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Antarctic Climate Change and the Environment – 2019 Update

Antarctic Climate Change and the Environment – 2019 Update

Information Paper submitted by SCAR

Summary

This paper presents an update on the Antarctic Climate Change and the Environment Report (2009 initial publication and 2013 update), providing an overview of recent science. This update is not intended as a synthesis report, but as a perspective on recent scientific advances.

Introduction

This update on recent advances in our understanding of climate change across the Antarctica and the Southern Ocean, and the impacts on the terrestrial and marine biota and ecosystems, builds on the material included in the Antarctic Climate Change and the Environment (ACCE) report, published by SCAR in 2009 (Turner et al. 2009), with an update of the key points in 2013 (Turner et al. 2014).

At the request of the ATCM, SCAR agreed to provide regular updates on the original report (e.g. ATCM Resolution 4 (2010)). This activity is coordinated by the SCAR ACCE Expert Group (see http://www.scar.org/ssg/physical-sciences/acce), which provides annual updates to the ATCM. The remit of the group is to keep abreast of recent advances in climate science, with a particular focus on Antarctic climate change and the environmental implications of such changes.

The original ACCE report and an overview of significant updates are available online as a wiki at http://acce.scar.org/wiki/Antarctic_Climate_Change_and_the_Environment. The online version is progressively updated by a number of editors with input from many active scientists.

As it is 10 years since the publication of the original ACCE volume, SCAR intends to prepare a paper for a refereed journal on major advances in our understanding of Antarctic climate change and its impact on the biota over this period.

Changes in the Antarctic physical environment

1. **There is increasing evidence of a human contribution to changes in the Antarctic atmosphere and the Southern Ocean.** A modelling study by Lenaerts et al. (2018) found evidence that the springtime decrease of stratospheric ozone (the 'ozone hole') had led to an increase in snowfall across the continent. This has implications for the mass balance of the Antarctic ice sheet (the difference between ice lost and ice gained) and therefore for sea level rise. The modelled increase in snowfall was of the same order of magnitude as the observed ice loss (see also 2). This suggests that the mass loss from the Antarctic ice sheet between 1992 and 2005 would have been roughly twice as large without the ozone hole. Another study by Swart et al. (2018) used observations and climate model output to show that the observed warming of the Southern Ocean over recent decades is inconsistent with natural variability and is primarily attributable to human-induced increases in greenhouse gas concentrations, with the 'ozone hole' playing a secondary role.

2. **The amount of ice lost annually from the Antarctic ice sheet increased at least six-fold between 1979 and 2017.** A study based on satellite observations and modelling has shown that the Antarctic Ice Sheet lost 2,720 ± 1,390 gigatons (Gt) of ice between 1992 and 2017, which corresponds to an increase in mean sea level of 7.6 ± 3.9 millimetres. Over this period, ocean-driven melting has caused rates of ice loss from West Antarctica to roughly triple; ice-shelf collapse has increased the rate of ice loss from the Antarctic Peninsula to increase almost five-fold (The IMBIE team, 2018). Over the longer period of 1979 – 2017, Rignot et al. (2019) found that the total mass loss from the ice sheet increased from 40 Gt per year in 1979–1990 to 50 Gt per year in 1989–2000, 166 Gt per year in 1999–2009, and 252 Gt per

year in 2009–2017 (Figure 1). In 2009–2017 the mass loss was dominated by the Amundsen/Bellingshausen Sea sectors in West Antarctica (159 ± 8 Gt per year). The contribution to sea-level rise from Antarctica averaged 3.6 ± 0.5 mm per decade with a cumulative 14.0 ± 2.0 mm since 1979. Most of the ice loss takes place by melting the ice shelves from below, due to incursions of relatively warm ocean water, especially in West Antarctica and to a lesser extent along the Peninsula and in East Antarctica (Rintoul, 2018).

