averages is not obviously owing to a model bias.

To further explore the realism of physical linkages between decadal changes in continental temperatures and atmospheric circulation, we show in Figures 2c and 2d the scatter relationships between SLP and surface temperature trends in each of the AMIP runs. The winter temperature trends are averaged over each green box (see Figures 2a and 2b) whereas the SLP trends are averaged over each blue box. A strong linear relationship exists, with a correlation of 0.86 and 0.72 for central/east Asia and central North America, respectively. The observed cooling trend over Eurasia (red circle in Figure 2) stands out as an extreme event of low-frequency variability but one that is well described by the linearity between circulation and surface temperature inherent in the models' statistical sample. By comparison, the observed North American cooling was not an extreme event, though again an occurrence consistent with a simple physical process of circulation driving as indicated by the agreement with the scatter relationship. It should also be noted that both regression lines show a preponderance of warming trends among the individual samples, indicative of a thermodynamic warming due to anthropogenic greenhouse gas (GHG) emissions, though as already emphasized, such forcing did not cause the continental cooling or the accompanying atmospheric circulation change. The results in Figure 2 indicate that the observed cooling in central/east Asia and central North America is transient, mostly due to changes in air mass exchange resulting from low-frequency atmosphere circulation variability.

### 3.2. Impact of Arctic Sea Ice Loss

One may argue that even though the midlatitude temperature trend in historical simulations is warming, the remote impact of Arctic sea ice loss alone might be cooling and the sea ice loss effect is just overwhelmed by other components of the GHG forcing.

Figure 3 shows the ensemble-mean winter SAT and SLP trend for Historical AMIP (left), CLIM_POLAR AMIP (middle), and ΔICE (right). The Historical AMIP ensemble from the combined CAM4 and ECHAM5 experiments (Figure 3a) has widespread warming over Eurasia, warming over the contiguous U.S. and cooling over western Canada—a pattern similar to the combined CAM4/5 ensemble shown in Figure 1b. Likewise, the forced atmospheric circulation change in these runs is similar to the prior Historical AMIP ensemble,

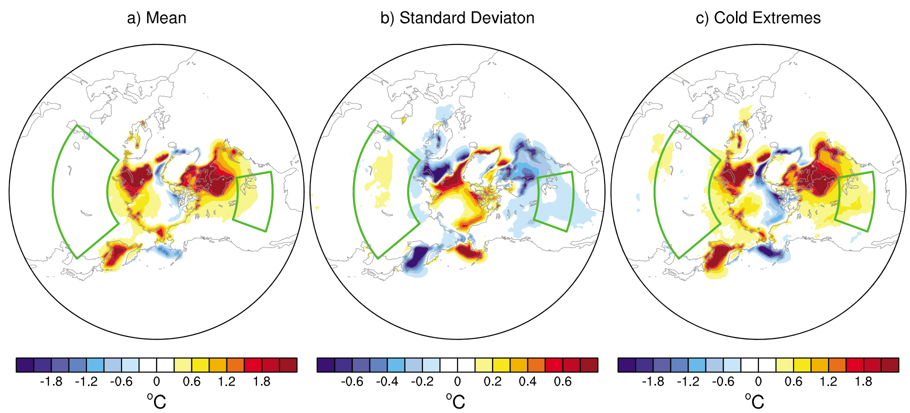


**Figure 4.** The 2004/2005–2013/2014 averaged winter surface air temperature response to Arctic sea ice loss for (a) mean value, (b) daily standard deviation, and (c) cold extremes (lowest 10% temperature value).

suggesting that the results are robust among different models. When repeating these experiments, but in the absence of sea ice loss (Figure 3b), the Arctic amplification largely disappears, particularly over those regions where winter ice loss is more pronounced, such as the Barents/Kara Seas and Hudson Bay. In the midlatitudes, however, almost all of the temperature and circulation trends in Historical AMIP are well reproduced in CLIM_POLAR AMIP suggesting that the main driver for these trends are SST changes outside the Arctic region. As a result, ΔICE (Figure 3c) shows that the sea ice loss signal is one of warming, confined mainly to the Arctic and high-latitude eastern North America. The results reveal no continental cooling signal. They further indicate no significant forced change in the surface pressure pattern over the middle and high latitudes, which is critical for dynamically driving the observed continental cooling trends. Therefore, our results indicate no significant impact of sea ice loss on midlatitude atmospheric circulation during 1990/1991–2013/2014 although sea ice loss plays a large role in causing Arctic surface climate change through thermodynamic effects.

