IP 35

XXXIX ANTARCTIC TREATY CONSULTATIVE MEETING
SANTIAGO - CHILE 2016
25 YEARS PROTOCOL ON ENVIRONMENTAL PROTECTION

Agenda Item:	ATCM 16, CEP 7a
Presented by:	SCAR
Original:	English
Submitted:	19/04/2016

Antarctic Climate Change and the Environment 2016 Update

Antarctic Climate Change and the Environment – 2016 Update

Introduction

Here we provide an update on recent significant advances in our understanding of climate change across the Antarctic continent and the Southern Ocean, and the impacts on the terrestrial and marine biota. This document builds on the material included in the Antarctic Climate Change and the Environment (ACCE) report, which was published by SCAR in 2009 (Turner *et al.*, 2009), with an update of the key points appearing in 2013 (Turner *et al.*, 2013). At the request of the ATCM, SCAR agreed to provide regular updates on the original report (e.g. ATCM Resolution 4 (2010)) and that activity is coordinated by the SCAR ACCE Advisory Group. The scope of the group is to keep abreast of recent advances in climate science, with a particular focus on Antarctic climate change and the biological implications of such changes. A recent development has been that the original ACCE report and the updated key points have been made available online as a wiki at http://acce.scar.org/wiki/Antarctic_Climate_Change_and_the_Environment. This online version is being progressively updated by a number of editors with input from many active scientists.

Changes in the Antarctic physical environment

1. Esperanza Station on the Antarctic Peninsula has recorded what may be the highest temperature ever observed on the Antarctic continent. On March 24 2015 a temperature of 17.5° C was measured, beating the previous record of 17.1° C, also recorded at Esperanza, on April 24, 1961. The new record occurred during a period of warm, maritime north-westerly airflow arriving at the Peninsula, with an increase in the temperature as a result of the Foehn effect as the air crossed the Peninsula.

2. The Antarctic ozone hole of 2015 was larger in area and formed later than the ozone holes of recent years. Analysis by Australia's Commonwealth Scientific and Industrial Organisation (CSIRO) placed the 2015 ozone hole as the 5th largest observed in terms of total ozone deficit. In terms of total area, the 2015 hole set new daily records from October to mid-November. The behaviour of the 2015 hole was consistent with current understanding of ozone depletion chemistry under conditions of below average temperatures that prevailed in the Antarctic lower stratosphere during the austral spring.

3. A number of recent papers have highlighted that temperature and precipitation change over the Antarctic continent is very closely tied to conditions of the surrounding sea ice and ocean surface temperature (Bracegirdle *et al.*, 2015; Krinner *et al.*, 2014; Schmithusen *et al.*, 2015). Key implications of this are that reliable reconstructions of sea ice in the past, and climate model projections into the future, are of central importance to reconstructing past and predicting future climate conditions over the Antarctic continent.

4. The latest palaeoclimate analyses from sediment cores collected from the Southern Ocean show that during the last glacial period carbon storage in sediments was greatly amplified, which caused bottom waters to become less well oxygenated (Jaccard *et al.*, 2016). During the last deglaciation a decrease in the supply of dust to the Southern Ocean surface reduced the supply of the limiting nutrient Fe, hence reducing productivity, which in turn reduced the oceanic entrapment of CO_2 by plankton, hence reducing ocean carbon storage and encouraging an increase in global atmospheric CO_2 and an increase in the oxygenation of bottom waters.

5. A new ocean-atmosphere-ice climate model applied by scientists from the Alfred Wegener Institute suggests that exceeding critical temperature limits in the Southern Ocean may cause the marine-based West Antarctic Ice Sheet to collapse, as it appears to have done during the last warm interglacial 125,000 years ago, when polar temperatures were about 2° C warmer than today, causing a sharp rise in sea level (Sutter *et al.*, 2016). The time frame for such a collapse, if global warming continues under the 'business-as-usual' scenario of the IPCC, is around 1,000 years. The model suggests that the first stage of the collapse involves retreat of the ice shelves that buttress the glaciers draining the hinterland. In the second phase those glaciers discharge rapidly into the ocean, draining the inland ice. The resulting rise in sea level accentuates the process.

