Solve Antarctica's sea ice puzzle

John Turner, Josefino Comiso and colleagues call for a coordinated push to crack the baffling rise and fall of sea ice around Antarctica.

On 1 March 2017, Antarctic sea ice shrank to a historic low. At about 2 million square kilometres — 27% below the mean annual minimum — its extent was the smallest observed since satellite monitoring began in 1978 (see Figure 1). This rapid decline surprised scientists: until then sea ice cover had been stable and even increasing in Antarctic waters[1]. Record maxima were recorded in 2012, 2013 and 2014[2].

At the other end of the world, a different story is unfolding. More than half of the Arctic's summer-time sea ice coverage has disappeared since the late 1970s[3] --- as global climate models predict for a warming world[4].

These stark differences are hard for researchers to understand[5]. Why has Antarctica managed to keep its sea ice until now? Why are there contrasting regional and seasonal patterns of sea ice change around Antarctica, whereas change is relatively uniform around most of the Arctic? Is the 2017 Antarctic decline a short-term anomaly or the start of a longer-term shift[6, 7]? Is sea ice cover more variable than we thought? Pressingly, why do the majority of world-class climate models have decreasing rather than increasing Antarctic sea ice in recent decades? We need to know whether crucial interactions and feedbacks between the atmosphere, ocean and sea ice are missing from the models, and to what extent human influences are implicated[6].

Why? Because what happens in the Antarctic affects the whole planet. The Southern Ocean plays a key role in global ocean circulation. A frozen sea surface alters the exchange of heat and gases, including CO_2, between the ocean and atmosphere. Sea ice reflects sunlight and influences weather systems, the formation of clouds and precipitation patterns, which in turn affect the mass balance of the Antarctic ice sheet (and its contribution to sea level rise). Furthermore, sea ice is of crucial importance for marine ecosystems, with the ice forming a critical habitat for a wide range of organisms that strongly depend on its seasonal rhythms of advance, retreat and duration e.g., krill, penguins, seals and whales.

So it's imperative that researchers understand the fate of Antarctic sea ice where its area and thickness are changing, and critically why. This needs an inclusive approach that brings together an understanding of the drivers behind the movement of the ice (via drift and deformation i.e. dynamics), as well as the controls on its growth and melt (thermodynamics) Such knowledge underpins climate models, which need to better represent the complex interactions between sea ice and the atmosphere, ocean and ice sheet. To achieve this requires a focused and coordinated international effort across the scientific disciplines that observe and model global climate and the polar regions.

Limited records

Satellites provide the best spatial information on sea ice around Antarctica. Regular observations reveal how ice cover varies over days, years and decades (see figure 1)[8]. Weather, especially high wind storm events, has a daily to seasonal influence. Longer term changes are driven by larger patterns in the temperature and circulation of the atmosphere and oceans.

But near-continuous satellite observations only reach back about four decades. Longer records are essential to link sea ice changes to trends in climate. Information from ships' logbooks, coastal stations, whale catch records, early satellite imagery and chemical analyses of ice cores hint that sea ice coverage might have been up to 25% higher in the 1940s to 1960s [6].

Collecting more ice cores and historical records, and synthesising the information they contain, could reveal local trends that help identify which climatic factors drive Antarctic sea ice changes[6]. For instance, in 2017 the area most depleted of sea ice was located south of the Eastern Pacific Ocean. This region has strong links to the climate of the tropics, including the El Niño – Southern Oscillation, suggesting that sea ice is sensitive to conditions far from the poles.

Another issue is how the balance between dynamics and thermodynamics drives the advance and retreat of sea ice. The thickness and volume of ice depend on many factors, including the flow of heat from the ocean to the atmosphere and to the ice. Sea ice influences the saltiness of the ocean. As it freezes, salt enters the water; as it melts, freshwater returns to the sea. Such processes are very uncertain, to within 50-100% of the signal, and hard to model.

Satellite altimeters can accurately measure the distance between the surfaces of the sea ice and ocean, and this distance can be used to calculate the ice thickness. But it is hard to interpret these data without knowing how much snow lies on the ice, its density and whether its weight pushes the ice surface below sea level (as is often the case). Calibrating and validating satellite data is vital, as is developing algorithms to merge and analyse information from a variety of sources.

