**IP 52**


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# Antarctic Climate Change and the Environment – 2011 Update

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## *Introduction*

This paper is the second update to the ATCM since the publication of the SCAR Antarctic Climate Change and the Environment (ACCE) report (Turner *et al*., 2009a). The ACCE report was a first step in compiling a comprehensive assessment of scientific information on the climate system and ecosystem responses to change in the Antarctic and Southern Ocean region. The present paper, developed by the new SCAR ACCE Expert Group, highlights some recent advances in our knowledge of Antarctic climate science and associated impacts on the environment.

## *Changes in the Antarctic physical environment and biota*

In recent decades the Antarctic Peninsula and some surrounding ocean areas have warmed faster than anywhere else in the Southern Hemisphere. Regional warming of the lowest few kilometres of the atmosphere has been accompanied by cooling of the lower stratosphere and decreases in intra-monthly air temperature variability and in cloud cover (Lagun *et al.*, 2010). Sea ice duration in Maxwell Bay, King George Island decreased from six to three months over 1968 – 2008, and thickness of the fast ice near Bellingshausen station decreased from 90 to 30 cm over the same period.

The rapid climate changes across the Antarctic Peninsula are altering ocean and terrestrial ecosystems. McClintock *et al.* (2008) presented an extensive survey of ecological response to climate change on the Peninsula, confirming much of what was noted in the ACCE report, especially that the biological community on the western shelf of the Peninsula is highly sensitive to environmental change.

A major influence on the existing community is the presence of extensive sea ice in winter and its persistence in summer. The ice shelters diatoms and other "ice algae" as well as the juvenile krill that feed on these primary producers. Ice cover is also essential to Adélie penguins, which use it to reach isolated feeding "hot spots" nourished by upwellings of the Antarctic Circumpolar Current (ACC). Shade from the ice probably limits the territory of the kelp-like macroalgae growing on the sea floor. Beneath the sea ice is a thriving community of benthic invertebrates, such as sponges and corals. As sea ice decreases, Adélie penguins are replaced by open-water loving species - Gentoo and Chinstrap Penguins. Nevertheless, even Chinstrap penguins are in overall decline as their main food, krill, declines with decreasing sea ice (Trivelpiece et al, 2011). McClintock *et al*. (2010) show that Gentoo Penguins have moved south along the western Peninsula over the past 30 years, and recently expanded into the Weddell Sea east of the Peninsula. Gentoos had been absent for 700 years from the areas they now occupy, confirming the effect of warming on the ecology.

In contrast to the Peninsula, most of East Antarctica has cooled slightly and net sea ice extent there has increased slightly (Turner *et al.*, 2009b). This is, in part, caused by the isolating influence of the ozone hole (Thompson and Solomon, 2002).

Antarctic Peninsula warming is well documented, but the magnitude and extent of recent temperature changes across West Antarctica are under review. Steig *et al*. (2009) estimated that most of West Antarctica warmed over the last 50 years at a rate of > 0.1° C per decade, with greatest warming in winter and spring, and that the average temperature for the continent increased since 1957. O'Donnell *et al.* (2011) question some aspects of those results, suggesting that average increases for the continent, East Antarctica, and West Antarctica were half or less than those found in the earlier study, though still significant. O'Donnell *et al.* (2011) did find that West Antarctica warmed from the Peninsula to Marie Byrd Land.

Atmospheric circulation has changed across West Antarctica as demonstrated by an instrumental-era calibrated proxy for northerly air mass incursions into central and western West Antarctica, collected by the International Trans Antarctic Scientific Expedition. This reveals a significant rise in recent decades compared to at least the last 200 years (Dixon *et al.*, 2011), consistent with changes in greenhouse gas warming, ozone depletion and associated intensification of the westerlies.

For the oceans, a recent paper by Purkey and Johnson (2010) verified the ACCE (Turner *et al*., 2009a) finding of a strong statistically significant abyssal warming trend in the Southern Ocean between the 1990s and 2000s.

Electronic tags have been used to show how Antarctic seals respond to environmental changes: Elephant seals prefer Circumpolar Deep Water (CDW), while Crabeater seals prefer the inner continental shelf. As warming extends CDW onto the shelf, the habitat of Elephant seals expands while that of Crabeater seals shrinks (Costa *et al.*, 2010).

The Census of Antarctic Marine Life ended in 2010. It provided unique biodiversity base-line information and a valuable benchmark for detecting future climate-related changes in the marine ecosystem (Gutt *et al.*, 2010). Faunistic data suggest that in the geologically recent past there was a seaway between the Weddell and Ross Sea (Barnes and Hillenbrand, 2010). This implies collapse of the West Antarctic ice sheet between these two seas as recently as the last interglacial 125,000 years ago, when temperatures were 2-3° C warmer than at present, and offers an analog for future warming in the region. Lake sediment records reveal that warm conditions permitted the invasion of a sub-Antarctic microflora at that time (Hodgson *et al.*, 2006).