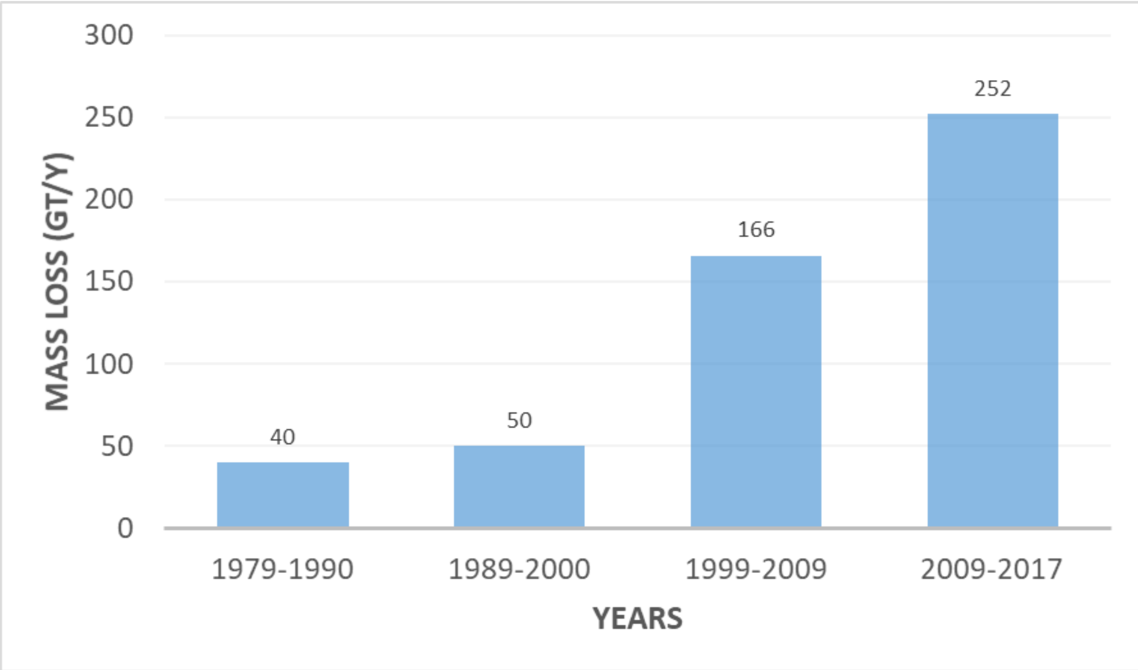

Figure 1: Antarctic ice sheet mass loss between 1979 and 2017 (based on data in Rignot et al., 2019)

3. **Glacier grounding lines are changing.** The locations of grounding lines of glaciers (where the ice starts to float) are key indicators of ice-sheet stability and some are retreating rapidly. Konrad et al. (2018) used satellite observations of ice elevation change to show that between 2010 and 2016, a number of surveyed grounding lines retreated at rates faster than 25 m per year (the typical pace since the Last Glacial Maximum roughly 20,000 years ago). This increased rate of retreat was observed in 22% of the surveyed grounding lines in West Antarctica, 3% in East Antarctica and 10% the Antarctic Peninsula.

4. **Antarctic sea-ice extent has declined significantly since 2014.** From the late 1970s until 2014 the extent of Antarctic sea ice increased at a statistically significant rate, reaching a maximum annual mean extent of 17.41 million square kilometres in 2014. However, this was followed by a decrease that was unprecedented in the satellite era, reaching an annual mean of 16 million square kilometres in 2017 (Figure 2) (Turner et al., 2017). Wang et al. (2019) showed that tropical convection in the Indian and western Pacific Oceans, combined with the influence of the stratospheric polar vortex, acted to create the record summer low in Antarctic sea ice that was observed in 2016. While these processes largely reflect unusual natural variability in the ocean-atmosphere system, the influence from the Indian Ocean may have been enhanced by anthropogenic forcing. In 2018 there was a slight recovery of the ice extent, but it was still well below the long-term mean. Climate models predict that as greenhouse gas concentrations continue to increase, Antarctic sea-ice extent will decrease by about one third by the end of this century. At present, we do not know whether the decrease we have observed since 2014 marks the start of the expected long-term decline or is just an indication of natural variability.