Ice, ocean and air must be sampled at appropriate intervals over a sufficiently wide area to establish how they interact. Research icebreaker cruises like the US PIPERS (Polynyas, Ice Production and seasonal Evolution in the Ross Sea) campaign in 2017, are essential for collecting in-situ observations. But these only travel along narrow routes for a short time, typically 1-3 months.

Increasingly, autonomous underwater, on-ice and airborne instruments and vehicles are providing data throughout the year and from inaccessible or dangerous regions. These robotic systems are providing revolutionary new information and insights into, for example, the formation, evolution, thickness and melting of sea ice. Sensors mounted on marine mammals (such as elephant seals), or floats and gliders, also beam back data on temperature, salinity and other physical and bio-geochemical parameters. But to operate continually these instruments need to be robust enough to withstand the harsh Antarctic marine environment.

Improve models

Current climate models struggle to simulate the seasonal and regional variability seen in Antarctic sea ice. Most models have biases, even in basic features such as the size and gross spatial patterns of the annual Antarctic sea ice-retreat cycle or the amount of heat input from the ocean to the ice. The models fail to simulate even gross changes[4], driven by for example tropical influences on regional winds[9]. Because ice and climate are closely coupled, even small errors multiply quickly.

Features that need to be modelled more accurately include the belt of strong westerly winds that rings Antarctica, and the Amundsen Sea Low, a stormy area southwest of the Antarctic Peninsula. Models disagree, for example, on when persistent westerly winds should increase or decrease sea ice coverage around Antarctica. Simulations of clouds and precipitation are also wanting. These cannot reproduce the correct amounts of snowfall or sea surface temperatures of the Southern Ocean (the latter is widely overestimated).

The mixing of waters by surface winds and the impacts of waves on the formation and break-up of sea ice must also be included in climate models. Precipitation and melt-water from ice sheets and icebergs influence the vertical structure of the ocean and how it holds heat, which also affects sea ice growth and decay. High-spatial-resolution models of the atmosphere – ocean – sea ice environment are needed.

Connect research

Gaining a better understanding of the recent variability in Antarctic sea ice, and improving projections of its future in a changing climate requires projects that bridge many disciplines. For example, ice core, historical data rescue and climate modelling communities will need to collaborate to track sea ice variability over timescales longer than the satellite record.

Some gaps in our knowledge can be filled through nationally-funded research. More demanding challenges must be met through international collaboration. Organisations, such as the Scientific Committee on Antarctic Research, Scientific Committee on Oceanic

Research, the World Climate Research Programme's Climate and Cryosphere project and the Past Global Changes project, are leading the way in promoting cross-disciplinary work but much remains to be done. For example, more detailed model comparisons and assessments, research cruises and continuity and enhancement of satellite observing programmes relevant to sea ice are essential. These organisations should partner with funding agencies to make that happen.

Better representations of the Southern Ocean and its sea ice must now be a priority for modelling centres, which have been pushing to simulate the recent loss of Arctic sea ice. Such models will be a vital ingredient in the next assessment of the Intergovernmental Panel on Climate Change, which is due around 2020-21. Initiatives such as the Great Antarctic Climate Hack (http://www.scar.org/antclim21/climatehack), which brings together diverse communities with an interest in Antarctic climate to assess the performance of models are a good example of the collaborative projects needed.

John Turner leads the polar climate and prediction group at the British Antarctic Survey, Cambridge, UK and is the President of the International Association of Meteorology and Atmospheric Sciences.
Josefino Comiso is a senior research scientist at the Goddard Space Flight Center, NASA.
e-mail: jtu@bas.ac.uk

Co-signatories:

Nerilie Abram, Australian National University
Cecilia Bitz, Atmospheric Sciences Department, University of Washington, USA
Thomas J. Bracegirdle, British Antarctic Survey, Cambridge, UK
Rachel Cavanagh, British Antarctic Survey, Cambridge, UK
Pranab Deb, British Antarctic Survey, Cambridge, UK
Hugues Goosse, Université catholique de Louvain, Belgium
Paul R. Holland, British Antarctic Survey, Cambridge, UK
J. Scott Hosking, British Antarctic Survey, Cambridge, UK
Anna Jones, British Antarctic Survey, Cambridge, UK
John C. King, British Antarctic Survey, Cambridge, UK
Ted Maksym, Department of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution, USA
Gareth J. Marshall, British Antarctic Survey, Cambridge, UK
Rob Massom, Australian Antarctic Division and Antarctic Climate & Ecosystems CRC, Hobart, Tasmania, Australia
Eugene Murphy, British Antarctic Survey, Cambridge, UK
Tony Phillips, British Antarctic Survey, Cambridge, UK
James Pope, British Antarctic Survey, Cambridge, UK

