

Recent warm and cold daily winter temperature extremes in the Northern Hemisphere

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Received 14 July 2011; accepted 31 July 2011; published 2 September 2011.

[1] The winters of 2009–2010 and 2010–2011 brought frigid temperatures to parts of Europe, Russia, and the U.S. We analyzed regional and Northern Hemispheric (NH) daily temperature extremes for these two consecutive winters in the historical context of the past 63 years. While some parts clearly experienced very cold temperatures, the NH was not anomalously cold. Extreme warm events were much more prevalent in both magnitude and spatial extent. Importantly, the persistent negative state of the North Atlantic Oscillation (NAO) explained the bulk of the observed cold anomalies, however the warm extremes were anomalous even accounting for the NAO and also considering the states of the Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO). These winters' widespread and intense warm extremes together with a continuing hemispheric decline in cold snap activity was a pattern fully consistent with a continuation of the warming trend observed in recent decades. **Citation:** Guirguis, K., A. Gershunov, R. Schwartz, and S. Bennett (2011), Recent warm and cold daily winter temperature extremes in the Northern Hemisphere, *Geophys. Res. Lett.*, 38, L17701, doi:10.1029/2011GL048762.

1. Introduction

[2] The winter of 2009–2010 (W10) made headlines for its fierce snowstorms and brutally cold temperatures in parts of the U.S. and Europe. According to the UK Met Office, England and Wales suffered their coldest winter since W79 and Scotland saw temperatures not seen since the 1960's [Met Office, 2010]. Miami Beach, Florida recorded its coldest January–February since records began, and parts of Maryland, Delaware, Washington DC and Pennsylvania set seasonal snowfall records [National Oceanic and Atmospheric Administration, 2010]. The winter of 2010–2011 (W11) that followed was likewise anomalously cold, and in fact was even more extreme for the majority of the U.S. These cold anomalies have raised important questions about what recent observations mean for the future outlook.

[3] Are these recent winters examples of short-term variability or a preview of winters to come? What does this mean in terms of global warming? What was the behavior of warm extremes, which are less newsworthy but also relevant in winter? Even in the presence of a warming trend, natural climate variability can lead to more or fewer cold outbreaks in a given season and region. Coupling of natural climate modes can change the climate state for years or even decades,

including prolonged warming and cooling [Tsonis *et al.*, 2007]. Model projections under climate change show periods of absent or decreasing temperature trends superimposed on an overall warming trend [e.g., Easterling and Wehner, 2009]. There remains much uncertainty about the behavior of cold extremes in a warming climate. Using stationary thresholds, as is so far the norm, a reduction in cold extremes would occur globally from increasing mean temperatures. However, extreme cold could become more or less likely regionally from changes in atmosphere or ocean circulation [Vavrus *et al.*, 2006; Kharin *et al.*, 2007; Favre and Gershunov, 2009].

[4] One important commonality seen during W10 and W11 was the persistence of the negative NAO. The pressure pattern that characterizes the negative NAO state (a reduced pressure gradient between the Azores and Iceland) establishes blocking patterns that promote Arctic air flow into the Eastern U.S. and Northern Eurasia [e.g., Hurrell, 1995; Hartley and Keables, 1998]. This anomaly pattern reached unprecedented strength in W10 and persisted into W11. Wang *et al.* [2010] demonstrated how the NAO promoted southward advection of Arctic air into the U.S. in W10; they foresee more frequent cold outbreaks due to the NAO's recent downward trend. Other research suggests the record-breaking NAO of W10 may be due to Arctic warming and melting sea ice [Overland and Wang, 2010; Petoukhov and Semenov, 2010]. Cattiaux *et al.* [2010] found that, although average wintertime temperatures in Europe were extremely cold in W10, given the strength of the NAO we should have expected even colder conditions. They conclude that a long term warming trend helped mitigate the NAO influence.