6. Estimating how much decay of the Antarctic ice sheet will contribute to sea level rise in the future is a very active area of research. A key unknown is the dependence of sliding on basal friction. Ritz et al. (2015) doubted the previous estimates of maximal loss of up to 1 m by 2100 and around 1.5 m by 2200, and suggested they were implausible under current understanding of physical mechanisms and potential triggers. That conclusion appeared to be supported by new findings from the application of coupled sea-level and ice sheet models by Gomez *et al.* (2015), who found that ice retreat tends to be accompanied by a rise in bedrock elevation and a lowering of sea-level close to the ice sheet (because of gravitational effects – glacial isostatic adjustment), thus tending to keep the ice sheet stable. These processes tend to work best where global warming forecasts are low. With fast warming, the slow process of glacial isostatic adjustment cannot keep up with rapid rates of loss of ice. However, a recent study by DeConto and Pollard (2016) used a model coupling ice sheet and climate dynamics — including previously underappreciated processes linking atmospheric warming with hydrofracturing of buttressing ice shelves and structural collapse of marine-terminating ice cliffs — that is calibrated against Pliocene and Last Interglacial sea-level estimates and applied this to future greenhouse gas emission scenarios. They estimated that Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500, if emissions continue unabated. In this case, atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.

7. Another model by Golledge *et al.* (2015) suggests that unless anthropogenic greenhouse-gas emissions are reduced to half of 1990 levels by 2050, global mean annual surface temperatures are likely to exceed 2° C above pre-industrial values by 2100 leading to a sea level rise of around 1 m, which is at the upper end of current IPCC estimates. With further warming the future contribution to a rise in sea level from Antarctica is substantial, because collapse of buttressing ice shelves leads to a dynamic ice-sheet response that greatly increases grounded ice discharge for hundreds to thousands of years into the future. In the model, ice-shelf stability is vulnerable to a critical temperature threshold. Prolonged ocean warming of 0.5° C above present, together with atmospheric warming of 2° C, leads to the loss of 80% to 85% of all floating ice in Antarctica. High emission scenarios lead to ice loss from Antarctic that will raise sea level by 0.6–3 m by the year 2300. "In the scenarios in which ice shelves are lost, the long-term contribution of the Antarctic ice sheet to global sea-level rise ranges from roughly 3 to 9 m. The majority of that contribution comes after 2300, with enhanced rates of sea-level rise lasting until at least 3000 — long after ocean temperatures have stabilized" (Robel, 2015).

8. It is increasingly clear that the Pine Island and associated glaciers in the Amundsen Sea Embayment are subject to thinning from the intrusion of warm Circumpolar Deep Water (CDW) onto the continental shelf, causing melting beneath the adjacent ice shelf, making these glaciers thin and increasing the speed in recent decades. New data show that the incursion of these warm waters slowed between 2010 and 2012, decreasing ice melting off Pine Island by 50% in 2012. The change was associated with a strong La Niña event that brought strong easterly winds to the region, causing coastal downwelling that deepened the thermocline and barred access of the CDW to the inner continental shelf (Dutrieux *et al.*, 2014). In East Antarctica, the Totten Glacier has also been identified as potentially subject to melting from beneath by the intrusion of CDW and is thinning faster than other outlet glaciers in the region (Greenbaum *et al*., 2015).

9. Pollard et al. (2015) point to a discrepancy between models and data, in that geological records show, from fluctuations in sea level during previous interglacials, that there must have been substantial contributions of ice from the East Antarctic Ice Sheet that are not seen in future projections made by numerical models. They point out that in response to atmospheric and ocean temperatures typical of past warm periods, floating ice shelves were likely drastically reduced or removed completely by increased oceanic melting, and by hydrofracturing due to surface melt draining into crevasses (which is what happened in the destruction of the Larsen B Ice Shelf in 2002). Ice at deep grounding lines is likely to be weakened by hydrofracturing and reduced buttressing, and may fail structurally if stresses exceed the ice yield strength, producing rapid retreat. Incorporating these mechanisms into their ice-sheet model accelerated the expected collapse of the West Antarctic Ice Sheet to decadal time scales, and also caused ice to retreat into major East Antarctic subglacial basins, producing 17 m of global sea-level rise within a few thousand years.

