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An Arctic Wild Card in the Weather

Has Arctic climate change stacked the deck in favor of more severe winter weather outbreaks in the United States and Europe?

BY CHARLES H. GREENE AND BRUCE C. MONGER

Earth's climate system is complex, often responding nonlinearly to both natural and anthropogenic forcings. Some of the feedback processes in these nonlinear responses are straightforward and have predictable consequences. Other feedbacks are less intuitive, occasionally leading to surprises that can catch society unprepared. The severe winter weather experienced in parts of the United States and Europe during the past three years appears to be one of the surprises resulting from enhanced warming of the climate system. New observational and modeling studies (Francis and Vavrus, 2012; Liu et al., 2012) provide strong evidence linking the recent decline in Arctic summer sea ice extent to more frequent winter outbreaks of extreme cold and snowfall in the Northern Hemisphere's middle latitudes.

Since the dramatic decline of Arctic sea ice during summer 2007, severe winter weather outbreaks have periodically affected large parts of North America, Europe, and East Asia (Liu et al., 2012). During the winter of 2011/2012, an extended and deadly cold snap descended on central and eastern Europe in mid-January. With bone-chilling temperatures approaching –30°C and snowdrifts reaching rooftops, the severe weather trapped over 100,000 people in their homes for more than a week. By the time it was over in mid-February, the death toll had exceeded 550.

During the previous two years, the US eastern seaboard as well as western and northern Europe experienced successive winters of anomalously cold temperatures and above average snowfall. The winter of 2009/2010, coinciding with El Niño conditions in the Pacific and the most negative Arctic Oscillation (AO) Index on record, was particularly severe, with several cities in the United States and Europe reporting record low temperatures and record high snowfalls (see http://www.ncdc.noaa.gov/special-reports/2009-2010-cold-season.html; Cattiaux et al., 2010). Perhaps the most memorable extreme snowfall event was the "Snowmageddon" storm that shut down the federal government in Washington, DC, for a week during February 2010.

While the weather experienced by the US eastern seaboard during the winter of 2010/2011 was moderated somewhat by La Niña conditions in the Pacific, the anomalously low temperatures and record snowfalls in New York City and Philadelphia during January 2011 still caught most weather forecasters by surprise. During the preceding autumn, the NOAA Climate Prediction Center had forecast a mild winter for the eastern seaboard because of the Pacific's La Niña conditions. In hindsight, the National Climatic Data Center (NCDC) explained the forecast's poor performance on its failure to account for a *wild card* in the weather, the winter's strong tendency towards negative AO conditions. By *wild card*, the NCDC meant that it considered the AO to be unpredictable more than two weeks in advance. However, what if changes in Arctic climate have stacked the deck in favor of more negative AO conditions?

Addressing this question requires understanding the AO's evolution in the context of recent changes in Arctic climate. Throughout most of the twentieth century, the AO was observed to be the principal mode of climate variability in the Northern Hemisphere (Thompson and Wallace, 1998). During its positive phase, the AO is associated with lower than usual atmospheric pressure in the Arctic and a strengthening of the Polar Vortex, which constrains colder Arctic air masses to latitudes above the Arctic Circle (Overland, 2011). During the last two decades of the twentieth century, the AO entered a persistently positive phase, which the Intergovernmental Panel on Climate Change predicted would

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continue with a steady rise in greenhouse forcing (IPCC, 2007). Contrary to that prediction, the amplified effects of greenhouse warming above the Arctic Circle have resulted in a weakening of the AO during the late 1990s and the subsequent development of climatic conditions that Overland and colleagues have referred to as the *Arctic Warm Period* (Overland et al., 2008; Overland and Wang, 2010).

Reductions in summer sea ice during the *Arctic Warm Period* have been dramatic, especially since 2007 (Perovich, 2011). The loss of summer sea ice exposes more of the ocean's darker surface waters to incoming solar radiation. The subsequent absorption of this solar radiation and excess heating of the ocean has two important feedbacks into the climate system. First, a portion of the excess heat further accelerates the summertime melting of sea ice, forming the basis for what has been referred to as the ice-albedo feedback mechanism (Deser et al., 2000). Second, much of the remaining excess heat is gradually released to the atmosphere through evaporation and radiation during autumn, increasing atmospheric pressure and moisture content in the Arctic while decreasing the latitudinal temperature gradient between the Arctic and middle latitudes (Overland and Wang, 2010).

The increase in Arctic atmospheric pressure and decrease in the latitudinal temperature gradient favor the wintertime development of more negative AO conditions. These conditions are associated with a weakening of the Polar Vortex and Jet Stream (Figure 1). A weakened Polar Vortex is less able to constrain the cold Arctic air masses, with their elevated moisture contents, from spilling out into the middle latitudes and delivering severe outbreaks of cold weather and snowfall to certain regions (Overland, 2011).

