in incentives and cognitive frameworks. This is particularly true for framework laws. Moreover, in the developing world, most climate laws are substantially under ten years old[1], and the full long-term effects may not have been realized. To provide guidance for climate governance, far greater understanding is required of the pathways through which climate laws work across different kinds of laws, jurisdictions and over time.

This work by Eskander and Fankhauser definitively signals that climate laws matter to emissions outcomes[8]. Future work may well contest or refine the exact magnitude of the impact, clarity on which is challenged by scope questions around both 'climate' and 'law'. This work clearly telegraphs the need for a more serious conversation than now exists about how laws interact with other aspects of governance in shaping emission outcomes. ❐

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Published online: 13 July 2020
https://doi.org/10.1038/s41558-020-0853-6

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ANTARCTIC SCIENCE

Warming reaches the South Pole

Over the last half of the twentieth century, surface temperature over the South Pole was steady if not slightly cooling, suggesting the high Antarctic interior might be immune to warming. Research now shows a dramatic switch; in the past 30 years, the South Pole has been warming at over three times the global rate.

Sharon E. Stammerjohn and Ted A. Scambos

Antarctic climate is riddled with contrasting changes. Over the last half of the twentieth century, westerly winds encircling the Southern Ocean intensified and shifted poleward, isolating Antarctica's climate and cooling the high Plateau[1]. At the same time, the Antarctic Peninsula experienced record warmth[2] and intense ice melt[3]. Most of West Antarctica also warmed[4]. Meanwhile, sea ice surrounding the continent showed contrasting regional trends in extent but overall a small net increase[5]. Then the twenty-first century brought a completely new set of changes. West Antarctica's coastal ice shelves thinned dramatically[6]. Sea-ice extent swung wildly, reaching record highs in 2014 and then plunging to unprecedented lows in 2016 (ref. [7]). Warming trends weakened over the Peninsula[8] and West Antarctica[9]. Now, Kyle Clem and colleagues[9] report that the most remote location on the planet — the South Pole — has been rapidly warming over the past 30 years, undoing the previous cooling. These new changes appear to be in response to increasing tropical western Pacific temperatures and to regional changes in winds induced by a warming planet.

The surface air temperature (SAT) record at the South Pole dates back to 1957. Initially, the station experienced near-steady annual temperatures and little year-to-year variability (Fig. 1). In the 1980s, variability sharply increased, and during the subsequent 20 years record-breaking cold conditions occurred in 1983 followed by several more near-record cold years. These trends flipped in the early 2000s, tending toward warmer SATs and five years of record-setting warmth. The end result is a warming rate at the South Pole during 1989–2018 more than three times the global rate (+0.6 °C per decade versus +0.2 °C per decade). The pace of warming greatly exceeds that of the rest of the continent, indicating a rather localized warming.

Why the sudden switch? Clem and colleagues attribute this to a tropical mode of ocean and climate variability, the Interdecadal Pacific Oscillation (IPO), which flipped phases from negative to positive in the early 1980s and back to negative around the turn of the twenty-first century. The negative IPO phase exhibits warmer sea surface temperatures in the western tropical Pacific, driving greater vertical atmospheric convection there and spawning southward-propagating Rossby waves — alternating trains of high and low atmospheric pressure that reach high latitudes. The authors show these patterns are locally amplified by a now-persistent tendency for stronger westerly winds around Antarctica. The winds represent the positive phase of the Southern Annular Mode (SAM), the dominant mode of Southern Hemisphere climate variability. The combined outcome is increased atmospheric cyclonic activity in the high-latitude South Atlantic (the Weddell Sea sector), causing advection of warm moist air from the South Atlantic into the high-altitude Antarctic interior.

While the South Pole switched from cooling to warming at the turn of the twenty-first century, the Antarctic Peninsula and West Antarctic also saw a trend reversal. Previously, the western Antarctic Peninsula was the fastest-warming place on Earth (annually warming at 0.6 °C per decade, but in winter at an astonishing 1.1 °C per decade)[2], with central West Antarctica not far behind[4]. But over the last 30 years Clem and colleagues[9] show these

