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Antarctic Climate Change and the Environment – 2014 Update

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Introduction

In 2009 SCAR carried out a major assessment of how the climate of the Antarctic and Southern Ocean had changed in the past, how it might change in the future under a range of greenhouse gas emission scenarios and how these changes affect the biota. The work was published in November 2009 as the Antarctic Climate Change and the Environment (ACCE) report (Turner et al. 2009), with a summary appearing in the peer reviewed literature (Convey et al. 2009). At the request of the ATCM, SCAR agreed to provide regular updates (e.g. ATCM Resolution 4 (2010)), and in 2013 a major review of the 'key points' from the original ACCE report was published (Turner et al. 2013). The SCAR ACCE Advisory Group keeps abreast of recent advances in climate science, with a particular focus on Antarctic climate change and the biological implications of such changes. The present paper, prepared by the SCAR ACCE Advisory Group, highlights some notable advances in Antarctic climate science over the last 2 years. A comprehensive reference list is provided so that more details of particular research can be consulted.

Changes in the Antarctic physical environment and biota

- Over the last 50 years stations on the Antarctic Peninsula have recorded a marked increase in near-surface air temperature, with the rest of the continent having experienced little warming. However, it was not clear how far the warming extended into West Antarctica. Recently, a complete temperature record for Byrd Station (80.0° S, 120.0° W) has been created, in which observations were corrected and gaps filled using global reanalysis data and spatial interpolation. The record showed that the location has warmed by about 2.4° C during the period 1958 - 2010 establishing central West Antarctica as one of the fastest-warming regions on Earth (Bromwich et al. 2013). Ice core records from West Antarctica indicate that recent changes in atmospheric circulation, and particularly the poleward migration of the westerlies, have led to unprecedented penetration of warm air masses into West Antarctica within the record extending back 100,000 years ago (Mayewski et al. 2013).
- The rapid recent warming of the Antarctic Peninsula has resulted in changes in the terrestrial ecology. However, the biological records are shorter in length than the meteorological data, and observed population changes cannot be securely linked to longer-term trends apparent in paleoclimate data. To overcome this limitation a new, unique time series of past moss growth and soil microbial activity has been developed from a 150-year-old moss bank at the southern limit of significant moss peat accumulation on northern Alexander Island (c. 70° S). It has been shown that growth rates and microbial productivity have risen rapidly since the 1960s, consistent with temperature changes. The recent increases in terrestrial plant growth rates and soil microbial activity are unprecedented in the last 150 years (Royles et al. 2013). Other moss banks are also being analysed to identify the spatial extent of this change and clarify the influence of climatic variables on moss growth rates in other parts of Antarctica (e.g. Clarke et al. 2012).
- Northwest of the Antarctic Peninsula ice core records from James Ross Island show surface melting events have increased in intensity since the mid-twentieth century and are now at a level unprecedented over the past 1,000 years (Abram et al. 2013).
- It has been known for some time that atmospheric and oceanic conditions across the tropical Pacific Ocean can affect the climate of the Antarctic, especially in the sector between the Antarctic Peninsula and the Ross Sea. This is the region of the climatological Amundsen Sea Low, variability of which affects the climate of West Antarctica (Hosking et al. 2013). The Amundsen Sea Low has deepened over the last 30 years contributing to the observed regional warming. West Antarctic ice core records for the past 2,000 years show results consistent with the large atmospheric variability in this region, with the recent warming trend estimated from proxy data to have been exceeded a number of times in the past. The implication is that the large natural variability may have masked anthropogenically-forced change (Steig et al. 2013; Thomas et al. 2013). Recently it has been suggested that sea surface temperature changes across the Atlantic Ocean can also affect the depth of the Amundsen Sea Low (Li et al. 2014).