Given the appreciable change in Arctic mean temperature, and given that this is a source region for air masses that occasionally migrate to lower latitudes on synoptic time scales, the question we next explore is how Arctic sea ice loss influences midlatitude daily temperature variability and cold extremes especially. We compare statistics of daily near-surface temperature data between Historical AMIP and CLIM_POLAR AMIP for the 2004/2005–2013/2014 periods for which Arctic sea ice loss is most pronounced (Figure 4). Specifically, we calculate the standard deviation of December to February daily values, as well as the lowest 10th percentile threshold value of daily data which provides a measure for the intensity of cold extremes. The winter mean temperature response to sea ice loss ΔICE for this period is very similar to the response over the whole 1990 to 2014 period (Figure 3c). The ΔICE of daily standard deviation indicates that within the Arctic Ocean, the daily temperature variability decreases (increases) significantly in the sea ice loss (increase) region and the reduced variability extends somewhat into the high-latitude continents (Figure 4b). The reduction in variability is associated with decreased meridional temperature gradient as a consequence of Arctic amplification [e.g., *Screen*, 2014; *Schneider et al*., 2015; *Sun et al*., 2015; *Blackport and Kushner*, 2016]. The effect of sea ice loss on cold extremes (Figure 4c) is similar to its effect on seasonal mean temperature, namely, a general increase in the threshold value of the coldest 10th percentile. This indicates that the risk of mid-high latitude cold extremes decreases in response to the recent observed Arctic sea ice loss, a result also found in *Screen et al.* [2015a, 2015b].

## 4. Summary and Discussion

The emergence of rapid Arctic warming in recent decades has coincided with unusually cold winters over NH continents. It has been speculated that this Warm Arctic, Cold Continents trend pattern is due to sea ice loss. To interpret this, it is necessary to employ ensemble methods of climate simulations that use the identical atmospheric forcings (i.e., SSTs, SIC, and GHGs) as observations and then repeatedly simulate the recent historical period. The statistics of these data are then used to explain what factors likely caused the observed trends. Here we use multiple models to examine whether such a pattern is indeed forced by sea ice loss specifically and by anthropogenic forcing, in general. While we show much of Arctic amplification in surface warming to result from sea ice loss, we find that neither sea ice loss nor anthropogenic forcing overall yields trends toward lower continental temperatures. Our findings provide an alternate explanation of the cooling. Specifically, a trend toward continental cooling over the NH during 1990/1991–2013/2014 represents a strong articulation of internal atmospheric variability, evidence for which is derived from model data and from physical considerations of dynamically driven temperature variability. These findings are also supported by the fact that the observed continental cooling trend itself is highly uncertain due to large interannual variability.

We also showed that sea ice loss impact on daily weather variability over the high-latitude continents consists of reduced daily temperature variability and fewer cold extremes indicating that the enhanced occurrences of cold spells during recent winters [e.g., *Cohen et al*., 2014] are not caused by sea ice loss. Collectively, our findings suggest that while "Warm Arctic" is to a large degree a consequence of sea ice loss, "Cold Continents" are actually transient and more related to low-frequency atmospheric variability.

Consistent with an overall forced signal of global warming, there is a coherence in sign of our model simulated continental temperature trends since 1990 toward warming, rather than toward cooling as observed. We have reconciled our experiments with this single record of observations by analyzing a very large ensemble of simulated trends. Our results support the argument that the recent observed continental cooling is not evidence for a systematic change in winter climate nor a new paradigm or fingerprint pattern of human-induced climate change. Indeed, we were able to show that several individual ensembles of our model experiments also yield cooling over both continents synchronously since 1990 (see Figure S6). But importantly, the majority of simulations show warming to occur over both regions.

Our results demonstrate that the models can reproduce the Asian part of the recent cooling within the spread of model simulations, though that the observed cooling was a very low probability state of the model solutions. The results also indicate that no model run produced a trend with the observed hemispheric pattern and its magnitude (see Figure S5). This may again reflect that the "Cold Continents" trend pattern of both Asia and North America observed during this period was indeed an extreme event of atmospheric decadal variability. However, the possibility cannot be dismissed either that some limitation of the models fail to generate sufficient unforced variability or that biases exist in their sensitivity to boundary and external forcings during the period. Analysis using different models will thus be important to confirm the robustness of the main interpretation of our results that the "Cold Continents" wintertime trend pattern resulted mainly from very strong atmospheric variability.

The results of this study lead to an important conclusion. The true forced pattern of NH temperature change since 1990—given the trajectory of observed sea ice loss, SST variations, and overall radiative forcing—is characterized as "Warm Arctic, Warm Continents". In consequence, the observed 24 year trend pattern of winter temperatures since 1990 should not be interpreted as expressing a sustainable trajectory of climate. Rather, the so-called "Warm Arctic, Cold Continents" regime is transient and is becoming increasing unlikely as climate continues to warm.