[5] An important question is how well the observed daily temperature extremes can be explained by the NAO and/or other natural climate modes such as ENSO and the PDO. In this paper, we focus on daily extremes, both warm and cold, to answer the question: How extreme were recent temperatures as compared to those experienced in previous years and decades? When placed alongside history, these winters were in fact very cold in some parts of the NH such as Northern Europe, the Southeastern U.S., and Northern Siberia. However, we find that the magnitudes of these regional cold extremes can be largely explained by the unprecedented strength of the anomalous NAO. The warm extremes, on the other hand, were much more severe, persistent, and expansive than the cold outbreaks. In contrast to cold extremes, recent warm extremes are not well explained by the states of the NAO or other natural prominent climate modes.

2. Data and Methodology

[6] Daily extremes were identified using near surface (.995 sigma level) daily temperatures from NCEP-NCAR

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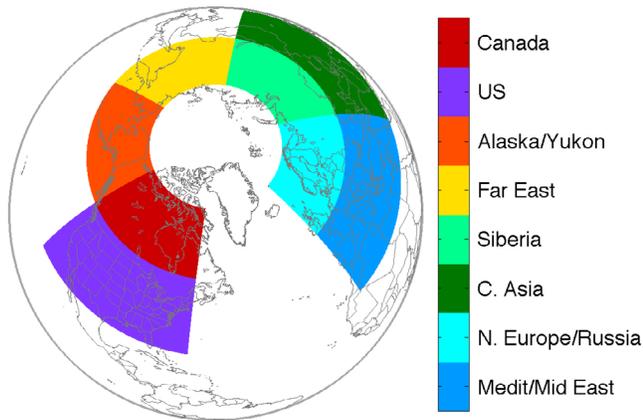


Figure 1. The eight regions discussed in the text.

global Reanalysis [Kalnay *et al.*, 1996]. A local “severe temperature index” is adapted from the methodology of Gershunov *et al.* [2009]. The index is calculated as a local (grid cell based) wintertime (December–February) threshold exceedance of deseasonalized daily temperature. The seasonal (annual and semiannual) harmonic cycle was first removed from all-year daily temperatures using least squares regression analysis. To identify extreme events we use absolute daily departures below the local 5th percentile threshold (“severe cold index”, SCI) and above the 95th percentile (“severe heat index”, SHI). A regional index is calculated as the spatial average of local daily exceedance values, and therefore represents intensity and spatial extent. A winter severity index is then defined as the seasonal sum of the SCI or SHI, which incorporates seasonal frequency and duration of temperature extremes. This article focuses on eight regions chosen to cover the NH continental mid-latitudes (Figure 1).

[7] Reanalysis was validated against station temperature data regionally and locally. For example, over the Eastern U.S. the daily SCI from reanalysis and station data (475 stations from *National Climatic Data Center* [2003]) showed an average correlation of 0.94. Over station-sparse Siberia and Central Asia reasonable agreement was found

for four stations selected for having adequate 1961–1990 averages as defined by Brohan *et al.* [2006]. In the Siberian plains the average daily temperature correlation was above 0.9. The poorest correspondence over recent decades was found over high mountainous terrain in the Himalayas (4508 m elevation, $r = 0.74$).

[8] To quantify the role of prominent climate modes in explaining the extremes of W10 and W11, we applied linear regression operating on the ranked seasonal SCI and SHI at each grid cell. Ranks were employed because of the skewed nature of these indices. We first determined the proportion of observed anomalies attributable to the NAO by regressing the ranked local seasonal SCI and SHI onto the DJF average NAO index. Next we included the DJF Nino3.4 and PDO indices in a stepwise multivariate regression model. The ENSO and NAO indices are from the Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/monitoring_and_data) and the PDO data are from the University of Washington (<http://jisao.washington.edu/pdo>). Lastly, we included a linear trend in the stepwise model to quantify the contribution of any long-term linear changes. The regression models of different complexities were least-squares fitted over W50–W09 and used to predict W10 and W11 ranked seasonal extremes.