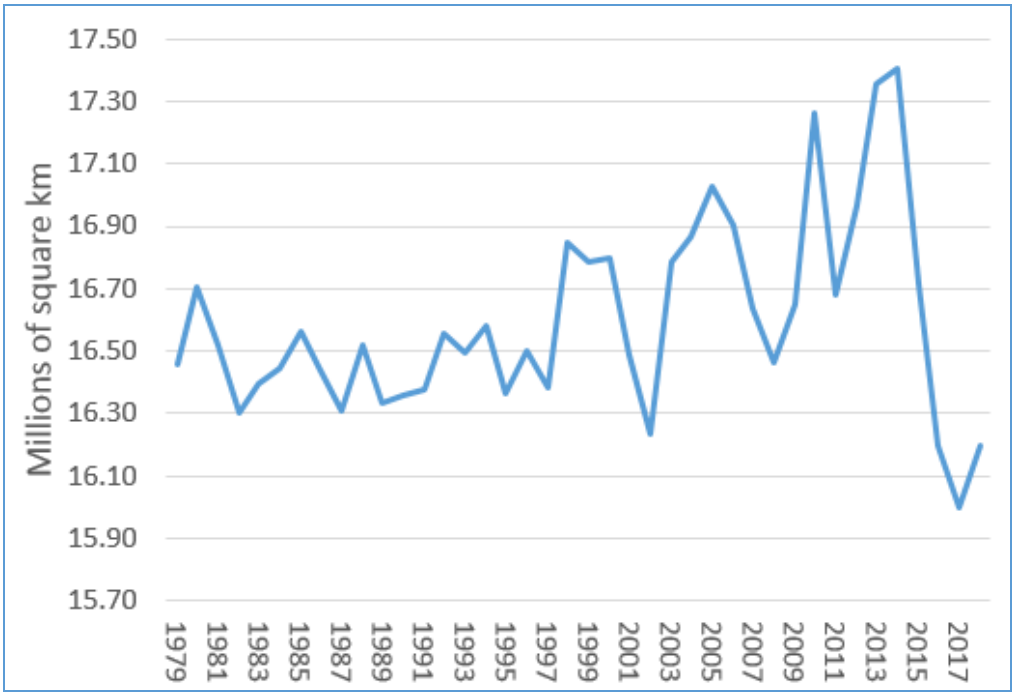

Figure 2. The annual mean extent of Antarctic sea ice (Turner et al 2017)

5. **Changes are taking place in the composition of cold and dense Antarctic Bottom Water (AABW).** AABW is a key component of the global ocean overturning circulation, which regulates climate on a global scale. Repeat surveys in the Indian sector of the Southern Ocean since 1994 reveal that AABW continues to become fresher (0.004 ± 0.001 kg per gram per decade), warmer (0.06° ± 0.01°C per decade) and less dense (0.011 ± 0.002 kg/m^3 per decade), carrying Antarctic climate change signals around the globe (Menezes et al., 2017).

6. **Lack of sea ice could make ice shelves more vulnerable to break up.** The collapse of the Larsen A and B and Wilkins ice shelves have been high-profile glaciological events in the Antarctic in recent decades. A recent study by Massom et al. (2018) has shown that the increasing seasonal absence of a protective sea-ice buffer at the edges of the ice shelves has exposed the vulnerable outer ice-shelf margins to ocean swells, which resulted in increased flexure and probably the weakening of these ice-shelf margins to the point of calving.

7. **Ice cores provide insights into long-term change in West Antarctica.** Ice core data from Roosevelt Island, Ross Ice Shelf and the West Antarctic Ice Sheet Divide have shown that, for most of the past 2,700 years, the Ross Sea experienced the effects of the 'Ross Sea Dipole', characterized by opposite trends of temperature between the eastern and western Ross Sea. The Dipole appears to be a response to the interactions of the Southern Annular Mode (the primary mode of climate variability at high southern latitudes and closely linked to the strength of the westerly winds) and tropical forcing. For most of this period, the eastern Ross Sea warmed, with increased snow accumulation and decreased sea-ice extent, while West Antarctica cooled and the western Ross Sea showed no significant temperature trend. However, from the 17th Century onwards, all three regions have shown signs of warming (RICE Community, 2017).

Changes in the Antarctic biological environment

1. **Terrestrial vegetation changes in response to drying**. Long-term monitoring data from mosses in the Windmill Islands, East Antarctica, has highlighted rapid changes in terrestrial vegetation in response to regional drying (Robinson et al. 2018). This drying trend is evident across the East Antarctic region, as demonstrated by changes in moss isotope signatures, community composition and declining health, as well as long-term observations of physical variables like lake salinity and weather. The study linked the

drying to a more positive Southern Annular Mode in recent decades, which in turn is likely to be related to Antarctic ozone depletion and increased greenhouse gases, and stronger westerly winds circulating close to the continent.

2. **Future expansion of ice-free areas will impact on biodiversity**. Less than one percent of the Antarctic continent is ice-free, but these ice-free areas are critical for terrestrial biodiversity. Using IPCC climate-forcing scenarios, a recent study demonstrated that under the strongest forcing scenario, by the end of the century the extent of ice-free areas could expand by up to 17,000 square kilometres or 25%, with the largest expansion of ice-free areas (300%) to occur in the Antarctic Peninsula (Lee et al. 2017). Currently isolated ice-free areas could combine, potentially creating larger homogenized areas, which might threaten the survival of less-competitive species and encourage the spread of invasive species (Lee et al. 2017).