10. Using the BISICLES adaptive mesh ice sheet model, Cornford *et al.* (2015) calculate that "Given sufficient melt rates …. grounding line retreat [will take place] … over hundreds of kilometers in every major ice stream, but the ocean models do not predict such melt rates outside of the Amundsen Sea Embayment until after 2100. Within the Amundsen Sea Embayment the largest single source of variability

is the onset of sustained retreat in Thwaites Glacier, which can triple the rate of eustatic sea level rise." "Simulations based upon these more realistic projections result in significant dynamic losses in the Amundsen Sea Embayment: up to 50 mm sea level equivalent by 2100 and 150 mm sea level equivalent by 2200 provided that Thwaites Glacier retreats".

11. Despite the Amundsen Sea Embayment being the site of recent ice loss, it is also the site of relatively recent snow gain, though the rate of gain decreases progressively from the base of the Peninsula into West Antarctica proper. Thomas *et al*. (2015) found that 300-year records of snow accumulation from two cores drilled in Ellsworth Land, West Antarctica, showed a dramatic increase in snow accumulation during the 20th century. This was linked to the deepening of the Amundsen Sea Low (ASL) pressure system, which took place in response to changes in the large scale atmospheric circulation (notably the strengthening of the zonal wind around Antarctica and the gradual movement of the Polar Front close to the continent). The trend to increased snowfall (and by inference the depth of the ASL) accelerated in the 1990s. Analyses of ICESat data (Ice Cloud and Land Elevation Satellite) between 2003-2008 suggest that gains from snow accumulation exceeded losses from discharge by 82±25 Gigatonnes per year for the Antarctic as a whole (Zwally *et al.*, 2015). Most of the gain occurred in East Antarctica, while losses continued from West Antarctica and the Peninsula. The overall gains were less than in the period 1992-2001, which suggests a trend towards progressive decline in ice gain (i.e. progressively more ice loss). This NASA report ran counter to what had been reported by the IPCC in 2014, and attracted significant media attention.

12. Using the output of 11 global climate models forced with two possible greenhouse gas emission scenarios, Hosking *et al*. (2016) showed that by the end of this century the ASL will likely migrate poleward in summer (December, January and February) and autumn (March, April, and May), and eastward in autumn and winter (June, July, and August). The autumn-winter changes could drive colder southerly winds over the Ross Sea and warmer northerly winds toward the Antarctic Peninsula. That would tend to increase the production of sea ice in the Ross Sea polynya, and to further decrease the production of sea ice along the Peninsula.

13. Using radar altimeter data from the European Space Agency's CryoSat-2 satellite, Chuter and Bamber (2015) have made the most complete and accurate measurements yet of Antarctic ice shelf thickness (Stanley, 2016). Their measurements include 92.3% of the total surface area of the continent's ice shelves — more than is covered by any other data set. The elevation data cover the period 2011-2014 and are four times more accurate than the best previous continent-wide measurements (e.g. compared to data from NASA's Ice, ICESat mission). The data were validated by comparison with several ice-penetrating radar data sets, which measure the ice thickness directly. The mean thickness difference between the new satellite-derived ice thickness and the ice-penetrating radar data was 3.3% for the Amery Ice Shelf, for example. These data will help to track change from year to year.

14. Some of the variation in climate over the past 10,000 years recorded in the Vostok ice core is likely to be due to variations in solar output (Zhao and Feng, 2014). This is not a surprising finding, in that the association of solar variation with temperature over that period is now reasonably well documented (Summerhayes, 2015). Zhao and Feng (2014) found that there was only a weak association between the indications of solar activity (or temperature) and the CO_2 concentration in air bubbles in the ice cores for this time period. That too should not be surprising, as Ruddiman *et al*. (2015) have demonstrated that CO_2 began to rise in the atmosphere around 6000 years before present, most likely due to forest clearance for agriculture, which destroyed the natural link between solar variation, atmospheric CO_2 and temperature for that period.

15. A drill core from the Ross Sea has provided the first evidence of orbitally-controlled glacial cycles 34-31 million years ago. Initially, when CO_2 levels were at or above 600 ppm, there was a small Antarctic ice sheet on the continent. It was highly responsive to local insolation forcing. A more stable ice sheet of continental scale with glaciers calving at the coast did not develop until 32.8 million years ago, when CO_2 levels fell below 600 ppm (Galeotti *et al.*, 2016).