3. Winter Extremes

[9] Historical data show that for the NH Continents, defined as the area spanning the eight regions combined, cold events since 2000 were less prominent than in any of the previous decades (Figure 2i). In fact, cold events have been declining since the 1970’s. Recent years have seen an increase in the overall magnitude of extreme warm events. For some regions (Canada, Mediterranean/Middle East, Alaska/Yukon, and the Far East) W10 and W11 saw stronger and more frequent warm events than most or all years past, with a recent tendency for warm extremes to exceed cold ones (Figures 2 and 3). For others (Northern Europe/Russia, Siberia, and the U.S.) cold extremes clearly dominated.

[10] For the NH as a whole, W10 and W11 were relatively mild in terms of extreme cold outbreaks, ranking 21st and 34th, respectively. The warm events were much more severe

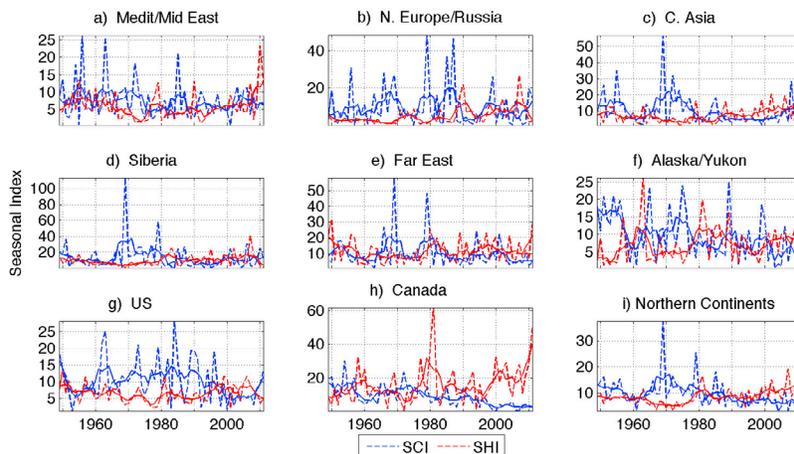


Figure 2. Seasonal Severe Cold Index (SCI, blue) and Severe Heat Index (SHI, red). Solid lines give the 2-point running mean.

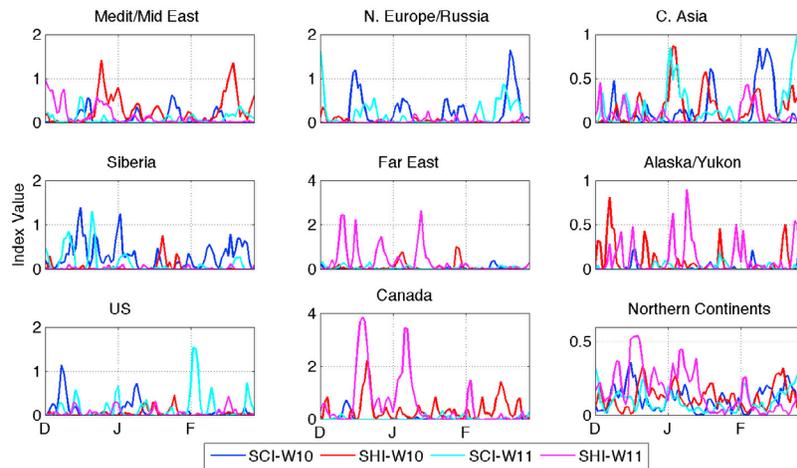


Figure 3. Daily SCI and SHI for W10 and W11.

and widespread. W10 (W11) ranked among the top 12(4) winters in terms of extreme warm weather, and regionally the magnitude of warm events exceeded that of cold ones. Figure 4 shows the ranking of W10 and W11 in terms of winter severity. Some parts of the NH experienced record cold weather – Mexico, the Southeast U.S. and Eurasia in W10 and the Southwest, Southeast, and Central U.S., England, and Scandinavia in W11. However, spatially there were more areas experiencing very extreme warm conditions. Just how spatially extensive as a function of their intensity were the warm extremes of W10 and W11? From Figures 4e–4h approximately 25–30% of the NH total area (2.5–3 times the expected area) saw warm extremes in the most severe category, therefore for these areas W10 and W11 were among the 10% of warmest winters on the 63-winter record. Meanwhile, the coldest extremes were less prevalent than expected based on climatology (i.e., below 10% area for each of the 3–4 coldest categories/bins). For the NH Continents, almost 20% of locations (twice the expected area) experienced warm extremes ranking in the warmest 10% of winters while cold extremes covered less than the expected area. In summary, from the 63-winter perspective, cold extremes in W10 and W11 were (on areal average) less extensive than climatology, while warm extremes were much more severe and extensive than average.

