**WP 17**

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| Agenda Item: | ATCM 16, CEP 7a |
| Presented by: | SCAR |
| Original: | English |
| Submitted: | 28/4/2021 |

# Antarctic and Southern Ocean Climate Change in a Global Context

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***Working paper submitted by SCAR***


## *Summary*

Climate change and its impacts are of much concern globally and to the Antarctic Treaty System given realised and expected impacts on global sea level rise and biodiversity.

The recent Special Reports of the Intergovernmental Panel on Climate Change (IPCC) provide the clearest recent summaries of global climate change that has taken place, impacts that are being realised, and changes that are projected.

Attention is drawn here to key findings from these IPCC Special Reports, focussing on substantial uncertainties about global and Antarctic impacts; and to the research being undertaken through SCAR to address these uncertainties. The paper presented here is not intended as a comprehensive synthesis.

Key uncertainties include the current and future behaviour of the Antarctic cryosphere (especially implications for global sea level and coastal populations and infrastructure); climatic variability over short timescales which is especially important given its significance for impacts and operational forecasts; and the future of marine and terrestrial Antarctic biodiversity, approaches to improve its conservation, and ways to mitigate climate change impacts on both.

Quantifying and reducing these uncertainties through focussed research is critical.

More critical is the need to convey to Treaty nations the importance of the Paris Climate Agreement, and expected strengthening of greenhouse gas emissions reductions targets, for maintaining Antarctic and Southern Ocean environments and their biodiversity as they have come to be known over the 60 years of the Antarctic Treaty.


## *Introduction*

The progress of global climate change and the interactions between climate change in the Antarctic and the Earth System are of primary concern to the ATCM and to the CEP. That concern was most clearly articulated through the report of the Meeting of Experts on Climate Change (ATME 2010), which also considered closely the SCAR Antarctic Climate Change and the Environment Report (ACCE Report)[1].

Much significant action has been taken by the ATCPs since then, including establishment of the CEP's Subsidiary Group on the Climate Change Response Work Programmme to prioritise implementation of the Climate Change Response Work Programme (CCRWP) (Decision 1 of 2017), and regular interactions with SCAR to receive up-to-date scientific information on climate change in the Antarctic region, its implications for the Earth System, and its impacts on Antarctica and its associated and dependent ecosystems (e.g. ATCM XLII IP 136 *Antarctic Climate Change and the Environment – 2019 Update*).

Now, more than 10 years after the publication of the ACCE Report, significant research progress has been made in understanding climate change, uncertainties about its progress and global impacts, and its likely influence on life both on the continent and in the Southern Ocean. Much of this progress for the Antarctic region has resulted from National Antarctic Programs focussing their research efforts on climate change and its impacts (following Resolution 6 of 2015), and through recognition globally of the humanitarian, economic and biodiversity impacts and costs that climate change is already bringing and will continue to bring.

[1] SCAR. 2009. *Antarctic Climate Change and the Environment*. J Turner et al. (Eds.). Scientific Committee on Antarctic Research, Cambridge, UK.

The recent Special Reports of the Intergovernmental Panel on Climate Change (IPCC) – Global Warming of 1.5°C (SR15, IPCC 2018)[2] and Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC, IPCC 2019)[3], provide the clearest recent summaries of global climate change that has taken place, impacts from such change that are being realised, and changes that are forecast. The SROCC is especially relevant to the Antarctic Region.

Based on these reports, on new science which is emerging continuously, and on insights from its three new Scientific Research Programmes (SRPs), all focussing in whole or in part on this area of scientific endeavour, SCAR will within the next year be providing a decadal update to its ACCE Report to the Antarctic Treaty System.

In the interim, SCAR here draws attention to critical findings from the IPCC Special Reports (information extracted from IPCC 2018; IPCC 2019) which have direct relevance to the Antarctic and Southern Ocean, provides summary information on its new SRPs which are, in part, a direct response to the priorities of the ATCM's CCWRP, and provides recommendations on the way forward.