- A circumpolar risk-map of krill hatching success under projected CO_2 levels shows high-risk areas for krill recruitment in important krill habitats such as the Weddell Sea and areas far off-shore in the western Indian sector of the Southern Ocean as well as off Prydz Bay, East Antarctica (Kawaguchi et al. 2013).
- Key ecological species were found to respond to environmental change with very dynamic population performance. For example, unusual growth events of glass sponges in McMurdo Sound correlated with shifts in phytoplankton productivity driven by the calving of a massive iceberg. At the same time almost complete mortality was documented in an adjacent area due to a variety of potential biological and physical reasons (Dayton et al. 2013). Dense populations of fast-growing ascidians were observed in 2007 in the Larsen areas east of the Peninsula. These were assumed to have developed since the disintegration of the iceshelves. The ascidians disappeared within the next 4 years, possibly due to intensive predation by gastropods. In the same period, species composition of brittle stars shifted from filter to deposit feeders (Dayton et al. 2013; Gutt et al. 2013).
- A comprehensive review of krill has been carried out mainly focussing on the impact of climate change, resulting in the general conclusion that despite some positive aspects, the cumulative impact of several factors is most likely negative, e.g. that of sea ice decline and ocean warming mainly on winter survival of larvae, which determines the biomass and abundance of the next generation of adults. (Flores et al. 2012).
- Antarctic marine invertebrates examined took 2 to 6 months to acclimate to a 2-3° C rise in temperature, an order of magnitude longer than equivalent species from temperate environments (Peck et al. 2014). Thus, they might be more at risk than related species from intermediate latitudes. This result, together with evidence from other studies (e.g. see review by Kaiser et al. 2013), suggests that the variability of temperature may significantly determine the response of organisms to general environmental change, particularly over the short term.
- Along the warming Antarctic Peninsula, gentoo penguins increased in abundance at 32 of 45 sites investigated between 1979/1980 and 2009/2010 and they are expanding southward, which correlates with the loss of November sea-ice coverage (Lynch et al. 2012).
- Antarctic coastal benthic communities are assumed to be especially climate-sensitive due to their high regional heterogeneity and uniqueness (Grange and Smith, 2013). Thus, these are at relatively high risk to decrease or change significantly their contribution to the overall Antarctic marine biological structure and functioning as well as ecosystem services.
- A study of grey-headed albatrosses showed that these top-predators were not able to find sufficient alternative prey in the event of climate-induced food shortage (Xavier et al. 2013).
- Two volumes have recently been published that provide an important biological update to the original ACCE volume. They consist of a total of 22 contributions from well known marine biologists and teams, dealing with microorganisms to top predators and ecosystems, and from ecology to molecular biology (di Prisco and Verde 2012; Verde and di Prisco 2012). The reviews address the impact of current climate change on biodiversity, adaptations and community dynamics, and include proposed research developments in the decades to come.
- A paper has been published recently summarising how cold temperatures affect microbial physiology in regions heavily impacted by global warming (Giordano et al. 2013). The authors focussed on the molecular, biochemical and genetic mechanisms of cold adaptation, and the insights were largely provided by genomic sequences. They also found that unique adaptive structural properties enhanced the overall flexibility of the protein, so that the structure becomes resistant to pressure-induced stress. Recent results from a genomic mutant strain also demonstrated the involvement of cold-adapted globin in the protection against the stress induced by high O_2 levels, and in the reactions with NO to produce nitrate anions.
- Evidence of diverse life forms dating back nearly a hundred thousand years has been found in subglacial lake sediments collected on the Antarctic Peninsula. Lake Hodgson was covered by more than 400 m of ice at the end of the last Ice Age, but is now considered to be an emerging subglacial lake, with a thin covering of just 3–4 metres of ice (Pearce et al. 2013). Continued climate change and glacier retreat is likely to expose more subglacial lakes at the edge of the ice sheet.
- An overview of permafrost conditions in the Antarctic Peninsula show that the dramatic warming of the climate over the few last decades has influenced the properties and distribution of permafrost (Bockheim

et al., 2013). Whereas permafrost is continuous in the South Orkney Islands (60–61°S) and along the eastern Antarctic Peninsula (63–65°S), it is discontinuous in the South Shetland Islands (62–63°S), and occurs only sporadically in the Palmer Archipelago and Biscoe Islands along the western Antarctic Peninsula (64–66°S). Permafrost then becomes continuous on Alexander Island (71–74°S) along the western Antarctic Peninsula as the maritime climate shifts to a more continental climate (Bockheim et al., 2013).