[11] Figure 5 gives results of regression analyses to quantify the degree to which climate modes explain temperature extremes in both W10 and W11. Extreme cold events were largely explained by the NAO, but extreme warm spells were not. Considering all locations where cold extremes were well modeled by the NAO (where the regression is significant at the 95% level) there were only 10 observations (grid cells) in W10 and 33 observations in W11 where the observed values fell above the 95% confidence interval (CI) of the NAO regression. For warm extremes there were many more outlying grid cells (336 in W10 and 195 in W11, respectively).

[12] A similar analysis was conducted to determine the contribution of multiple climate modes (NAO, PDO, ENSO) and a linear trend on the warm extremes (results not shown). For W10, a multivariate regression model comprised of the

NAO, PDO, and ENSO was found to explain an additional 15% of the warm extremes as compared to the NAO-only model. Including a linear trend as the fourth predictor explained an additional 50% of the warm extremes, leaving 138 grid cells above the 95% CI as compared to 276 for the NAO/PDO/ENSO model. This is consistent with an apparent acceleration in warm extremes since 1990 (Figure 2i). During W11 the NAO/PDO/ENSO model explained an additional 8% of warm extremes as compared to the NAO-only model, while a linear trend further explained 51% (194, 178, and 87 grid cells outside the 95% CI for the NAO model, NAO/PDO/ENSO model, and NAO/PDO/ENSO plus trend, respectively). In summary, the major climate modes did not account for the recorded warm extremes nearly as well as for cold ones. A linear trend better accounted for (but still underestimated) the W10 and W11 warm extremes. However, natural variability, namely the NAO, explained the vast majority of cold extremes in W10 and W11.

4. Conclusions

[13] The winters of 2009–2010 and 2010–2011 brought extreme cold weather to parts of Europe and the Southeastern U.S., causing disruptions to traffic, infrastructure, and day-to-day life not generally seen in recent years. This led to widespread speculation about whether this marked a return to the more severe winter conditions seen in 1970's and 1980's. This article presented the cold and warm temperature extremes of the past two winters in the context of a 63-year record resolved over the NH. From this perspective, akin to the timescale of a mature human's experience, the cold weather extremes of the most recent two winters did not appear extraordinary, although some local records were broken. These exceptional cases occurring mostly in Northern Eurasia and the Southeastern U.S. were largely explained by the anomalous and persistent negative NAO. The broader Hemispheric and regional picture shows that warm events occurring during the two most recent winters were much more extreme than the cold outbreaks and are consistent with a long-term and accelerating warming trend. For longer term projections, in future work, the methodology