## *Observed and projected effects of climate change in Antarctica on the Earth system*

**Ice sheet changes.** Antarctic ice loss is dominated by acceleration, retreat and rapid thinning of major West Antarctic Ice Sheet outlet glaciers, driven by melting of ice shelves by warm ocean waters (IPCC 2019, Chapter 3 Summary). There is limited evidence and high agreement that recent Antarctic Ice Sheet mass losses could be irreversible over decades to millennia (IPCC 2019, 3.3.1; Cross-Chapter Box 8 in Chapter 3; 4.2.3.1.2).

**Sea level**. Global mean sea level (GMSL) rise has accelerated in recent decades due to mass loss from the Antarctic Peninsula and West Antarctic Ice Sheet, and the Greenland Ice Sheet (IPCC 2019, 3.3.1, table 4.1). The Antarctic and Greenland ice sheets are the largest reservoirs of land ice on Earth and will be primary drivers of future changes in sea level.

Melting of the Antarctic Ice Sheet may contribute up to 0.28 m to GMSL rise by 2100 (RCP8.5; IPCC 2019, table 4.4), with a total expectation of GMSL up to 1.1 m. But deep uncertainty remains about the expected changes to the Antarctic Ice Sheet. Expert elicitation studies indicate that a GMSL rise of 2 m at the end of this century cannot be ruled out (IPCC 2019, 4.2.3.1.2). New work continues to illustrate that with higher temperature rises, substantial losses to the Antarctic Ice Sheet will be experienced[4], and reveals much about variation at small scales relevant to cryosphere behaviour[5].

**Sea ice change.** Total Antarctic sea ice cover has exhibited no significant trend over the period of satellite observations. A significant positive trend in mean annual ice cover between 1979 and 2015 has not continued due to three consecutive years of below-average ice cover (2016-2018) driven by atmospheric and oceanic forcing (IPCC 2019, 3.2.1.1.1). New research is unveiling the mechanisms underlying long-term variability and suggests declines may continue over the longer term[6].

**Southern Ocean carbon and heat sink.** The Southern Ocean plays a disproportionately large and increasing role in the global ocean uptake of heat and carbon dioxide from the atmosphere (IPCC 2019, 3.2.1.2.1, 3.2.2.3). Under future climate change scenarios, the Southern Ocean is predicted to store increasing amounts of carbon dioxide, before its capacity slows or halts around the year 2070 ± 10 under RCP8.5 (IPCC 2019, 3.2.2.3).

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[2] IPCC. 2018. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. V Masson-Delmotte et al. (Eds.). https://www.ipcc.ch/sr15/

[3] IPCC. 2019. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* H-O Pörtner et al. (Eds.). https://www.ipcc.ch/srocc/

[4] J Garbe et al. 2020. *Nature* 585: 538; E Gilbert & C Kittel. 2021. *Geophysical Research Letters*, doi: 10.1029/2020GL091733

[5] A Wåhlin et al. 2021. *Science Advances* 7: eabd7254.

[6] X Crosta et al. 2021. *Nature Geoscience* 14: 156.

**Fisheries sustainability.** The anticipated effects of climate change on Antarctic living marine resources may impact the global supply of fish and krill. The distribution of Antarctic krill (*Euphausia superba*) is expected to continue to migrate southwards in response to projected warming and ocean acidification, especially in the southwest Atlantic region (IPCC 2019, 3.2.3.2.1). There is, however, low confidence for the projected effects of climate change on toothfish (*Dissostichus* spp.) (IPCC 2019, 3.2.3.2.3). Fisheries management may need to respond to climate-driven changes in the distribution and abundance of fish and krill stocks to ensure their sustainability into the future (IPCC 2019, 3.5.2.1).

## *Observed and forecast effects of global climate change in Antarctica*

**Irreversible ice sheet loss.** In addition to contributing to global sea level rise, Antarctic Ice Sheet mass losses and Marine Ice Sheet Instability could irreversibly change Antarctic environments and ecosystems over timescales from decades to millennia. Under scenarios for 1°C of global warming, there is a moderate risk of large-scale singular events that cause abrupt and potentially irreversible changes in systems, such as the disintegration of the Antarctic Ice Sheet (high risk under 2.5°C of global warming) (IPCC 2018, 3.5.2.5).