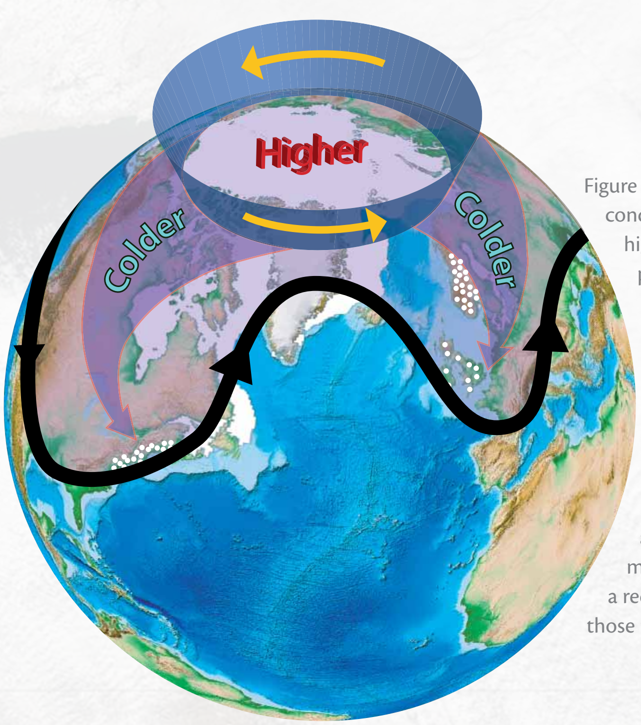

Figure 1. Negative Arctic Oscillation conditions are associated with higher than usual atmospheric pressure in the Arctic and a weakening of the Polar Vortex and Jet Stream. Such conditions increase the probability of Arctic air masses spilling out into the middle latitudes and delivering severe winter weather outbreaks. A weakened Jet Stream is also characterized by larger amplitude meanders in its trajectory and a reduction in the wave speed of those meanders.

A weakened Jet Stream is characterized by larger amplitude meanders in its trajectory and a reduction in the wave speed of those meanders (Francis and Vavrus, 2012; Liu et al., 2012). These characteristics tend to increase the persistence of middle-latitude weather patterns, further increasing the probability of more extreme weather events.

An extended *Arctic Warm Period*, with reduced sea ice during summers and a tendency toward more negative AO conditions during winters, will stack the deck in favor of severe winter weather outbreaks in the United States and Europe into the foreseeable future. Of course, while such outbreaks may become more probable, there are other factors that feed into the determination of winter weather patterns as well. For example, the El Niño-Southern Oscillation has an important influence on winter weather patterns throughout the continental United States. In the southeastern and Middle Atlantic regions of the United States, El Niño years bring wetter winter weather, while La Niña years bring dryer winter weather. The combination of negative AO and El Nino conditions can produce cold, harsh winters, as was observed during the severe winter of 2009/2010. Additionally, negative AO conditions can produce severe weather that runs counter to the dry, mild winters expected during La Niña years. This situation was observed during winter 2010/2011 when the low temperatures and record snowfalls in New York City and Philadelphia surprised those forecasting a mild winter.

The unusually mild weather observed in the eastern United States this past winter serves as a reminder that no two winters are alike and there will always be some uncertainty in forecasting regional weather. As in 2010/2011, this year's winter weather was forecast to be mild due to a La Niña in the Pacific. When negative AO conditions emerged during mid-January and Europe was pummeled by deadly cold and heavy snowstorms, weather in the eastern United States remained unseasonably mild. Unlike the previous year, a La Niña-associated, high-pressure blocking pattern over the northeast Pacific steered the Jet Stream further north over North America during mid-winter's negative AO conditions, allowing the eastern United States to experience its fourth warmest winter on record. By early March, the blocking pattern strengthened, further amplifying these conditions and resulting in record high temperatures throughout the eastern United States. Despite this extended period of unseasonable warmth in the eastern United States, it should be noted that other parts of the Northern Hemisphere experienced an unusually cold winter and early spring. In fact, the NCDC reported that the average global temperature for March 2012 was the coolest of the new millennium.

Winter weather surprises, running both cold and warm, have captured headlines in the United States and Europe during the past three years. Remarkably, remote climate forcing from the Arctic appears to have played a prominent role in the dynamics of both. The dynamical teleconnections linking recent changes in Arctic climate to middle-latitude weather are gradually being disentangled from the background noise in Earth's climate system. As our understanding of these teleconnections increases, seasonal forecasting of the potential for extreme weather will improve. In addition, society will be better prepared to manage the risks associated with this extreme weather as it adapts to the challenges posed by anthropogenic climate change (IPCC, 2012).

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BACKGROUND IMAGE | An exceptionally severe winter storm dropped a large amount of snow around the Washington, DC, area in early February 2010. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this true-color image on February 7, 2010, showing part of the region affected by heavy snowfall. *Credit: NASA Earth Observatory*

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