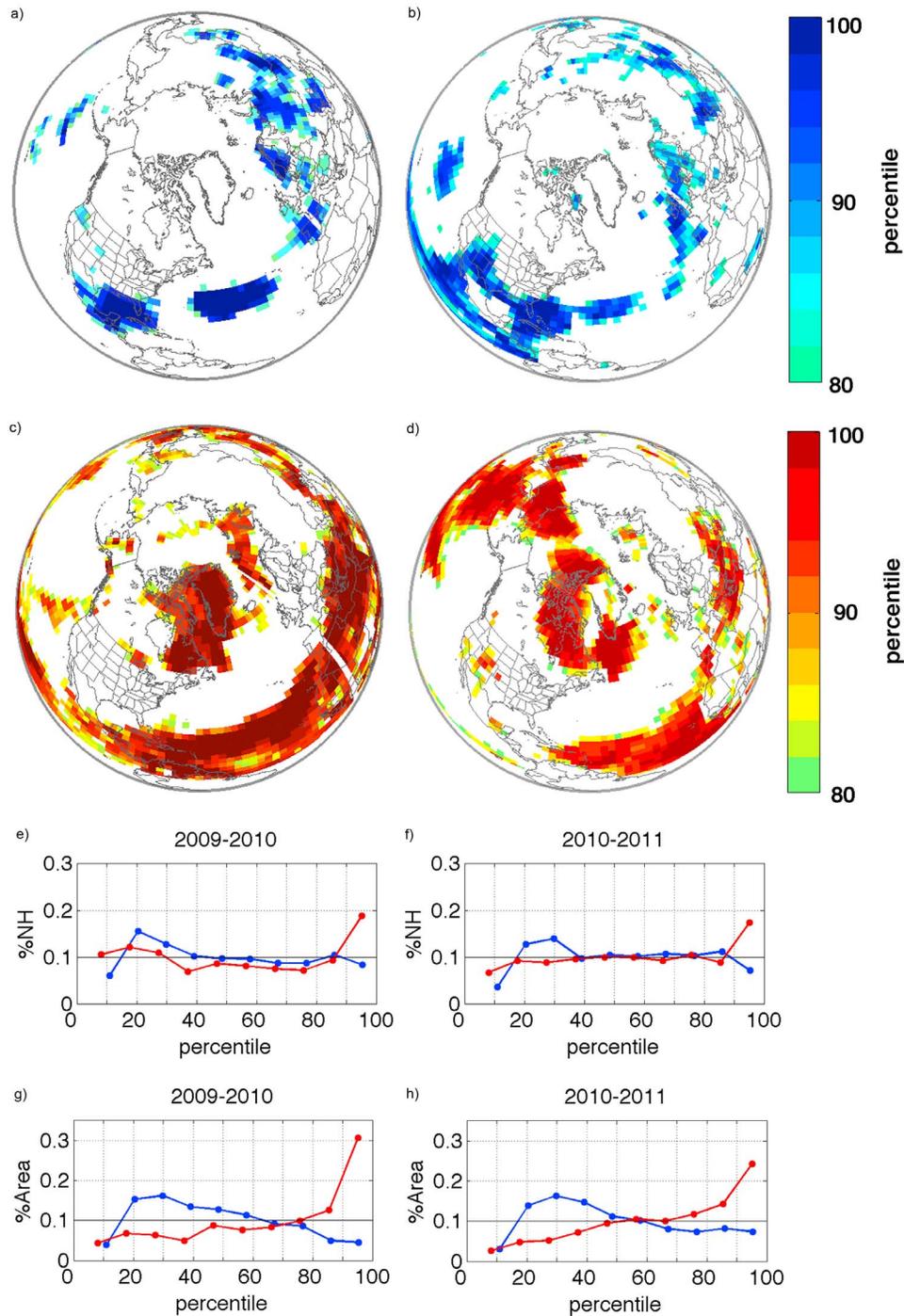


Figure 4. Maps show the local rankings of (a, c) W10 and (b, d) W11 in terms of severe cold (Figures 4a and 4b) and severe warmth (Figures 4c and 4d). Specifically, W10 and W11 are ranked according to their severity (seasonal sum of the SCI/SHI) as compared to the historical record such that a value of 100 is the most extreme of 63 winters. Locations that ranked above the 80th percentile are shaded. Line plots show the proportion of the (e, f) NH total area and (g, h) NH midlatitude continental area where observed SCI and SHI index values in W10 (Figures 4e and 4g) and W11 (Figures 4f and 4h) fell within a percentile range binned by 10% increments of their respective climatologies. Empirical SCI and SHI percentiles were calculated using the 63-year record at each continental grid cell, so that the expected climatological (i.e., for an average winter) value for each bin is 0.1 (10% of the area, black line), since each year's extreme index values have the expected probability of 10% of falling into each of the ten bins by construction. Data were weighted by grid cell area using cosine of the latitude.