**Primary productivity increases.** Warming temperatures, declining sea ice extent and enhanced input of iron from ice-shelves, icebergs and glacial meltwater are expected to increase net primary productivity in Antarctic waters by changing nutrient availability (IPCC 2019, 3.3.3.3). Ice shelf retreat can also create areas of open water surrounded by sea ice (polynyas) where rates of primary production increase due to increased light and nutrient levels. For example, primary productivity doubled in the area exposed by the recent calving of the Mertz Glacier Tongue in East Antarctica (IPCC 2019, box 3.3).

**Ocean salinity and acidification.** Antarctic Ice Sheet and glacial melt has increased the input of freshwater into the Southern Ocean (high confidence in the Amundsen and Bellingshausen Seas) (IPCC 2019, 3.3.3). It is very likely that the Southern Ocean will experience year-round conditions of surface water undersaturation for mineral forms of calcium carbonate by 2100 under RCP8.5; under RCP2.6, the extent of undersaturated waters are reduced markedly. Differences in sensitivity and the scope for adaptation to projected levels of ocean acidification exist across a broad range of marine species groups (IPCC 2019, Chapter 3 Summary, 3.2.1, 3.2.2.3, 3.2.3).

**Biodiversity change or loss.** Climate-induced changes in the Southern Ocean, such as ocean acidification, warming and sea ice loss, are likely to have detrimental impacts on many Antarctic species and ecosystems (IPCC 2019, box 3.4). These changes are predicted to cause shifts in the distribution and relative abundance of animals, including marine mammals, birds, fish and krill (IPCC 2019, 3.2.3.2), which will affect Marine Protected Area efficacy[7]. Species that are sensitive to temperature changes, ocean acidification, and sea-ice dependent species, may be particularly affected. On land, changes to ecosystems are being documented across the region, though these changes differ between species and regions[8].

**Non-native species.** Weakening climatic barriers and retreating ice cover are likely to increase habitat suitability and availability in Antarctica for non-indigenous species, particularly on the Antarctic Peninsula and offshore maritime islands (IPCC 2019, box 3.4). In concert with greater shipping activity and increasing numbers of Antarctic visitors, climate change is forecast to increase the establishment likelihood and invasion success of a broad range of potentially invasive species.

**Historic sites and monuments (HSMs).** Several studies have shown that historic huts and their wooden and metal contents are susceptible to degradation through either biological or physical means, especially at higher humidities and temperatures[9]. In the case of wooden structures, saprophytic fungi are well documented in Antarctica, though responses of indigenous species and populations to changing environmental conditions are complex[10]. Nonetheless, research from the Arctic[11], and high degradation rates

[7] MA Hindell et al. 2020. *Nature* 580: 87.
[8] MJ Amesbury et al. 2017. *Current Biology* 27: 1616; WS Andriuzzi et al. 2018. *Ecology* 99: 312; SA Robinson et al. 2018. *Nature Climate Change* 8: 879.
[9] BW Held et al. 2005. *International Biodeterioration and Biodegradation* 55: 45; RL Farrell et al. 2011 *Polar Biology* 34: 1669; BW Held & RA Blanchette. 2017. *Fungal Biology* 121: 145.
[10] BE Arenz & RA Blanchette. 2009. *Canadian Journal of Microbiology* 55: 46; KK Newsham et al. 2016. *Nature Climate Change* 6: 182; M Misak et al. 2021. *Global Change Biology* 27: 1111.
[11] Pedersen et al. 2020. *Scientific Reports* 10: 14577.

in some Antarctic HSMs at high temperatures and humidities[9], imply that climate change may have an impact on HSMs, though formal research about this process remains sparse.