**Acknowledgments**
We thank Michael Alexander, Clara Deser, Isaac Held, Thomas Knutson, and Rong Zhang for valuable discussions and two reviewers for their helpful comments that improved the manuscript. We thank Xiao-Wei Quan, Dave Allured, Lesley Smith, and Don Murray for the access to different historical simulation data. All the data analyzed in this paper can be found at NOAA's Physical Science Division FACTs website: http://www.esrl.noaa.gov/psd/repository/alias/facts. The research is supported by NOAA's Climate Program Office and NASA's MAP program.

## References

Barnes, E. A., and J. A. Screen (2015), The impact of Arctic warming on the midlatitude jetstream: Can it? Has it? Will it?, *WIREs Clim. Change*, *6*, 277–286.

Blackport, R., and P. Kushner (2016), The transient and equilibrium climate response to rapid summertime sea ice loss in CCSM4, *J. Clim.*, *29*, 401–417, doi:10.1175/JCLI-D-15-0284.1.

Cohen, J. L., J. C. Jones, J. C. Furtado, and E. Tziperman (2013), Warm Arctic, Cold Continents, *Oceanography*, doi:10.5670/oceanog.2013.70.

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

Dee, D. P., et al. (2011), The ERA-Interim reanalysis: configuration and performance of the data assimilation system, *Q. J. R. Meteorol. Soc.*, *137*, 553–597, doi:10.1002/qj.828.

Deser, C., R. A. Tomas, M. A. Alexander, and D. Lawrence (2010), The seasonal atmospheric response to projected arctic Sea Ice loss in the late twenty-first century, *J. Clim.*, *23*, 333–351, doi:10.1175/2009JCLI3053.1.

Deser, C., L. Terray, and A. S. Phillips (2015), Forced and internal components of winter air temperature trends over North America during the past 50 years: Mechanisms and implications, *J. Clim.*, doi:10.1175/JCLI-D-15-0304.1.

Folland, C., D. Stone, C. Frederiksen, D. Karoly, and J. Kinter (2014), The international CLIVAR Climate of the 20th Century Plus (C20C+) Project: Report of the sixth workshop, *CLIVAR Exchange.*, *19*, 57–59.

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.

Francis, J. A., and S. J. Vavrus (2015), Evidence for a wavier jet stream in response to rapid Arctic warming, *Environ. Res. Lett.*, *10*, doi:10.1088/1748-9326/10/1/014005.

