Effects of a warming Arctic

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Are cold winters connected to the warming Arctic?

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One of the most controversial areas of climate science is the extent to which the warming Arctic might be affecting climate and weather extremes at lower latitudes.

Recent years have seen a series of anomalously cold winters in northern midlatitudes, including the eastern US where they have been accompanied by extremely heavy snowfalls. Some atmospheric scientists have argued that such cold events may be associated with climate change, specifically with the rapid warming of the Arctic that has been observed over recent decades and is manifested in the precipitous decline of Arctic sea-ice extent since the early 1990s. Others have argued precisely the opposite: that the cold events merely reflect the chaotic variability of the climate system and are in fact becoming less likely under climate change. Unlike most scientific debates about climate change, which are limited to specialist fora, this one has exploded into the public domain. How can different atmospheric scientists come to such different conclusions from the same data?

On basic thermodynamic grounds, climate change is expected to warm wintertime surface temperatures over land, with an amplified warming in the Arctic. This is what is seen in observations over sufficiently long periods (Fig. 1a). All else being equal, this would lead not only to fewer cold events, but also to less variability in surface temperature due to the reduced latitudinal temperature gradient. (However heavy snowfalls could increase due to the moister atmosphere[1].) Arguments for more frequent cold events thus rely on a change in atmospheric dynamics, and here the scientific understanding is very poor[2]. Various mechanisms have been proposed, but they represent hypotheses rather than predictive theories[3].

The climatological transport of heat from middle to high latitudes is mainly accomplished by atmospheric weather systems during the winter season, and varies from year-to-year through natural climate variability. Some years are characterized by a strong tropospheric polar vortex which inhibits the Arctic-midlatitude exchange of air masses, and other years by a weaker and wavier polar vortex which enhances the exchange, leading to midlatitude cold spells and to a warmer Arctic (Fig. 2). The difference between these two states shows up as a cold-continents/warm-Arctic pattern, although North America and Eurasia can vary independently. The observed changes over recent decades (Fig. 1b) align with this pattern, with a cooling tendency over the eastern US and especially central Asia, and an accelerated warming of the Arctic compared with that seen in Fig. 1a.

Given the uncertainties surrounding dynamical aspects of climate change, a reasonable null hypothesis would be that climate change is dominated by its thermodynamic aspects, and that the anomalous behaviour seen in recent decades (e.g. the difference between Figs. 1a and 1b) reflects natural variability. The contrary hypothesis is that the accelerated warming of the Arctic is part of the climate-change signal, and has changed the weather patterns in midlatitudes through changes in the tropospheric polar vortex. Such a hypothesis is not as far-fetched as it may sound, as there are general grounds for expecting that the dynamical response to climate change will project onto the modes of internal variability[4]. Unfortunately this makes it difficult to separate the signal from the noise as they will have similar spatial patterns.

One aspect of the scientific debate has focused on whether the observed changes associated with particular hypotheses are statistically significant. This is rather beside the point since the definition of statistical significance is arbitrary[5], a lack of statistical significance does not mean the effect is not there, and a positive finding does not imply any attribution to climate change. It is also extremely challenging to accurately characterize the low-frequency noise from the limited observational record. A deeper difficulty in any such analysis is that correlation does not imply causality. A recent study[6] has used the concept of causal effect networks to overcome this limitation; importantly, it finds that a loss of Barents/Kara sea ice (which induces local warming) can indeed be considered a causal driver of a weakened tropospheric polar vortex.

Another aspect of the debate has focused on what numerical models predict. Many studies have attempted to model the midlatitude circulation response to Arctic warming, usually induced through reduced sea-ice extent. The results have generally been all over the map, showing only that the answer depends sensitively on details of the model set-up. The one result that does seem to consistently emerge is a cooling in central Asia (much as seen in Fig. 1b) resulting from loss of Barents/Kara sea ice[7], which can be understood in terms of the circulation response to a local warming. This matches the observationally determined causal relationship[6], and could account for the observed attribution of an increase in cold extremes in central Asia to circulation changes[8].

Comprehensive climate models do not provide any indication of increased wintertime cold events in northern midlatitudes in response to climate change, suggesting that any such tendency arising from Arctic warming (if it exists) is overwhelmed by other factors. However, one can question whether these models represent the relevant physical processes in a sufficiently accurate way for this to be considered a definitive answer. Interestingly, the models with stronger Arctic warming have a tendency towards surface pressure increases over northern Eurasia[9], which is broadly consistent with the above-mentioned studies.