**Infrastructure and sea level change.** Forecasting sea level rise around the Antarctic coastal margin, to assess likely infrastructure impacts, is complicated by the fact that different outcomes may be expected over time depending on the relative rates of mass loss from the Greenland and Antarctic Ice Sheets (especially WAIS)[12]. Sea level forecasts include initial periods of rise or fall, depending also on which particular area of Antarctic coast is being considered. Nonetheless, all scenarios imply potential impacts on coastal infrastructure. This is an active area of investigation[13].

### *Uncertainty in Antarctica's contribution to global change*

Uncertainty in GMSL forecasts for the end of the century are largely caused by uncertainty around the timing and spatial extent of ice sheet instabilities in Antarctica (IPCC 2019, 4.2.3.2). This arises from limited evidence about historical ice sheet changes, inadequate model representation of ice sheet processes, and limited understanding of the complex interactions between the atmosphere, ocean and cryosphere (IPCC 2019, Cross-Chapter Box 8 in Chapter 3, 3.3.1, 4.1).

There is also low confidence in Antarctic sea ice projections due to challenges associated with modelling seasonal and interannual variability in Antarctic sea ice, and other interacting processes related to clouds, ocean stratification and salinity (IPCC 2018; 2019, 3.2.2.1).

Uncertainty in predicting species and ecosystem responses arises from a lack of information about possible indirect responses to climate change, and the relatively short time series data available for ecologically important species (IPCC 2019 3.2.3.2).

### *SCAR Scientific Research Programmes*

Recognising the need for quantifications of and rapid reductions in uncertainty about: (i) the current and future behaviour of the Antarctic cryosphere (especially implications for GMSL), (ii) climatic variability over short timescales given its significance for impacts and operational forecasts, and (iii) the future of marine and terrestrial Antarctic biodiversity, approaches to improve its conservation, and ways to mitigate climate change impacts on both, SCAR has agreed three new Scientific Research Programmes[14] (SRPs) which focus on these areas.

**Instabilities and Thresholds in Antarctica (INSTANT)** is an interdisciplinary programme which quantifies the Antarctic Ice Sheet's contribution to past and future global sea-level.

**Near-term Variability and Prediction of the Antarctic Climate System (AntClim$^{now}$)** investigates the prediction of near-term conditions in the Antarctic climate system on timescales of 1 to 30 years.

**Integrated Science to Inform Antarctic and Southern Ocean Conservation (Ant-ICON)** answers fundamental questions relating to the conservation and management of Antarctica and the Southern Ocean given their changing environments.

These SRPs are expected to continue over an eight-year period (with a mid-term review) and will provide science evidence that is of both global interest and of direct relevance to the priorities of the ATCM and CEP.

### *Recommendations*

SCAR recommends that the Parties:

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[12] P Stocchi et al. 2013 *Nature Geoscience* 6: 380; RE Kopp et al. 2014. *Earth's Future* 2: 383; T Frederikse et al. 2020 *Nature Communications* 11: 390; BD Hamlington et al. 2020. *Reviews of Geophysics* 58: e2019RG000672.
[13] RH Levy et al. 2020. *Sea-Level Projections for New Zealand's Scott Base Rebuild*. GNS Science Report 2020/13, Lower Hutt, New Zealand.
[14] https://www.scar.org/science/srp/

1) Further consider the scientific research outcomes provided by SCAR which can inform regional and continent-wide policy responses and actions being proposed through the CCRWP and the SG-CCRWP;
2) Reaffirm their support for scientific investigations of climate change and responses to it in the region;
3) Emphasise to their nations the significance of Antarctica and the Southern Ocean with respect to global climate regulation, and the need for continued protection of the Antarctic and Southern Ocean environment, to ensure a sustainable future for humanity and for the biodiversity on which we depend;
4) Convey to their nations the importance of the Paris Climate Agreement, and expected strengthening of greenhouse gas emissions reductions targets, for maintaining Antarctic and Southern Ocean environments and their biodiversity as they have come to be known over the 60 years of the Antarctic Treaty;
5) Consider the Reports of the IPCC, especially the Summary for Policymakers of each report.