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Ice core records suggest that Antarctica is warming faster than the global average

Weather station records are too short and sparse to effectively detect the signature of climate change in Antarctica. Using the isotopic composition of ice cores as a temperature proxy suggests that Antarctica is warming faster than the global average temperature and expectations from climate models for the region.

This is a summary of:
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The question

Polar amplification causes polar regions to experience larger temperature increases than the low and mid latitudes. Observations have revealed that over the twentieth century the Arctic has been warming three times faster than the global average temperature. However, evidence of polar amplification in Antarctica remains elusive owing to the lack of data because there are barely 50 years of weather records in Antarctica. This lack of data has led to conflicting evidence as to whether the southern high latitudes are experiencing polar amplification, particularly in East Antarctica[1]. For example, anecdotal evidence of record warming obtained from just two weather stations at the South Pole and Vostok[2] contradicts observations from a larger network of mostly coastal stations, which show limited warming[1].

The solution

Ice cores recovered in Antarctica hold the potential to solve this conundrum because they provide a comprehensive network of temperature-sensitive records[3]. This temperature sensitivity is caused by the distillation of heavier isotopes during the advection of air masses, which yields an approximately linear relationship between the change in oxygen isotopic ratios ($\delta^{18}O$) and temperature. Yet, the interpretation of water isotopes from ice core records remains challenging owing to the numerous archival processes involved in their formation[4], which add layers of noise onto the isotopic signal. By performing an in-depth evaluation of the noise level and the calibration between isotopic composition and temperature, we suggest that a meaningful climatic signal can be retrieved at scales ranging from interannual to centennial when enough ice cores are combined. Therefore, ice cores are a helpful resource for evaluating the multi-decadal anthropogenic warming signal in Antarctica.

Here, we studied a network of 78 ice cores from all around Antarctica[3]. To extract the warming signal, we combined traditional statistical estimators (trend and spectral analyses, Fig. 1a) with dynamical system theory (part of chaos theory, Fig. 1b). In the latter, the persistence time (the average time for which the system remains in a given state) can be a powerful way to measure a trend with an amplitude of similar magnitude to that of the natural variability.

We found that the warming trend since 1950 in Antarctica is outside of the range of natural variability compared to temperature trends from the past 1,000 years. Additionally, this warming is occurring nearly twice as fast as warming in the rest of the world and is 20–50% larger than climate model predictions. Climate models also underestimate the natural variability, with the predicted variability at a decadal scale being half that observed in the ice core data. Our results suggest that East Antarctica is experiencing substantial warming of a similar amplitude to that of the Antarctic Peninsula and West Antarctica, thus confirming the anecdotal evidence from the South Pole and Vostok[2].

The implications

The fact that climate models underestimate both natural and forced climate variability suggests that the feedback loops controlling polar amplification are not adequately parameterized in models of Antarctica. Although climate models can accurately evaluate anthropogenic warming at global scales, their performance remains limited at local and regional scales. An underestimation of Antarctic warming by climate models is concerning as it could mean that there will be further unforeseen destabilization of the climate system, for instance, accelerated sea-level rise[5].

Owing to the model–observation mismatch, it was not possible to perform detection–attribution experiments and directly attribute the inferred Antarctic amplification to a specific forcing or process. However, there are indications that interactions between the Southern Annular Mode and the ozone layer have been limiting the effective warming in East Antarctica. Therefore, recovery of the ozone layer or reversal in the phase of the Southern Annular Mode could lead to even more warming.

So far, we have not been able to compile local temperature reconstructions in Antarctica because a large number of ice cores must be averaged to recover a meaningful decadal signal, which can only be achieved by studying large sub-continental regions. In the future, more ice cores need to be recovered to generate local temperature reconstructions and to better identify the spatial pattern of warming and temperature variability in the Antarctic.

