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Antarctic Climate Change and the Environment – An Update

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Introduction

1. The SCAR Antarctic Climate Change and the Environment (ACCE) report was a major initiative to review the climatic changes that had taken place on the continent and across the Southern Ocean, and to consider the possible impact on the biota and other aspects of the environment. It examined changes on the geological time scale and through the instrumental period of the last 50 years, and considered how the Antarctic climate and environment might evolve over the next century under a range of greenhouse gas emission scenarios.
2. The report was published online ahead of the COP-15 meeting in December 2009 and launched to the media at the Science Media Centre in London on 30 November. It was well received and generated significant attention worldwide, with the editors appearing on TV and radio programs, and conducting interviews with journalists. However, Antarctic science is advancing at a very rapid rate and SCAR has always intended to develop a means of maintaining the momentum of the ACCE initiative. SCAR will prepare periodic updates to the report that highlight new advances in our knowledge of Antarctic climate science. As the ACCE report was published quite recently, here we consider some key questions that climate and other environmental scientists are concerned with.

The separation of natural climate variability from anthropogenic signals

3. The long climate records that can be obtained from ice and ocean sediment cores show the highly variable nature of the Antarctic climate system on all timescales, from the millennial to the decadal and inter-annual. High latitude climates are much more variable than those of the tropics and mid-latitudes, primarily because of interactions between the atmosphere, ocean and ice, making the separation of natural climate variability from anthropogenic signals difficult.
4. Over the last 50 years the Antarctic Peninsula has warmed more than anywhere else in the Southern Hemisphere and is one of the 'hot-spots' of recent global climate change (Zazulie *et al.*, 2010) along with Alaska/northern Canada and Siberia. It is often taken for granted that the Peninsula warming reflects increasing greenhouse gas concentrations, but several processes operating on a range of timescales are responsible for the observed changes. Since around 1980 the ozone hole significantly changed the atmospheric circulation around the continent, increasing the winds over the Southern Ocean and bringing warm air to the eastern side of the Peninsula to contribute to the breakup of the Larsen Ice Shelf. Observations from the stations on the Peninsula show that temperatures have been rising there since the 1950s, pre-dating the ozone hole. An ice core recently collected at Gomez in the southwest corner of the Peninsula provides a 150-year record of accumulation and isotopic temperature data, showing that accumulation has doubled at this site since the 1850s, the most rapid increase being over the last few decades (Thomas *et al.*, 2008). The stable isotope record (Thomas *et al.*, 2009) shows that the large warming at Faraday/Vernadsky station is not just a local phenomena but part of a statistically significant 100-year regional warming trend that began around 1900. It is not clear yet whether this change is a natural climate cycle, or whether anthropogenic factors play a part.
5. Changes have also been observed in oceanic conditions on the decadal time scale. Garbato et al. (2009) show that in the 1970s, warming and salinification of Sub-Antarctic Mode Water (SAMW) in the Drake Passage occurred in parallel to an increase in the Inter-decadal Pacific Oscillation (IPO) index and NE migration of the South Pacific Convergence Zone (SPCZ), which led to a positive anomaly in winter mean evaporation. Post-1990 SAMW cooling and freshening were accompanied by a tendency toward a negative state in the IPO associated with southwestward migration of the SPCZ and a negative anomaly in winter mean evaporation. Thus the IPO plays a significant role in forcing changes in the inter-decadal variability of the Southern Ocean and its associated climate.
6. Changes have also been noted in the locations of the oceanic polar fronts. Sokolov and Rintoul (2009) show that the multiple fronts of the Antarctic Circumpolar Current (ACC) shifted to the south

by 60 km between 1992-2007. The southward shift in fronts is attributed to the southward shift of the westerly winds associated with the southern hemisphere subtropical gyres. As noted above, the ozone hole is regarded as having caused a 15% increase in wind strength since the late 1970s, and may thus be driving the movement of the fronts.