Re-examination of data on the long-term primary productivity of microalgae in the Southern Ocean showed lower average values than previously recorded, and found that microalgae were very patchily distributed (Arrigo *et al.*, 2008a; Arrigo *et al.*, 2008b. Microalgae were especially productive on the continental shelf, where they must act as a major $CO_2$ sink that has so far been underestimated in global budgets of anthropogenic $CO_2$.

In the Dry Valleys, and elsewhere, (Cary *et al.*, 2010) found evidence that warming could heighten microbial activity and biogeochemical cycling, and contribute to shifts in biodiversity through encouraging introduction of non-native species

In the Amundsen Sea Embayment of West Antarctica, the Pine Island and Thwaites Glaciers have accelerated and thinned, leading to an increasingly negative mass balance (Rignot, 2008). Between 1996 and 2006 the net loss of ice rose from 41 to 90 Gt per year (Rignot et al., 2008). Rignot *et al.* (2011) used data from the gravity satellite mission (GRACE) and other missions to show that in 2006 the Greenland and Antarctic ice sheets experienced a combined mass loss of 475 ± 158 Gt/yr, equivalent to 1.3 ± 0.4 mm/yr sea level rise. The acceleration in ice sheet loss over the last 18 years was 21.9 ± 1 Gt/yr for Greenland and 14.5 ± 2 Gt/yr for Antarctica. This contribution is three times larger than for mountain glaciers and ice caps (12 ± 6 Gt/yr). If this trend continues, ice sheets will be the dominant contributor to sea level rise in the 21st century.

A recent modelling study (Joughin *et al.*, 2010) found that the factor most responsible for mass loss by the Pine Island Glacier was melting due to exposure of the underside of the ice shelf to warm subsurface ocean currents. These thin the ice shelf, cause the grounding line to retreat, and so increase the speed of ice stream flow to the sea. This process may explain loss of other ice shelves over the past 15,000 years (Smith *et al.*, 2007). *Autosub* data obtained in 2009 under the Pine Island Glacier showed that warm sea-water flows beneath the ice shelf over a submarine ridge to melt the base of the ice shelf, thus moving the limit of grounded ice inland by 30 km (Jenkins *et al.*, 2010). A February 2008 oceanographic section in Pine Island Bay (Antipov *et al.*, 2009), confirmed significant penetration of warm CDW with a temperature of +1.0°C onto the continental shelf. This is likely to be the cause of the melting. Overlying the warm water is a cold, fresh layer, probably comprising melt water from outlet glaciers and ice shelves.

The thinning ice of West Antarctica currently contributes ~10% to the observed rise in global sea level. Joughin et al. (2010) suggest that mass loss here may continue through the 21st century at rates similar to, or even slightly greater than today, yielding a rise in sea level by the year 2100 due purely to mass loss by Pine Island Glacier of up to 2.7 cm.

Many factors cause climate variability and change in Antarctica and the Southern Ocean. They include natural variability, changes in greenhouse gas concentrations, depletion of stratospheric ozone, forcing from the tropics, aerosols from volcanic eruptions, and variability in the amount of solar radiation. We expand here on the last of these since it was not covered in detail in the ACCE report.

Proxies for atmospheric circulation derived from ice cores reveal the impact of solar variability on changes in atmospheric circulation (Mayewski et al., 2005). Increased (decreased) solar irradiance is associated through changes in stratospheric ozone with increased (decreased) westerly winds near the edge of the

Antarctic polar vortex. Given the observations of Turner *et al.* (2009b) that changes in stratospheric ozone affect surface winds, these palaeoclimatic data signify that both natural and human-induced changes in stratospheric ozone are important drivers of Antarctic climate change.

Seppälä et al. (2009) found that, during winter, polar surface air temperatures in years with a high level of solar-induced geomagnetic activity differed from those in years with a lower amount of such activity. The difference was statistically significant, with temperature differences up to 4.5°C in some fairly small areas. However, it should be noted that other factors, such as changes in sea ice extent, can produce comparable, or even larger, changes of temperature. This highlights the need to consider broad-scale change in trying to separate natural from anthropogenic influences on the Antarctic climate system. Research is underway to understand the link between upper atmosphere changes in such activity and surface conditions.

The SCAR Expert Group on ACCE currently includes: John Turner, Colin Summerhayes, Mike Sparrow, Paul Mayewski, Pete Convey, Guido di Prisco, Julian Gutt, Dominic Hodgson, Sabrina Speich, Tony Worby, Sun Bo and Alexander Klepikov.

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