Gent, P., et al. (2011), The Community Climate System Model version 4, *J. Clim.*, *24*, 4973–4991, doi:10.1175/2011JCLI4083.1.
Gerber, F., J. Sedlácek, and R. Knutti (2014), Influence of the western North Atlantic and the Barents Sea on European winter climate, *Geophys. Res. Lett.*, *41*, 561–567, doi:10.1002/2013GL058778.
Honda, M., J. Inoue, 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.
Horton, D. E., N. C. Johnson, D. Singh, D. L. Swain, B. Rajaratnam, and N. S. Diffenbaugh (2015), Contribution of changes in atmospheric circulation patterns to extreme temperature trends, *Nature*, *522*, 465–469, doi:10.1038/nature14550.
Hoskins, B. J., and T. Woollings (2015), Persistent extratropical regimes and climate extremes, *Curr. Clim. Change Rep.*, *1*(3), 115–124, doi:10.1007/s40641-015-0020-8.
Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, and J. Rosinski (2008), A new sea surface temperature and sea ice boundary dataset for the community atmosphere model, *J. Clim.*, *21*, 5145–5153, doi:10.1175/2008JCLI2292.1.
Intergovernmental Panel on Climate Change (2013), Climate change 2013: The physical science basis, in *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker et al., 1535 pp., Cambridge Univ. Press, Cambridge, U. K., and New York, doi:10.1017/CBO9781107415324.
Kay, J. E., et al. (2015), The Community Earth System model (CESM) large ensemble project: A community resource for studying climate change in the presence of internal climate variability, *Bull. Am. Meteorol. Soc.*, doi:10.1175/BAMS-D-13-00255.1.
Kug, J.-S., J.-H. Jeong, Y.-S. Jang, B.-M. Kim, C. K. Folland, S.-K. Min, and S.-W. Son (2015), Two distinct influences of Arctic warming on cold winters over North America and East Asia, *Nat. Geosci.*, doi:10.1038/ngeo2517.
Kumar, A., J. Perlwitz, J. K. Eischeid, X. Quan, T. Xu, T. Zhang, M. Hoerling, B. Jha, and W. Wang (2010), Contribution of sea ice loss to Arctic amplification, *Geophys. Res. Lett.*, *37*, L21701, doi:10.1029/2010GL045022.
Li, C., B. Stevens, and J. Marotzke (2015), Eurasian winter cooling in the warming hiatus of 1998–2012, *Geophys. Res. Lett.*, *42*, 8131–8139, doi:10.1002/2015GL065327.
Liu, J., J. A. Curry, H. Wang, M. Song, and R. M. Horton (2012), Impact of declining Arctic sea ice on winter snowfall, *Proc. Natl. Acad. Sci. U.S.A.*, *109*, 4074–4079.
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.*, *7*, 869–873, doi:10.1038/ngeo2277.
Neale R. B., et al. (2012), Description of the NCAR Community Atmosphere Model (CAM 5.0), NCAR Technical Note NCAR TN 486.
Neale, R. B., J. Richter, S. Park, P. H. Lauritzen, S. J. Vavrus, P. J. Rasch, and M. Zhang (2013), The mean Climate of the Community Atmosphere Model (CAM4) in forced SST and fully coupled experiments, *J. Clim.*, *26*, 5150–5168, doi:10.1175/JCLI-D-12-00236.1.
Overland, J., J. Francis, R. Hall, E. Hanna, S. Kim, and T. Vihma (2015), The melting arctic and Mid-latitude weather patterns: Are they connected?, *J. Clim.*, *28*, 7917–7932, doi:10.1175/JCLI-D-14-00822.1.
Overland, J. E., and M. Wang (2015), Increased variability in early winter subarctic North American atmospheric circulation, *J. Clim.*, *28*(18), 7297–7305, doi:10.1175/JCLI-D-15-0395.1.
Overland, J. E., K. R. Wood, and M. Wang (2011), Warm Arctic-cold continents: Climate impacts of the newly open arctic sea, *Polar Res.*, *30*(SUPPL.1), 1–14, doi:10.3402/polar.v30i0.15787.
Perlwitz, J., M. Hoerling, and R. M. Dole (2015), Arctic tropospheric warming: Causes and linkages to lower latitudes, *J. Clim.*, *28*, 2154–2167, doi:10.1175/JCLI-D-14-00095.1.
Roeckner, E., et al. (2003), The atmospheric general circulation model ECHAM5. Part I: Model description, Max Planck Institute for Meteorology Tech. Rep. 349, 127 pp. [Available at http://www.mpimet.mpg.de/fileadmin/publikationen/Reports/max_scirep_349.pdf.]
Schneider, T., T. Bischoff, and H. Płotka (2015), Physics of changes in synoptic midlatitude temperature variability, *J. Clim.*, *28*, 2312–2331.
Screen, J. A. (2014), Arctic amplification decreases temperature variance in northern mid- to high-latitudes, *Nat. Clim. Change*, *4*, 577–582.
Screen, J. A., and I. Simmonds (2010), The central role of diminishing sea ice in recent Arctic temperature amplification, *Nature*, *464*, 1334–1337, doi:10.1038/nature09051.
Screen, J. A., I. Simmonds, C. Deser, and R. Tomas (2013), The atmospheric response to three decades of observed arctic Sea Ice loss, *J. Clim.*, *26*, 1230–1248, doi:10.1175/JCLI-D-12-00063.1.
Screen, J. A., C. Deser, and L. Sun (2015a), Reduced risk of North American cold extremes due to continued Arctic sea ice loss, *Bull. Am. Meteorol. Soc.*, *96*, 1489–1503, doi:10.1175/BAMS-D-14-00185.1.
Screen, J. A., C. Deser, and L. Sun (2015b), Projected changes in regional climate extremes arising from Arctic sea ice loss, *Environ. Res. Lett.*, *10*, 084006.
Smoliak, B. V., and J. M. Wallace (2015), On the leading patterns of northern hemisphere sea level pressure variability, *J. Atmos. Sci.*, *72*, 3469–3486, doi:10.1175/JAS-D-14-0371.1.
Stroeve, J. C., V. Kattsov, A. P. Barrett, M. Serreze, T. Pavlova, M. Holland, and W. N. Meier (2012), Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations, *Geophys. Res. Lett.*, *39*, L16502, doi:10.1029/2012GL052676.
Sun, L., C. Deser, and R. A. Tomas (2015), Mechanisms of stratospheric and tropospheric circulation response to projected Arctic sea ice loss, *J. Clim.*, *28*, 7824–7845, doi:10.1175/JCLI-D-15-0169.1.
Tang, Q., X. Zhang, X. Yang, and J. A. Francis (2013), Cold winter extremes in northern continents linked to Arctic sea ice loss, *Environ. Res. Lett.*, *8*, doi:10.1088/1748-9326/8/1/014036.
Vihma, T. (2014), Effects of Arctic sea ice decline on weather and climate: A review, *Surv. Geophys.*, doi:10.1007/s10712-014-9284-0.
Walsh, J. E. (2014), Intensified warming of the Arctic: Causes and impacts on middle latitudes, *Global Planet. Change*, *117*, 52–63.