16. Mounting evidence from models and geological data implies that the Antarctic Ice Sheet may behave in an unstable manner and retreat rapidly in response to a warming climate, which is a key factor motivating efforts to improve estimates of Antarctic ice volume contributions to future sea-level rise. McKay *et al*. (2016) review Antarctic cooling history since peak temperatures of the Middle Eocene Climatic Optimum (approx. 50 Ma) to provide a framework for future initiatives to recover sediment cores from subglacial lakes

and sedimentary basins in Antarctica's continental interior. While the existing inventory of cores has yielded important insights into the biotic and climatic evolution of Antarctica, strata have numerous and often lengthy time breaks, providing a framework of 'snapshots' through time. Further cores, and more work on existing cores, are needed to reconcile Antarctic records with the more continuous 'farfield' records documenting the evolution of global ice volume and deep-sea temperature. To achieve this, the authors argue for an integrated portfolio of drilling and coring missions that encompasses existing methodologies using ship- and sea-ice-/ice-shelf-based drilling platforms as well as recently developed seafloor-based drilling and subglacial access systems.

Changes in the Antarctic biological environment

17. The continental shelf around West Antarctica is wide and deep and the rich benthos colonising it has always represented important potential for carbon accumulation and sequestration. Recently the annual carbon accumulation on West Antarctic shelves was estimated at nearly 3×10^6 tonnes/yr (Barnes, 2015). More importantly, this was shown to have doubled in the last 25 years in response to sea ice losses. If Arctic continental shelf benthos is responding similarly, this would be the largest known negative feedback against climate change (i.e. more important than that estimated for sequestration than arcto-boreal forests). Regional shelves around Antarctica differ significantly in their carbon accumulation, related to a number of factors, but most importantly reductions in sea ice area and duration correlate with longer phytoplankton blooms (Barnes *et al.*, 2016).

18. A study by McIntyre *et al*. (2015) assessed spatial and temporal patterns of changes in body conditions of southern elephant seals (*Mirounga leonina*) from Marion Island, based on changes in drift rates (which are related to gains and losses of blubber). Increased condition was consistently negatively related to sea surface temperature, suggesting that seals were generally improving their condition faster in cooler water masses. These results support previous studies predicting that continued warming of the Southern Ocean will result in changes to the habitat-use patterns exhibited by southern elephant seals at sea.

19. A study of Adélie penguins (Southwell *et al*., 2015) combined new data, new analytical methods, and re-interpreted historical survey data to assess decadal-scale change in East Antarctic breeding populations. The authors show that, in contrast to the west Antarctic Peninsula (WAP) and western Ross Sea, where breeding populations have decreased or shown variable trends over the last 30 years, East Antarctic regional populations have almost doubled in abundance since the 1980s and have been increasing since the earliest counts in the 1960s. The population changes are associated with five-year lagged changes in the physical environment, suggesting that the changing environment impacts primarily on the pre-breeding age classes.

20. A study by Steinberg *et al.* (2015) examined trends in summer abundance of major taxa of macrozooplankton along the WAP over two decades (1993-2013) and their relationship with environmental parameters. Trends for krill species included no directional long-term trend for *Euphausia superba* (Antarctic krill), but an increase in *Thysanoessa macrura* in the north; variability in both species was strongly influenced by primary production two years prior. *E. crystallorophias* (ice krill) abundance and anomalies of the salp *Salpa thompsoni* and the pteropod *Limacina helicina* were best explained by the Southern Annular Mode SAM and Multivariate El Niño Southern Oscillation Index (MEI). Long-term changes were also observed in carnivorous gelatinous zooplankton (polychaete worm *Tomopteris* spp.), amphipods and chaetognaths. Such long-term changes and sub-decadal cycles of WAP macrozooplankton community composition may affect energy transfer to higher trophic levels, and alter biogeochemical cycling in this seasonally productive and sensitive polar ecosystem.

21. Rapid warming in the highly productive WAP region has affected multiple trophic levels, yet viral influences on microbial processes and ecosystem function remain understudied in the Southern Ocean. In a study by Brum *et al.* (2016), cultivation-independent ecological and metagenomic assays, combined with new comparative bioinformatic techniques, were used to investigate viruses during the WAP spring-summer transition. This study demonstrates that (i) temperate viruses dominate this region, and (ii) Southern Ocean viral assemblages are genetically distinct from lower-latitude assemblages. This new information suggests fundamentally different virus-host interactions in polar environments, due to intense seasonal changes in bacterial production. The results suggest that temperate virus-host interactions are critical to predicting changes in microbial dynamics brought on by warming in polar marine systems.

