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Recent Arctic amplification and extreme mid-latitude weather

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AA and mid-latitude weather outside of winter

New studies propose that the rapid melt of Arctic sea ice and snow cover in spring and summer are having an impact on summer weather patterns as well, most commonly by building mid-tropospheric geopotential heights especially in the region of Greenland. Increased geopotential heights were observed during the summers of record low sea ice

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between 2007-2012 that projects strongly on to the summer negative N/AO[1,2]. Strong persistent positive height anomalies over Greenland locally contributed to record Greenland ice melt[2,3], with influences on weather patterns also at lower latitudes. Northern Europe experienced an unprecedented occurrence of above normal precipitation and flooding during the same six summers of 2007-12, as low pressure downstream of the Greenland blocking high diverted the storm track anomalously south across Europe[4]. The persistence of the Greenland block into October is also cited as a primary cause of steering Hurricane Sandy towards the Mid-Atlantic coast of the United States inflicting unprecedented flooding and damage along the coast[5]. However, there are additional complications making the link between AA and mid-latitude weather in summer. Observed AA is weakest in summer, especially near the surface (Fig. 1) and models generally show no or very weak responses to sea ice loss in summer[6,7]. Finally it has been argued that the overall weakened zonal jet not only operates in winter[8] but all seasons and may have led to the observed increase in heat wave frequency across the mid-latitudes[1, 9] and an increase in East Asian summer monsoon rainfall[10-13].

Challenges and opportunities

Based on the research conducted so far, we can identify several key factors underlying the current uncertainty, and offer a perspective on the challenges and opportunities moving forward:

- Signal to noise. The internal variability of the climate system is large. Recently observed weather patterns and even extreme events can be attributed to natural variability without including any changes to external forcings. AA has been large for a relatively short period of time and thus, it is difficult to detect the midlatitudes impact of AA over other influences. In both observations and models, the impacts of AA are generally only marginally statistically significant, or fail to achieve statistical significance.

- Causality. The variability in the Arctic and midlatitudes are intricately coupled. Many of the hypothesized linkages are based on the observed coincidence of events, trends or statistical correlations, but cause and effect are not clear.
- Competing influences. AA is only one influence on midlatitude weather, and probably not the largest. In an effort to better understand the impacts of AA, many studies have focused on the response to specific forcings (most commonly, sea ice loss). This is a necessary step to enhance process understanding, but the impacts of individual forcing should not be considered in isolation. Others forcings can compound or oppose the impacts of AA. Understanding the relative importance of disparate forcings, and how they interact, remains a key challenge.
- Definitional issues. Some key results are sensitive to how a relevant aspect of the atmospheric circulation are defined, including relating to blocking, the jet stream and wave amplitude. Another key challenge is defining an extreme event. Extreme events are inherently subjective and it seems unlikely to successfully attribute extreme events to either internal or external forcings without developing common metrics that are based on geophysical parameters.
- Observations. The Arctic is one of the most data poor regions of the globe. Increased and better observations inside (and outside of the Arctic), would not

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only improve our understanding of the Arctic and its climate but also better constrain the models.

- Model uncertainty. Modeling studies show a large spread in their simulated responses to sea ice loss, often displaying trends of opposite sign in key dynamical variables. This may partially reflect difficulties in modeling some aspects of the relevant dynamics, especially high-latitude surface forcing and troposphere-stratosphere interactions and upscale energy cascade following baroclinic instability. Better coordination of modeling studies would allow models to be more directly compared.
- Dynamical theory. Much work remains to be done to understand the dynamical links between recent Arctic Amplification and mid-latitude weather. Many open dynamical questions remain including the relative importance of the stratosphere, the low-level thermal gradient, upper level thermal gradient, and internal variability in forcing the synoptic variations associated with extreme weather events. Inclusion of hierarchical models of increasing complexity to study the problem would help to further our understanding and complexity of the problem.
- Hemispheric or regional. Sea ice melt has been closely associated with the negative phase of the N/AO, which is hemispheric in scale. The temperature pattern associated with the N/AO exhibits anomalies of the same sign across the NH continents. And in recent winters such as 2009-2011 winters were cold across Northern Eurasia and eastern North America. However in winter 2011-12 while it was cold across Eurasia it was relatively mild across North America and in winter 2013-2014 it was cold in North America yet mild across much of

Europe and East Asia. A greater understanding of whether the atmospheric response to sea ice loss is regional or hemispheric and its relation to large-scale climate modes is still needed.

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