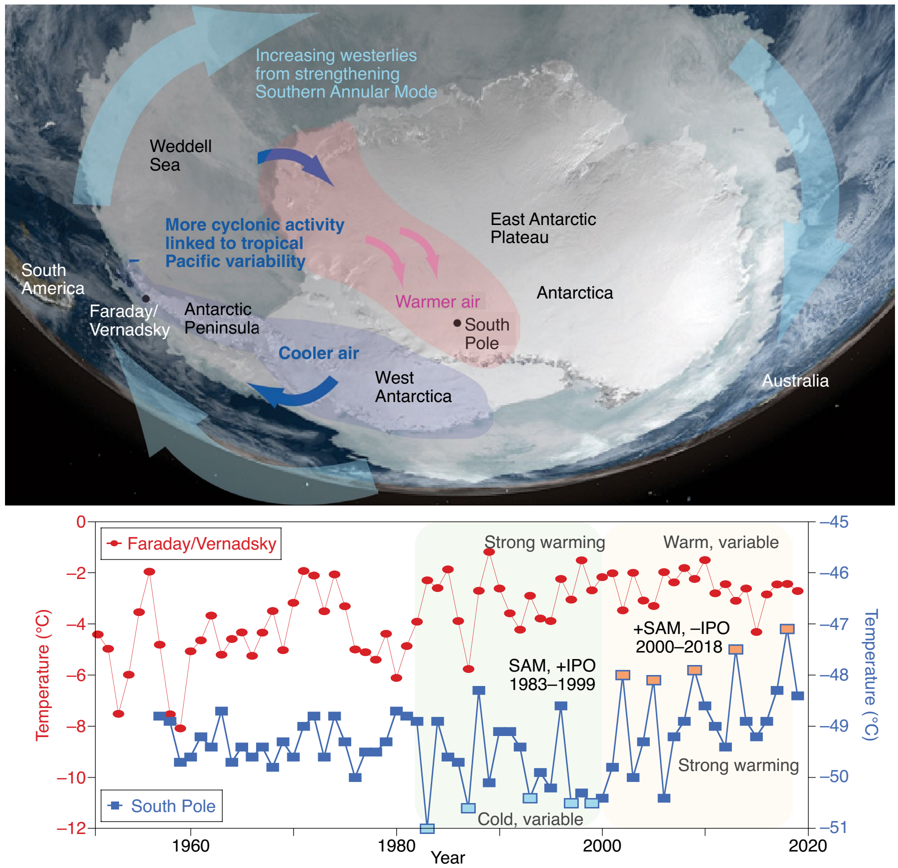

Fig. 1 | Changes in Antarctic atmospheric circulation patterns and air temperature. Top, Antarctica as seen from space with illustration of mechanisms discussed by Clem and colleagues[9]. Stronger westerlies driven by warming, combined with tropical teleconnections from the negative phase of the Interdecadal Pacific Oscillation, produce enhanced cyclonic activity in the Weddell Sea (dark blue arrows). This increases the advection of warm moist air into the high Antarctic interior (red arrows), but shifts wind direction over the Peninsula, slowing the warming there. Bottom, mean annual air temperatures at Faraday/Vernadsky Station and the South Pole (locations shown in top image). Near-record lows (1983, 1987, 1993, 1997 and 1999) and highs (2002, 2005, 2009, 2013 and 2018) are identified in the South Pole series with blue and red squares, respectively.

trends have now weakened (+0.1 °C per decade) or reversed (–0.3 °C per decade), respectively. The reversal is mostly explained by the IPO switch, which also changed the atmospheric circulation patterns impacting these regions.

Although it is well known that the Southern Ocean and Antarctica's coastal regions are sensitive to tropical climate variability, this study now shows the most remote region on the planet (in latitude and altitude) also feels the shifts in tropical heat. But was recent warming at the South Pole encouraged by increasing greenhouse gases? Clem and colleagues show the 1989–2018 warming lies within the upper bounds of the model-simulated range for natural climate variability. They further show that IPO-driven decadal variability, when augmented by SAM, results in a warming rate three times the signal that could be expected from anthropogenic forcing alone. And therein lies the crux for detecting anthropogenic signals in Antarctic climate: climate variability there still exceeds the global climate trend. This does not mean that anthropogenic climate change is not playing a role in Antarctica, but its role is often masked by high intrinsic variability.

Will these high temperatures persist, or might extreme variability shift regional warming again, as it did at the turn of the twenty-first century? The answer will partly be the latter; extreme variability will always dominate Antarctic climate given its welcoming geography and embracing ocean that feels every global perturbation. Although the record analysed by Clem and colleagues ended in 2018, then the warmest year on record for the South Pole (2.4 °C above the 1981–2010 mean), there was yet another record high SAT observed on the Eastern Antarctic Plateau in February 2019, followed by another one in October 2019 (ref. [10]). The underlying cause for the warm event in October 2019 was, however, episodic in nature[10], underscoring the wiliness of Antarctic climate.

But the real take-home message from Clem and colleagues[9] is that no place is immune to climate change. Warming at the South Pole is significant, but its mean temperature is still far below freezing. This is not the case for the coastlines of Antarctica, nor for its 'weak underbelly'[11], the marine-grounded West Antarctic Ice Sheet. The effects of climate change have long made their mark there, with more than 90% of the Peninsula's glaciers in retreat[12] and West Antarctica losing ice at alarming rates[6,13]. Without a doubt, these are unprecedented times, both for the health of our planet and for its inhabitants. Unless we take measures to flatten the curve on global carbon emissions, Antarctica's contribution to a warmer world and sea-level rise could potentially be catastrophic given the strong feedbacks and tipping points inherent in polar systems[14]. The collateral damage will not just be accelerated warming and disappearing coastlines, but everything we value that sustains us. We also know, perhaps better than before, we can live more sustainably. Sheltering in place has given our planet a significant break in carbon emissions[15]. We can make a difference, and we need to make a difference. ❐

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Published online: 29 June 2020
https://doi.org/10.1038/s41558-020-0827-8

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