22. Similarly, a recent study has reported widespread death in terrestrial and freshwater microbial mats in the South Shetland Islands (Velazquez *et al.*, 2016). Such mats represent one of the most significant microbial communities in Antarctica. Velazquez *et al.* describe lysis plaque-like macroscopic blighted patches within the predominant microbial mats on Livingston Island. These are associated with decay in physiological traits as well as nitrogen depletion and changes in microstructure, which were probably related to disruption of biogeochemical gradients within the microbial ecosystem caused by an unusually high fungal abundance and consequent physical alterations. This decay coincides with unprecedented rates of local warming in the Antarctic Peninsula area, and may be encouraged by the warmer temperatures.

23. Coastal glaciers have receded at unprecedented speed during the past decade along the WAP. Thanks to a long-term dive programme on sea-bed communities in Potter Cove, King George/25 de Mayo Island, South Shetland Archipelago, Sahade *et al*. (2015) documented a sudden shift from a "filter feeders–ascidian domination" to a "mixed assemblage", attributed to the deposition of muds released by the melting glaciers in the cove. This finding suggests that this fjord system is characterised by certain thresholds (for example, of tolerable sedimentation) and, if critical values are exceeded, by the development of alternative equilibrium states. A similar short-term study by Moon *et al*. (2015) in the adjacent Marian Cove showed that physical disturbance at a retreating glacier cliff is a major driver of benthic communities and that these respond sensitively and measurably to climate-induced impacts.

24. Based on a comprehensive large-scale resurvey of Signy Island (South Orkney Islands), allowing comparison of new (2009) and historical data (1960s), Cannone *et al.* (2016) show that the two native Antarctic vascular plant species have exhibited significant increases in the number of occupied sites and percent cover since the 1960s: *Deschampsia antarctica* increasing in coverage by 191% and in number of sites by 104%, and *Colobanthus quitensis* increasing in coverage by 208% and number of sites by 35%. These changes likely occurred in response to an increase of 1.2° C in local summer air temperature over the same time period. Both species exhibited changes with elevation due to the interaction of multiple drivers (climatic factors and animal disturbance), producing heterogeneity of responses across an elevation gradient. Below an elevation of 20 m fur seal activity, which has increased drastically since the late 1980s, has exerted strongly negative impacts. Between 20 and 60 m, both plant species underwent considerable increases in the number of sites and percent cover, likely influenced by both climate warming and nutrient input from seals. Above an elevation threshold of 60 m the maximum elevation of the sites occupied decreased for both species, perhaps as a consequence of physical disturbance at higher elevations due to the permafrost conditions and/or the snow cover thickness and persistence. Research into the contribution of multiple disturbance drivers for vegetation change in cold regions should be prioritized to facilitate improved forecasting of biological responses and feedbacks to environmental change.

The SCAR ACCE Advisory Group consists of John Turner (Chair), Colin Summerhayes, Mike Sparrow, Paul Mayewski, Pete Convey, Guido di Prisco, Julian Gutt, Dominic Hodgson, Sabrina Speich, Tony Worby, Sun Bo and Alexander Klepikov.

References

Barnes, D. K. A. 2015. Antarctic sea ice losses drive gains in benthic carbon drawdown. *Current Biology* 25 [18]: R789-R790.

Barnes, D. K. A., Ireland, L., Hogg, O. T., Morley, S., Enderlein, P. and Sands, C. J. 2016. Why is the South Orkney Island shelf (the world's first high seas marine protected area) a carbon immobilization hotspot? *Global Change Biology* 22: 1110-1120.

Bracegirdle, T. J., Stephenson, D. B., Phillips, T. and Turner, J. 2015. The importance of sea-ice extent biases in 21st century multi-model projections of Antarctic temperature and precipitation. *Geophysics Research Letters* .

Brum, J. R., Hurwitz, B. L., Schofield, O., Ducklow, H. W. and Sullivan, M. B. 2016. Seasonal time bombs: dominant temperate viruses affect Southern Ocean microbial dynamics. *Isme Journal* 10 [2]: 437-449.

Cannone, N., Guglielmin, M., Convey, P., Worland, M. R. and Favero-Longo, S. E. 2016. Vascular plant changes in extreme environments: effects of multiple drivers. *Climatic Change* 134: 651-665.