To the extent we trust the current generation of climate models, and given the impossibility of ruling out natural variability as the explanation for the observed behaviour in recent decades, the null hypothesis is certainly a scientifically defensible position[10]. However there are multiple lines of evidence supporting the hypothesis of an Arctic-midlatitude connection in central Asia — though not, it must be said, in the eastern US. Moreover the either/or dichotomy between forced response to climate change and natural variability is overly simplistic. For example, the meanders in the tropospheric polar vortex induced by teleconnections from

Pacific sea-surface temperature variations can be expected to be larger if the vortex was weaker. Thus it is easy to imagine variability and the forced response acting together to affect extreme weather.

The question is not whether Arctic changes are affecting midlatitudes, but rather how and by how much. Framing studies in this way will avoid polarization and aid progress. It is already encouraging to see scientists from what might be considered 'opposing' camps collaborating[11]; this sort of productive interaction will move the science, and with it the public discourse, forward.

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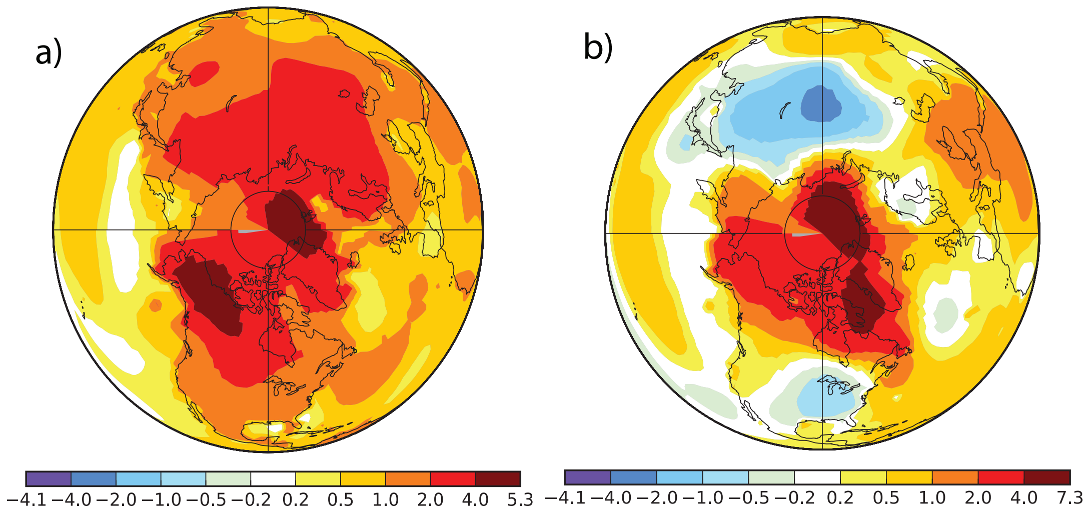

Figure 1. Change in average temperature (in °C) during the winter season December-January-February over (a) the last 50 years (1966-2016) and (b) over the last 25 years (1991-2016) during which Arctic sea ice extent has declined precipitously. Data from GISTEMP, NASA Goddard Institute for Space Studies[12].

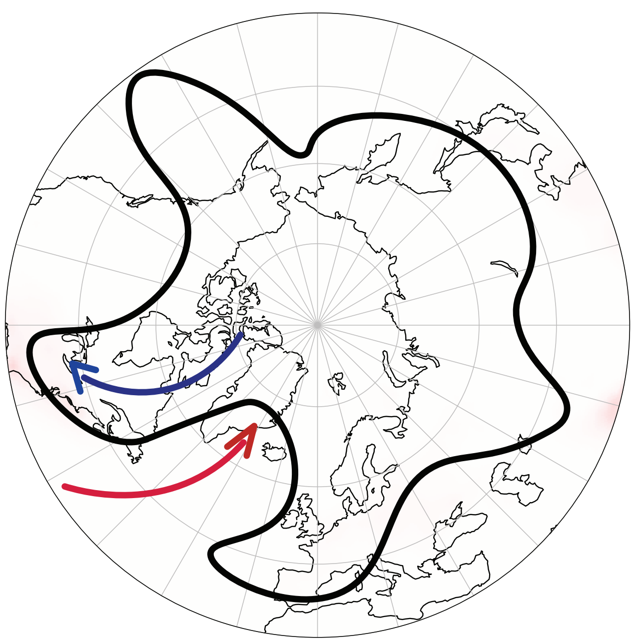

Figure 2. Schematic of the weather situation on January 26, 2015, when Winter Storm Juno hit Boston. The black line depicts the edge of the tropospheric polar vortex, which lies within the core of the jet stream and represents a boundary between cold Arctic air and warmer midlatitude air. The vortex is deformed by Rossby waves which generally move eastward but can sometimes stall. The blue arrow depicts transport of cold air to the eastern US, and the red arrow transport of warm air into the Arctic. Figure courtesy of Dr. Michaela Hegglin.