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What does the United Nations Paris Climate Agreement mean for Antarctica?

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Background Paper submitted by SCAR

Summary

This presentation to the XL ATCM will outline the implications of the 2015 Paris Climate Agreement[1] for Antarctica. It will briefly examine the relationship between the ATS, its agreements and SCAR and the United Nations Framework Convention on Climate Change (UNFCCC). The consequences for Antarctica and the Southern Ocean of 1.5°C, 2°C, and more than 2°C of global warming are presented based on the latest international science, much of which has been conducted under the auspices of SCAR's strategic research programmes[2]. However, the presentation will primarily focus on one of the biggest uncertainties in policy-relevant climate science, which was highlighted in Intergovernmental Panel on Climate Changes (IPCC) 5th Assessment Report in 2013[3]. This is, "how fast and how much will Antarctic ice mass loss contribute to global sea-level rise (SLR) over the coming century and beyond, and will achieving the target of the Paris Climate Agreement mitigate significant global SLR?" Impacts and avoided impacts for the Antarctic environment, the ATS and its activities, and the rest of the world are addressed.

The Paris Climate Agreement

Something quite remarkable happened towards the end of 2015 in Paris at the 21st meeting of the Conference of Parties (COP 21) to the UNFCCC. The 196 member nations agreed to keep global warming below the 2°C, the "safe guardrail for dangerous climate change" identified by the IPCC, and introduced by the UNFCCC at Copenhagen in 2009[4]. This goal is to be achieved through nationally determined commitments (NDCs) aimed to reduce all anthropogenic greenhouse gas emissions to zero before the end of this century. Following pressure from vulnerable African and low-lying coastal nations, the parties further agreed to "pursue efforts to" limit temperature increase to 1.5°C, and the IPCC was charged with producing a Special Report on the (avoided) impacts of global warming of 1.5°C and related greenhouse gas emissions pathways. The Paris Climate Agreement was subsequently signed by 194 countries in New York on Earth Day, 22nd April 2016, and the Agreement went into force on 7th November 2016.

The Paris Agreement is challenging, especially given, that at the current rate of global emissions (40Gt per year), Earth's surface temperature could reach 1.5°C in 5 years and 2°C in ten years (Fig. 1). The NDCs tabled in Paris, if implemented, will restrict global warming to ~2.7°C (Fig. 2). This is still above the UNFCCC safe guardrail and well-above the more ambitious goal of 1.5°C. Moreover, an assessment of current policy settings sees global temperatures stabilizing closer to 3.5°C (Fig. 2). To be on track to meet the Paris target, all parties need to commit to 40% reduction in global GHG emissions with respect to 1990 levels, by 2030. This is the EU commitment, but many nations NDCs fall well short of this. The Agreement requires parties to increase their commitments during 5-yearly global stock takes, to achieve the target.

How the ATS and SCAR interact with the UNFCCC and the IPCC

While, the ATS has no status within the UNFCCC, SCAR does have observer status within the IPCC, via its membership of the International Council of Scientific Unions (ICSU). SCAR/ICSU nominates participants to attend IPCC plenary sessions and meetings, as well as candidates to be considered for authorship of special and assessment reports. More importantly SCAR helps mobilise the international science community to address the impact of climate change on Antarctica, and the role Antarctica plays in the global climate system. The SCAR Horizon Scan process held in New Zealand in 2014 identified several scientific priorities[5,6] that are of direct relevance and interest to the IPCC as it prepares for its 6th integrated assessment report and two newly commissioned Special Reports - "Global Warming at 1.5°C" and "Climate Change and the oceans and the cryosphere". Two of SCAR's strategic research programmes, *Past Antarctic Ice Sheet Dynamics* (PAIS) and *Antarctic Climate in the 21st Century* (AntClim21) made significant contributions to the IPCC's 5th Assessment Report from the legacy of several large IPY research initiatives, and are positioning themselves to make even more significant contributions to 6th Assessment Report.

Climate Change and Antarctica

Changes caused by natural and anthropogenic drivers (e.g. CO_2) are communicated to Antarctica by oceanic and atmospheric processes and influence the polar atmosphere, ocean, ice sheet, sea ice and biosphere. Likewise, change in Antarctica and the surrounding Southern Ocean have world-wide consequences.