Chuter, S. J. and Bamber, J. L. 2015. Antarctic ice shelf thickness from CryoSat-2 radar altimetry. *Geophysical Research Letters* 42 [24].

Cornford, S. L., Martin, D. F., Payne, A. J., Ng, E. G., Le Brocq, A. M., Gladstone, R. M., Edwards, T. L., Shannon, S. R., Agosta, C., Van den Broeke, M. R., Hellmer, H. H., Krinner, G., Ligtenberg, S. R. M., Timmermann, R. and Vaughan, D. G. 2015. Century-scale simulations of the response of the West Antarctic Ice Sheet to a warming climate. *Cryosphere* 9 [4]: 1579-1600.

DeConto, R. M. and Pollard, D. 2016. Contribution of Antarctica to past and future sea-level rise. *Nature* 531: doi:10.1038/nature17145.

Dutrieux, P., De Rydt, J., Jenkins, A., Holland, P. R., Ha, H. K., Lee, S. H., Steig, E. J., Ding, Q. H., Abrahamsen, E. P. and Schroder, M. 2014. Strong Sensitivity of Pine Island Ice-Shelf Melting to Climatic Variability. *Science* 343 [6167]: 174-178.

Galeotti, S., DeConto, E. and Naish, T. 2016. Antarctic ice sheet variability across the Eocene-Oligocene boundary climate transiition. *Science* : DOE:10.1126/science.aab0669.

Golledge, N. R., Kowalewski, D. E., Naish, T. R., Levy, R. H., Fogwill, C. J. and Gasson, E. G. W. 2015. The multi-millennial Antarctic commitment to future sea-level rise. *Nature* 526 [7573]: 421.

Gomez, N., Pollard, D. and Holland, D. 2015. Sea-level feedback lowers projections of future Antarctic Ice-Sheet mass loss. *Nature Communications* 6.

Greenbaum, J. S., Blankenship, D. D., Young, D. A., Richter, T. G., Roberts, J. L., Aitken, A. R. A., Legresy, B., Schroeder, D. M., Warner, R. C., van Ommen, T. D. and Siegert, M. J. 2015. Ocean access to a cavity beneath Totten Glacier in East Antarctica. *Nature Geoscience* 8 [4]: 294-298.

Hosking, J. S., Orr, A., Bracegirdle, T. J. and Turner, J. 2016. Future circulation changes off West Antarctica: Sensitivity of the Amundsen Sea Low to projected anthropogenic forcing. *Geophysics Research Letters* 43: 367-376.

Jaccard, S. L., Galbraith, E. D., Martinez-Garcia, A. and Anderson, R. F. 2016. Covariation of deep Southern Ocean oxygenation and atmospheric CO_2 through the last ice age. *Nature* 530: 207-210.

Krinner, G., Largeron, C., Menegoz, M., Agosta, C. and Brutel-Vuilmet, C. 2014. Oceanic Forcing of Antarctic Climate Change: A Study Using a Stretched-Grid Atmospheric General Circulation Model. *Journal of Climate* 27 [15]: 5786-5800.

McIntyre, T., Donalson, A. and Bester, M. N. 2015. Spatial and temporal patterns of changes in condition of southern elephant seals. *Antarctic Science*, doi: 10.1017/S0954102015000553.

Mckay, R. M., Barrett, P. J., Levy, R. S., Naish, T. R., Golledge, N. R. and Pyne, A. 2016. Antarctic Cenozoic climate history from sedimentary records: ANDRILL and beyond. *Philosophical Transactions of the Royal Society A-Mathematical Physical and Engineering Sciences* 374 [2059].

Moon, H. W., Hussin, W. M. R. W., Kim, H. C. and Ahn, I. Y. 2015. The impacts of climate change on Antarctic nearshore mega-epifaunal benthic assemblages in a glacial fjord on King George Island: Responses and implications. *Ecological Indicators* 57: 280-292.

Pollard, D., DeConto, R. M. and Alley, R. B. 2015. Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. *Earth and Planetary Science Letters* 412: 112-121.

Ritz, C., Edwards, T. L., Durand, G., Payne, A. J., Peyaud, V. and Hindmarsh, R. C. A. 2015. Potential sea-level rise from Antarctic ice-sheet instability constrained by observations. *Nature* 528 [7580]: 115-+.

Robel, A. 2015. The long future of Antarctic melting. *Nature* 526 [7573]: 327-328.