Mathieu Casado[1] & Raphaël Hébert[2]
[1]Laboratoire des Sciences du Climat et de l'Environnement, Paris, France.
[2]Alfred-Wegener-Institute Helmholtz Center for Marine and Polar Research, Potsdam, Germany.

EXPERT OPINION

"Antarctic near-surface temperatures on annual and longer time scales reflect 'climate noise' and climate change. Extracting the signal of change, likely due to anthropogenic forcing, in the presence of decadal to multidecadal variability is a very important consideration. The authors statistically analyse the water isotope records from Antarctic ice cores, which provide temperature proxies, to tackle this issue over time scales that far exceed those of direct meteorological observations."
David Bromwich, Ohio State University, Columbus, OH, USA.

FIGURE

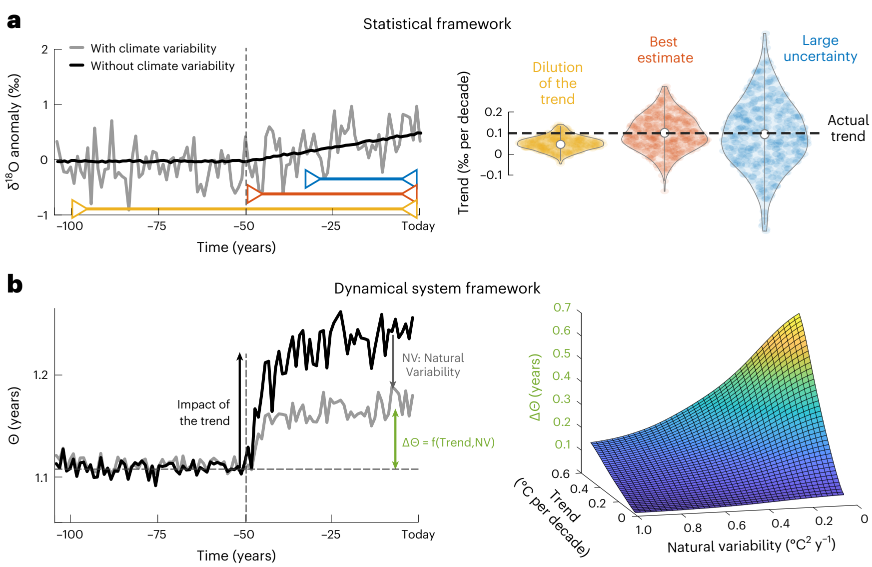

Fig. 1 | Quantification of the impact of climate change in Antarctica when a large amount of natural variability competes with the warming signal. a, Statistical framework for trend estimates. Left, time series of the isotopic composition ($\delta^{18}O$) with (grey line) and without (black line) the effects of climate variability for a 30- (blue), 50- (red) and 100-year (yellow) window length. Right, trend estimates for the three window lengths. **b**, The application of the dynamical system theory to the same time series. Left, persistence (Θ) changes induced by the trend alone (black) and by a mix of a trend and natural variability (NV, grey). Right, change in persistence ($\Delta\Theta$) for an extended range of amplitude of trend and natural variability. © 2023, Casado, M. et al.

BEHIND THE PAPER

It is challenging to detect the signature of climate change in Antarctica and previous ice core studies have failed to identify this signature. Therefore, we started this work wanting to evaluate how many additional ice cores would be needed to find this signature. We also wanted to find out what year the climate signal emerges from natural variability, which is extremely large in polar regions. We realized that an unequivocal warming is already apparent in the temperature reconstructions from the compilation of existing cores. This finding was at odds with the results of meteorological studies of the warming in Antarctica; therefore, we used the dynamical system theory, which can detect fine changes in the underlying properties of the climate system, to confirm these findings. **M.C. & R.H.**

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FROM THE EDITOR

"This study presents a compelling combination of multiple lines of evidence from ice core records to model projections to shed new light on how global warming has already affected Antarctica, an effect that is challenging to measure in observational data alone."
Editorial Team, *Nature Climate Change*.