ATMOSPHERIC SCIENCE

Local processes with a global reach

Recent, rapid and (in many cases) unprecedented climate changes in the Arctic continue to outpace all other regions. New research argues that local, not remote, mechanisms are responsible for amplifying polar climate change.

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The enhanced climate sensitivity of Earth's polar regions is a phenomenon referred to as polar amplification. Over the past 30 years, the consequences of this phenomenon have been witnessed first hand, as evidenced most clearly by the 70% reduction in September sea ice volume since 1980[1]. The impacts of Arctic climate change permeate the globe, putting food, energy, water and security systems at increased risk[1,2]. The concept of polar amplification has been with us for more than 100 years[3] and is understood by invoking the principle of energy conservation; the poles change more rapidly because energy accumulates there at a faster rate. Both remote mechanisms and processes local to the polar regions represent potential sources of energy accumulation, but their relative importance is contested. Writing in *Nature Climate Change*, Malte Stuecker and colleagues[4] provide substantial new evidence that local processes drive polar amplification and that remote mechanisms play a limited role.

Early explanations of polar amplification assign liability to local processes, which include surface albedo and lapse rate feedbacks (see Fig. 1). The surface albedo feedback operates such that warmer temperatures melt sea ice and snow, increasing absorbed sunlight and amplifying warming. The lapse rate feedback owes its existence to the very stable conditions in the polar regions that restrict energy exchange between near-surface air and air aloft, trapping energy near the surface, reducing the cooling efficiency[5] and encouraging heating.

In the 1970s, the first simulations of the climate response to a doubling of CO_2 using a modern climate model[6] endorsed these local processes as the driver of polar amplification, pointing specifically to the surface albedo feedback[7]. This explanation remained largely unchallenged until the 2000s, when several idealized experiments disrupted this picture. Surprising to many, these experiments[8,9] produced polar amplification in the absence of snow and sea-ice feedbacks, spurring investigation into other possible mechanisms.

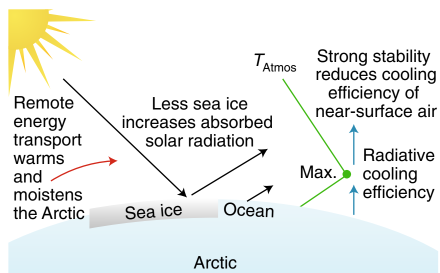

Fig. 1 | Schematic of processes contributing to polar amplification. The surface ice albedo feedback, lapse rate feedback and remote energy transport are shown. The surface albedo feedback occurs because more sunlight (incoming black arrow) is reflected by sea ice (or snow) as opposed to the ocean (or land), as illustrated by the longer outward black arrow over sea ice than over open ocean. The lapse rate feedback mechanism is illustrated by the two blue arrows. The green line represents the typical vertical profile of Arctic air temperature, indicating that less energy is radiated to space (smaller blue arrow) by the air below the maximum T_{Atmos} (green dot) than by the air above. Remote energy transports bring warmer, moister air into the Arctic from lower latitudes (red arrow) influencing polar amplification.

Remote mechanisms were one such area of research, influencing the polar climate by changing the amount of energy (including heat and moisture) entering the polar regions by atmospheric winds and ocean currents. This line of research has been stimulated by the anomalously warm Arctic conditions that have been observed in recent years. Several individual winters, for example, have experienced daily temperature anomalies more than 30 °C above average, the causes of which have been traced to anomalous atmospheric winds. While it is clear that remote mechanisms are able to warm the Arctic, contributing to polar warming, their ability to generate polar amplification is not so cut and dried.

Stuecker and colleagues[4] investigate these apparent discrepancies in local versus remote drivers of polar amplification by applying a CO_2 forcing to distinct geographical regions in climate model simulations: the deep tropics, mid-latitudes and poles. The temperature changes and feedback processes from the regional forcing experiments sum to the global forcing response, enabling the decomposition and attribution of local and remote processes. These experiments reveal that polar amplification is only produced when applying the CO_2 forcing in the polar regions. Experiments applying the radiative forcing in the deep tropics and mid-latitudes, by contrast, produce polar warming through atmospheric circulation-related exports, but not amplification.

Stuecker and colleagues further isolate the individual processes responsible for polar amplification using an established feedback analysis technique[10] — as opposed to turning processes on and off, as in previous idealized experiments. The results reveal that polar amplification results jointly from the CO_2 forcing and the lapse rate feedback, with the surface albedo feedback playing a smaller role. Thus, although processes inside and outside the polar regions contribute to polar warming, only local polar processes — specifically driven by CO_2 forcing and lapse rate feedbacks — generate amplification.

Stuecker and colleagues provide a significant advance in our understanding of polar amplification, painting a clear picture of the roles that local processes and remote mechanisms play in polar climate change. While demonstrating that only local polar processes produce amplification, Stuecker and colleagues also show that approximately half of the total polar warming occurs in response to the mid-latitude CO_2 forcing. This new understanding can be used to indicate where it is best to focus our scientific efforts. Given the large uncertainty in the projected amount of polar amplification, the results of Stuecker et al. suggest that to reduce uncertainty in polar climate change we need to constrain local processes through a combination of field experiments and long-term satellite observations to understand how they generate amplification.

Climate projections differ more in the polar regions than anywhere else. The impacts of polar climate change, including global sea-level rise and the carbon cycle, span the globe and may contain tipping points and surprises[1]. Understanding the mechanisms responsible for polar amplification is critical for reducing uncertainty in climate projections and making better assessments of the global impacts of climate change. ❐

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Published online: 19 November 2018
https://doi.org/10.1038/s41558-018-0342-3

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