- Warming of the climate system is unequivocal, and the human influence is clear[3].
- One of the clearest globally integrated responses to this warming is global sea-level rise (SLR) (Fig. 3). 20cm SLR observed since 1850. 15cm of SLR occurred in the last 30 years[3].
- The Antarctic ice sheet holds 90% of the world's ice, 70% of the world's fresh water and if returned to the ocean would raise sea-level by 58m (Fig. 4). The East Antarctic Ice (EAIS) Sheet contain 54m SLR, the West Antarctic Ice sheet (WAIS) contains 4m SLR[7,8].
- The loss of mass from the Antarctic Ice Sheet is contributing to global sea level rise at an accelerating rate[9,10] and by mid-century may be the single biggest term contributing to global sea-level rise[3] (Fig. 5).
- The largest uncertainty in predicting future sea level rise is predicting the response of the Antarctic Ice Sheet to continued warming in the ocean and atmosphere[2].
- At present, the Southern Ocean takes up more anthropogenic heat and CO_2 than oceans in other latitudes, which acts to slow the pace of surface climate change around Antarctica. 95% of the heat and 25% of the CO_2 has gone into the ocean[2,11].
- The tug of war between ozone hole that acts cool Antarctica and global greenhouse gases warming the rest of the planet steepens the pole-equator temperature gradient of the Southern Hemisphere[12], invigorating zonal atmospheric circulation and causing warm circumpolar deep waters to upwell along the coast of West Antarctica[13]. This increased heat flux to the marine margins of the West Antarctic ice sheet (WAIS) is causing collapse of stabilizing ice shelves and rapid thinning and retreat of the ice sheet[14,15,16,17,18]. (Fig. 6).
- Freshening of the surface waters from ice melt has reduced the production of cold salty Antarctic Bottom Water by 50% between 1970 and 2014, with consequential changes for heat transport via the global ocean conveyor[19].
- By returning nutrient-rich deep water to the sea surface and exporting nutrients to lower latitudes, the Southern Ocean overturning circulation supports 75% of global marine primary production north of 30°S[20].
- Given the global reach of Antarctic and Southern Ocean processes, climate change in the region will have widespread consequences for the Earth system and for human society dependent on it.

The Gorilla in the room: How do Antarctica's ice sheets contribute to sea-level rise, and how fast and how much will they contribute to future sea-level rise (SLR)?

Arguably, the biggest uncertainty with societal and policy relevance facing climate science today is the future contribution of the Antarctic ice sheet to global sea-level rise. After assessing the evidence, the IPCC[3] noted but did not include in their global sea-level predictions, the potentially large contribution from rapid retreat of unstable parts of the Antarctic ice sheet. They argued at the time of writing, that the scientific evidence was not clear enough for quantifying the likelihood of a rapid and potentially non-linear response by Antarctica, but cautioned that "based on current understanding, collapse of marine-based sectors of the Antarctic ice sheets, if initiated, could cause global mean sea level to rise tens of centimetres above the *likely* range [of up to 98cm] during the 21st century"[3].

So what do geological archives tell us about the sensitivity of Antarctica's ice sheets to past higher than pre-industrial levels of atmospheric CO_2?

- Climate reconstructions from the geological past show that the Antarctic ice sheet is highly sensitive to relatively small increases in Earth's average temperature[3]. (Fig. 7)
- This sensitivity is because of amplifying feedbacks and processes that cause the polar regions to warm 2 to 3 times more than the global average[3,21] (Fig. 8). This phenomenon of polar amplification is responsible for the observed rapid warming and sea-ice loss in the Arctic, but is yet to manifest around Antarctica as discussed above. However, climate models and paleoclimate reconstructions show the emergence of amplified Antarctic temperatures once the ozone hole repairs and CO_2 warming dominates with rapid warming reducing the volume of seasonal sea-ice.
- This ice sheet sensitivity is also because two-thirds of Antarctica's ice mass sits below sea-level (Fig. 4). Once the ice shelves have gone, some studies[13,14] predict that ongoing dynamic loss of the WAIS maybe unstoppable as warm ocean waters penetrate into the deep sub-glacial basins. (Fig. 6)
- The last time Earth experienced atmospheric CO_2 concentrations of 400ppm (todays concentration) was 3 million years ago[3,22](Fig. 7). Global temperature equilibrated at 2-3°C warmer[3,23] , polar temperatures were 6-7°C warmer (Fig. 8) and Antarctica lost most of its marine-based ice sheets, contributing +13m to global sea level[24-28]. (Greenland melting also contributed another +7m[29]). (Fig. 9).
- 400-500ppm atmospheric CO_2 (3-4°C global warming, ~15 million years ago) appears to be a threshold for loss of the West Antarctic Ice Sheet (+3m SLR), and marine-based sectors of the East Antarctic Ice Sheet (+17m SLR)[31-3] (Fig. 7)
- 600-700ppm atmospheric CO_2 (4-5°C global warming, ~35 million years ago) appears to be a threshold for loss of Antarctica's land-based ice, and at 1000ppm CO_2 Antarctica has no ice[31-34] (Fig. 7)
- In the past, about 14,500 years ago as the world was warming out of the last ice age, Antarctica ice melt contributed a rate of 1.2m/century (12mm year) to global SLR[35]. Currently the global rate of SLR is only 3.4 mm/y[3]. For the 3000 years prior to the industrial revolution global SLR was zero[3].

What does the new scientific evidence since IPCC 5th Assessment Report in 2013 tell us about the future contribution of Antarctic ice sheet to global sea-level rise?