- If greenhouse gas concentrations continue to increase it is anticipated that the acidity of the oceans will increase with a potential impact on the marine biota. A recent experimental study using sea urchins has shown that different responses are found if the larvae are introduced to the more acidic water at different rates (Suckling et al. 2014), implying that there may be greater capacity within these organisms to adapt to changing acidification levels than previously suspected. Ocean acidification was also identified as a key threatening process for Southern Ocean krill, with predictions that the entire population could collapse by 2300 unless CO_2 emissions are mitigated (Kawaguchi et al. 2013).
- The retreat and thinning of the Pine Island Glacier on the coast of West Antarctica continues to attract a great deal of observational and modelling research, as well as public and media interest. It is now well known that intrusions of warm Circumpolar Deep Water under the ice shelf are important in the melting of the ice. However, it has been shown that the melting is very variable, having decreased by 50% between January 2010 and 2012. The ocean conditions in 2012 have been partly attributable to atmospheric forcing associated with a strong La Niña event in the tropical Pacific (Dutrieux et al. 2014). Recent research (Johnson et al. 2014) has shown that there has been rapid thinning of the Pine Ice Glacier in the past, with glacial-geological and geochronological data indicating that such a thinning also took place in the Early Holocene some 8,000 years ago. How the Pine Island Glacier will change over the coming decades is an extremely important question because of the possible implications for the large-scale loss of ice from West Antarctica with consequent impact on sea level rise. A recent paper presenting modelling results has suggested that regardless of how ocean and atmospheric conditions change over the coming decades, retreat of the Pine Island Glacier is now irreversible (Favier et al. 2014).
- The slight increase over the last 30 years in the extent of Antarctic sea ice is in stark contrast to the marked decline of Arctic sea ice. The mechanism or mechanisms responsible for the increasing sea ice extent are still being discussed (Bintanja et al. 2013), although some research suggests that it could be a result of natural variability (Polvani and Smith 2013). The ongoing increase in sea ice extent was highlighted by the fact that it reached a record for the satellite era in September 2012 (Turner et al. 2013), which was then exceeded by the extent in September 2013.
- New insight has been obtained on the relationship between CO_2 concentrations and Antarctic temperatures during the last deglaciation. A novel nitrogen isotope technique to establish the difference between the gas age and the age of the surrounding ice in several Antarctic ice cores was developed (Parrenin et al. 2013). Results show that atmospheric CO_2 concentrations and Antarctic temperatures were tightly coupled throughout the last deglaciation, within an uncertainty of less than ±200 years. The correlation between CO_2 and Antarctic temperature using the new gas-age chronology is very high (0.993), suggesting that the rise in CO_2 could have contributed to much of the rise in temperature in Antarctica during the last deglaciation, even at its onset.
- A new annually resolved ice core record from the West Antarctic Divide has provided insight into the most recent Antarctic deglaciation (Fudge et al. 2013). The records show that 18,000 years ago snow accumulation in West Antarctica began increasing, coincident with increasing CO_2 concentrations, warming in East Antarctica and cooling in the Northern Hemisphere, associated with an abrupt decrease in Atlantic meridional overturning circulation. However, significant warming in West Antarctica began at least 2,000 years earlier. Circum-Antarctic sea-ice decline, driven by increasing local insolation, is the likely cause of this warming. The marine-influenced West Antarctic records suggest a more active role for the Southern Ocean in the onset of deglaciation than is inferred from ice cores in the East Antarctic interior, which are largely isolated from sea-ice changes.

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