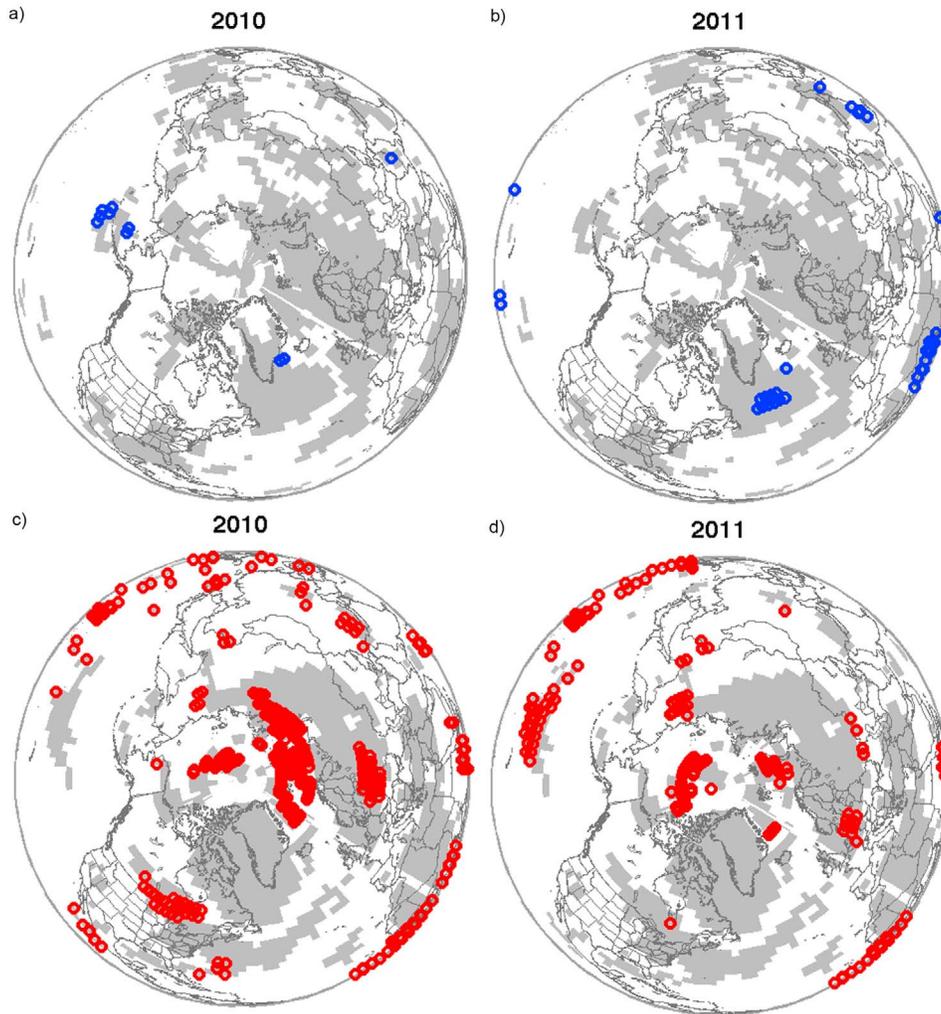


Figure 5. Locations where the seasonal SCI (blue circles) or SHI (red circles) fell above the 95% confidence interval of the NAO regression for (a, c) W10 and (b, d) W11. Shading shows the locations where the NAO regression is significant at the 95% level.

presented here will be modified to account for nonstationarity and applied to AR5 model integrations to study impacts of climate change on extreme weather in all seasons.

[14] **Acknowledgments.** This research was funded in part by the Vettlesen Foundation via the Scripps Partnership for Hazards and Environmental Applied Research (SPHEAR). This work was additionally supported by the University Corporation for Atmospheric Research under the Postdocs Applying Climate Expertise (PACE) fellowship. The paper benefited from the comments and suggestions of two anonymous reviewers.

[15] The Editor thanks the anonymous reviewers for their assistance in evaluating this paper.

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