- The current IPCC sea-level rise projections for the end of the century and beyond under-estimate the contribution of the Antarctic ice loss.
- A new generation of computerized Antarctic ice sheet models, developed since the 2013 IPCC report, predict higher rates and magnitudes of future Antarctic ice mass loss[36,37] (Figs. 10, 11).
- These models now incorporate key observed processes that lead to rapid collapse of floating ice shelves and marine-based ice sheets[26,36,37,38].
- Model skill and performance has been developed and tested (within the SCAR PAIS programme) on past warm climate analogues constrained by geological data and reconstructions[25,26,37,39] (Fig. 9).
- The new predictive models indicate Antarctica may contribute an additional 80 cm of global SLR by 2100 under the business as usual, high-emissions IPCC scenario where CO_2 levels reach 800 ppm by the end of the century[37]. (Fig. 11)
- Of concern is the models also show that if a given CO_2 threshold is passed[36,37,40], Antarctica's ice sheets will continue to melt for centuries to come even if CO_2 levels and atmospheric temperatures are stabilized. This commitment to ongoing multi-meter sea-level rise is because of the high degree of thermal inertia in the ice sheet and ocean system (Fig. 12).

Avoided impacts of 2°C global warming for Antarctic management and operations

- There is a good news story. The results of the new models show that stabilization of Earth's temperature below 2°C, the Paris Climate Agreement goal, saves the Antarctica ice sheet from significant melting (contributing less than 1m total to global SLR)[36,37] which dramatically improves the prospects for island and low lying coastal nations. (Fig. 13)
- In other words, there appears to be a stability threshold in the Antarctic ice sheet around 2°C of global warming, that once exceeded commits the planet to multi-meter sea-level rise[36,37,40].
- The threshold response is because of the stabilizing role of ice shelves, which provide back pressure effectively holding back the marine based ice sheets from faster flow into the ocean. Above 2°C global warming, surface melting and catastrophic collapse of ice shelves is expected, after which ocean heat can rapidly remove marine ice sheets grounded in deep sub-glacial basins.
- Also relevant to the Paris Agreement, is that the stability threshold may be as low as 1.5 °C.
- If global warming is stabilized between 1.5-2°C, we are still committed to 0.5m global SLR, mostly from unstoppable ice loss we are committed to in the Amundsen Sea sector[36,37] (Fig. 13). However, large ice shelves will likely stay intact and seasonal sea-ice will likely decline by only 10%.
- Global sea-level does not rise uniformly due to regional changes in the Earth's crust and the gravitational field. For example, if the majority of future sea-level rise comes from Antarctic ice sheet melting under a high emissions scenario, global sea-level could rise as much as 2m by the end of the century. This would manifest as a 2.5m SLR in the far-field of the ice sheet along the eastern sea-boards of the USA, but a sea-level fall of up to 5m would occur around parts of Antarctica's coastline[41,42]. (Fig. 14).
- A recent report on regional sea-level rise projections for the USA by the National Ocean Atmosphere Administration (NOAA), that takes into account new Antarctic ice sheet contributions, identifies 2.5m of SLR by 2100 as a plausible threat[43].

Future research focus

Less than one third of the 194 member states of the UNFCCC belong to ATS and have direct access to Antarctica for research, yet the UNFCCC, through the IPCC process, requires that scientific knowledge. The ATS and its agreements (e.g. the Protocol on Environmental Protection and the Convention on the Conservation of Antarctic Marine Living Resoruces) also require evidence-based policy and decision-making, that includes knowledge of the impacts of climate change. Critical knowledge gaps have been identified in the IPCC's 5th Assessment Report[3], through strategic assessments carried out by national Antarctic programmes and funding agencies[e.g.44], and the SCAR Horizon Scan process[5,6]. There are many areas such as conservation, environmental protection and management, where understanding the impacts of climate change on Antarctica is a priority. However, an overarching theme of global reach continues to be understanding the response of Antarctica's ice sheet and the Southern Ocean to climate change and improving estimates of its contribution to global sea-level rise. The urgency and scale of these strategic research priorities requires:

- Multi-disciplinary international collaboration including expertise and alignment of resource
- Access to new satellite data, autonomous vehicles and instruments and observatories that can access the ice sheet interior, the ocean, the cavity under ice shelves, the base of ice sheets and sediments and rocks under the ocean and the ice sheet.
- More access to aircraft, ships and over snow traverse capability.
- Commitment to long-term stable funding.
- Use of emerging technologies for energy and storing and communicating data in real time.
- Access to remote areas of Antarctica all year round.

To meet these challenges the Council of Managers of National Antarctic Programmes (COMNAP) have undertaken the Antarctic Road Map Challenge (ARC), which identifies the resources, infrastructure, logistics and supporting technologies needed to enable priority science objectives to be achieved over the coming decades[45].

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