3. **Ecosystem change in response to unusual weather events**. Another long term study, this time in the McMurdo Dry Valleys, showed that an unusually warm austral summer and associated climatic shift, caused a distinctive and significant ecosystem response (Gooseff et al. 2017). The intense glacial melt triggered by the warmer summer, and more stable climate in years thereafter, had flow on effects to lakes, streams, and productivity in the region. Responses differed among the biological communities, with some showing immediate increases in productivity, and others responding asynchronously a few years after the event. Theses ecosystem responses to climate change point to significant transformations of Antarctic ecosystems, both now and in decades to come.

4. **Climate change affecting populations of long-lived seabirds**. A recent study on Black-browed albatrosses, highlighted the importance of considering the whole life cycle and assessing the sensitivity of multiple pathways when assessing and predicting how climate change influences seabird populations (Jenouvrier et al. 2017). This study found that changes in sea surface temperature were linked to changes in population growth rate through effects on juvenile survival and pre-breeding foraging activity. In a related study, the direction and strength of change in growth and age-structure of black-browed populations were shown to be related to both the mean and the variation in environmental parameters like sea surface temperature (Pardo et al. 2018).

5. **Breeding failures of Adélie penguins.** A population of 20,000 pairs of Adélie penguins in Terre Adélie, East Antarctica has experienced two massive breeding failures, with no chicks surviving the 2013–14 and 2016–17 breeding seasons (Ropert-Coudert et al. 2018). In both seasons the sea ice in front of the colony extended farther and lasted longer than in other years, but there were crucial differences in the timing of sea-ice recession compared to other years. The absence of a polynya (an ice-free area) in a crucial phase of the cycle was paramount in driving these failures. The change in the icescape in the region of the station, following the calving of the Mertz glacier in 2010, together with increased precipitation and changes in sea-ice firmness explain the breeding failure.

6. **Seabird distribution under climate change.** A modelling study examined how the distribution of seven species of large seabird may change taking into consideration environmental variables such as sea surface temperature, wind speed and chlorophyll-a under the four IPCC scenarios of increasing greenhouse gas concentrations. The resulting projections were consistent across the four IPCC scenarios, indicating that there is a strong likelihood of poleward shifts in the distribution of seabirds, with several range contractions (Krüger et al., 2018).

7. **Winners and losers under climate change.** Can we determine which species are most threatened by rapid and complex climate change over the coming decades? The polar oceans are changing, with variations in sea-ice extent, temperatures and acidity amongst others. There is a vital need to assess the vulnerability of particular polar species, as most do not occur anywhere else, and their loss from the polar regions will be a loss to global biodiversity. A recent study used an ecological risk assessment approach to examine the influence of multiple stressors on a wide spectrum of polar life, from encrusting worms to whales (Morley et al. 2019) and identified the vulnerability of polar species under a changing climate. As new habitats are created where sea ice is lost, surprisingly, Morley et al.'s (2019) study found that predicted climate change is likely to result in more winners than losers. However, caution is needed when interpreting these findings, as the study examined less than 1% of polar species, and krill

feeders (which include many of the largest and iconic Antarctic animals) scored consistently as at the greatest risk.

8. **Linking Antarctic Peninsula ecosystems and climate.** Using a range of climate and environmental data from the Palmer Long-Term Ecological Research Project, a recent study developed a novel seascape classification approach to better understand how key ecological parameters are changing over time (Bowman et al. 2018). Eight 'seascape units' were identified and mapped in this process and used in models to clarify the influence of climate related parameters (e.g. sea-ice) on the distribution of key ecosystem indicators, including chlorophyll a and nutrients. Further insights into the interactions between sea-ice, upper mixed layer depth and phytoplankton productivity were provided by a second LTER study, which clearly showed a close relationship between biological systems and sea ice on the Western Antarctic Peninsula (Schofield et al. 2018).

9. **Changes are taking place in krill (*Euphausia superba*) distribution.** Antarctic krill is a critical part of the Southern Ocean ecosystem, supporting a wide variety of predators. Data collected in the main krill population centre between 20° and 80°W in the Southern Ocean over the last 90 years are indicative of a climate-related poleward contraction in the distribution of this cold-water species (Atkinson et al. 2019). These changes are related to changes in the strength of the westerlies. Stronger westerlies precede years of low population density and fewer small krill, suggesting reduced survival of young krill due to increasingly hostile conditions. These changes have implications for biogeochemical cycling and fisheries management.

10. **Ocean warming could affect krill.** Projected ocean warming negatively impacts krill growth rates and could cause penguin numbers to decline in the southwest Atlantic sector by up to 30% by the end of the 21st century, with up to 50% of modelled penguin populations declining by more than 25% (Klein et al., 2018). The authors suggested that krill fishing at current catch limits is anticipated to further increase the risk to krill predators and concluded that spatial protection measures at appropriate scales might help to reduce this additional risk.

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