7. Biastoch et al. (2009) use a high resolution ocean model to show that the transport of Indian Ocean Waters around Cape Agulhas (S Africa) into the Atlantic increased during recent decades in response to increased wind forcing and the southward shift in southern hemisphere westerlies. This has led to a salinity increase in the South Atlantic in the upper limb of the Meridional Overturning Circulation (MOC), showing how changes in the Southern Ocean affect global change and vice versa.

8. Changes in the oceans at the edge of the continent also have implications for future climate change. Ecologists predict that formerly ice-shelf covered areas will turn out to be new carbon sinks equivalent to 6000 to 17000 ha of rain forest, acting as a negative feedback to climate change (Peck *et al.*, 2009).

9. On the timescale of ice ages, recent work has also shown large variability. Sime et al. (2009) analysed three 340 kyr long Antarctic ice cores to show that previous estimates of temperatures during past interglacial intervals were too low. The evidence is consistent with a peak interglacial temperature at least 6°C higher than the present day, about double the previously quoted 3°C.

The Antarctic ice sheet and sea level

10. The Antarctic ice sheet is a critical part of the global hydrological system. Past changes in the volume of ice locked into the ice sheet have resulted in large changes to global sea level. Understanding conditions during past interglacials can help us understand how sea level might rise in the future. Kopp et al. (2009) noted that the last interglacial stage (125 kyr ago) serves as a partial analogue for global warming scenarios in which temperature is projected to rise 1-2°C, and find a 95% probability that global sea levels peaked then at least 6.6 m higher than today, but are unlikely (33% probability) to have exceeded 9.4 m. The results suggest the long-term vulnerability of ice sheets to even relatively low levels of sustained warming. Taking the papers by Sime et al and Kopp et al together it could be argued that sea levels were higher then because temperatures were significantly higher, which might invalidate Kopp et al's conclusion about the extent of ice sheet vulnerability.

11. Estimating recent changes in the volume of the ice sheet is a high priority. Several studies have tried to determine this quantity. Velicogna (2009) used monthly measurements of time-variable gravity from the GRACE (Gravity Recovery and Climate Experiment) satellite gravity mission to determine the ice mass-loss for the Greenland and Antarctic Ice Sheets between April 2002 and February 2009, and found that the mass loss was accelerating with time. Prior GRACE studies did not report any increase in mass loss for Antarctica. In Antarctica the mass loss increased from 104 Gt/yr in 2002-2006 to 246 Gt/yr in 2006-2009, an acceleration of -26 ± 14 Gt/yr^2 in 2002-2009. Similar values were found for Greenland. These changes correspond to a total 1.1 ± 0.2 mm/yr sea level rise, helping to explain increases in the rate of sea level rise in recent years. Further evidence for change was found by Pritchard et al. (2009). They used high-resolution ICESat (Ice, Cloud and land Elevation Satellite) laser altimetry to map change along the entire grounded margins of the Greenland and Antarctic ice sheets and found that dynamic thinning of glaciers (i) intensified on key Antarctic grounding lines, (ii) penetrates far into the interior of the ice sheet, and (iii) is spreading as ice shelves thin by ocean-driven melt. They also noted that some glaciers in the Amundsen Sea embayment had thinned more than 9.0 m/yr, and that the largest changes in the ice sheets currently result from glacier dynamics at ocean margins.

12. In terms of sea level projections, Vermeer and Rahmstorf (2009) have updated the approach used by Rahmstorf (2007) to estimate the range of sea level rise anticipated by 2100, by using a numerical model linking global sea-level variations to global mean temperature. This relationship has a correlation of >0.99, explaining 98% of the variance in of sea level and temperature data from 1880–

2000. When applied to synthetic data from a global climate model for the next century, the relationship projects a sea-level rise ranging from 0.75 to 1.9 m for the period 1990–2100. The maximum is higher than the 1.4m maximum sea level rise projected by Rahmstorf in 2007, and the 0.79m projected by the IPCC in 2007.

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