Ruddiman, W. F., Fuller, D. Q., Kutzbach, J. E., Tzedakis, P. C., Kaplans, J. O., Ellis, E. C., Vavrus, S. J., Roberts, C. N., Fyfem, R., He, F., Lemmen, C. and Woodbridge, J. 2015. Late Holocene Climate: Natural Or Anthropogenic? *Reviews of Geophysics*: DOI: 10.1002/2015RG000503.

Sahade, R., Lagger, C., Torre, L., Momo, P., Monien, P., Schloss, I., Barnes, D. K. A., Servetto, N., Tarantelli, S., Zamboni, N. and Abele, D. 2015. Climate change and glacier retreat drive shifts in an Antarctic benthic ecosystem. *Science Advances*: doi: 10.1126/sciadv.1500050.

Schmithusen, H., Notholt, J., Konig-Langlo, G., Lemke, P. and Jung, T. 2015. How increasing CO2 leads to an increased negative greenhouse effect in Antarctica. *Geophysical Research Letters* 42 [23].

Southwell, C., Emmerson, L., McKinlay, J., Newbery, K., Takahashi, A., Kato, A., Barbraud, C., DeLord, K. and Weimerskirch, H. 2015. Spatially Extensive Standardized Surveys Reveal Widespread, Multi-Decadal Increase in East Antarctic Adelie Penguin Populations. *Plos One* 10 [10].

Stanley, S. 2016. Tracking the fate of Antarctica's ice. *Eos* 97: doi:10.1029/2016EO045085.

Steinberg, D. K., Ruck, K. E., Gleiber, M. R., Garzio, L. M., Cope, J. S., Bernard, K. S., Stammerjohn, S. E., Schofield, O. M. E., Quetin, L. B. and Ross, R. M. 2015. Long-term (1993-2013) changes in macrozooplankton off the Western Antarctic Peninsula. *Deep-Sea Research Part I-Oceanographic Research Papers* 101: 54-70.

Summerhayes, C. P. 2015. Earth's Climate Evolution. 394. Wiley/Blackwell.

Sutter, J., Gierz, P., Grosfeld, K., Thoma, M. and Lohmann, G. 2016. Ocean temperature thresholds for Last Interglacial West Antarctic Ice Sheet collapse. *Geophysics Research Letters* : DOI: 10.1002/2016GL067818.

Thomas, E. R., Hosking, J. S., Tuckwell, R. R., Warren, R. A. and Ludlow, E. C. 2015. Twentieth century increase in snowfall in coastal West Antarctica. *Geophysical Research Letters* 42 [21]: 9387-9393.

Turner, J., Barrand, N. E., Bracegirdle, T. J., Convey, P., Hodgson, D. A., Jarvis, M., Jenkins, A., Marshall, G. J., Meredith, M. P., Roscoe, H. K., Shanklin, J. D., French, J., Goosse, H., Guglielmin, M., Gutt, J., Jacobs, S. S., Kennicutt, M. C. I., Masson-Delmotte, V., Mayewski, P., Navarro, F., Robinson, S., Scambos, T., Sparrow, M., Speer, K., Summerhayes, C. P. and Klepikov, A. V. 2013. Antarctic Climate Change and the Environment - An Update. *Polar Record*: doi:10.1017/S0032247413000296.

Turner, J., Bindschadler, R. A., Convey, P., di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D. A., Mayewski, P. A. and Summerhayes, C. P. 2009. Antarctic Climate Change and the Environment. Turner, J., Bindschadler, R. A., Convey, P., di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D. A., Mayewski, P. A., and Summerhayes, C. P. 526. Cambridge, Scientific Committee on Antarctic Research.

Velazquez, D., Lopez-Bueno, A., Aguirre de Carcer, D., de los Rios, A., Alcami, A. and Quesada, A. 2016. Ecosystem function decays by fungal outbreaks in Antarctic microbial mats. *Scientific Reports* 6: doi:10.1038/srep22954 .

Zhao, X. H. and Feng, X. S. 2014. Correlation between solar activity and the local temperature of Antarctica during the past 11,000 years. *Journal of Atmospheric and Solar-Terrestrial Physics* 122: 26-33.

Zwally, H. J., Robbins, J. W., Saba, J. L. and Brenner, A. C. 2015. Mass Gains Of The Antarctic Ice Sheet Exceed Losses. *Journal of Glaciology* 61: 1019-1036.