Phil Reid, Australian Bureau of Meteorology and Antarctic Climate and Ecosystems CRC, Hobart, Tasmania, Australia
Sharon Stammerjohn, University of Colorado, USA
Liz Thomas, British Antarctic Survey, Cambridge, UK
Jeremy Wilkinson, British Antarctic Survey, Cambridge, UK

Possible images

Sea ice with an embedded iceberg. Marguerite Bay, Antarctica.

Scientists measuring sea ice properties during a research cruise. In situ observations are crucial to both measuring properties that cannot be measured from space and to calibrating/validating larger-scale satellite observations, and in support of process studies. Photography courtesy of Rob Massom.

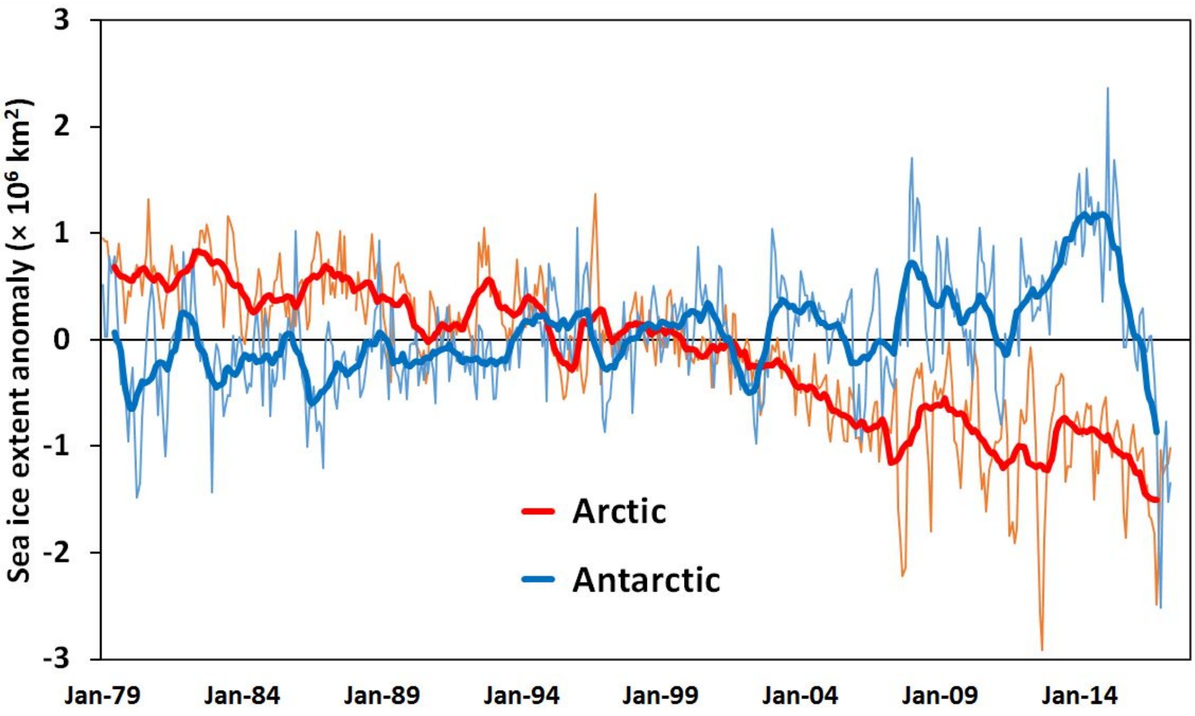

Figure 1. The Arctic and Antarctic monthly sea ice extent anomalies for 1979 – 2017 based on the 1981 – 2010 means. Thin lines show the full data, with the 12 year running mean data indicated by the bold lines. The figure shows the decline of Arctic sea ice, especially since the mid-1990s. The increase of Antarctic sea ice extent until 2014 is also apparent, along with the rapid decrease in 2017. Data from the US National Snow and Ice Data Center (https://nsidc.org/data/seaice_index/archives.html). Plot courtesy of Phil Reid.

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