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

New Zealand: 60 years in Antarctica

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What does the United Nations Paris Climate Agreement Mean for Antarctica?: Implications for New Zealand's future research priorities

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Earlier this year I was invited to present the Scientific Committee on Antarctic Research (SCAR) Lecture to the 45th Antarctic Treaty Consultative Meeting (ATCM) in Beijing, China. Through discussion with SCAR's president, Steven Chown, we decided I should address the overarching question – "What will the success or failure of the Paris Climate Agreement mean for Antarctica's physical and biological systems, and what will be the broader impacts for humanity?"

So, why this choice of topic? The ATCM is attended largely by lawyers, diplomats, and officials charged with the governance of activities of the Parties in the Antarctic region, as outlined by Antarctic Treaty System (ATS) and its Agreements – The Protocol for Environment Protection (CEP) and the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR). Understandably, the interests of ATCM have been inwardly focussed, specifically towards the stewardship of the Antarctic environment and ecosystems, and maintaining the continent as a place for peace and science. Historically the ATS and United Nations (UN) have not had a close relationship, but there is growing recognition of the important role the ATS could play on the global stage, particularly within the framework of the UN and its programmes. The role of Antarctica and the Southern Ocean in climate change and sea-level rise is especially significant.

SCAR is developing future research priorities that address the rapid pace of environmental change, and the growing global sustainability problems it brings. SCAR will continue to provide rigorous, defensible scientific evidence to the ATS, but in addition it aims to expand its partnerships and influence, such as its engagement with the Intergovernmental Panel on Climate Change and United Nations Framework Convention on Climate Change (UNFCCC). In particular, SCAR recognises the importance of the global adoption of the Sustainable Development Goals, and initiatives to give effect to them, such as Future Earth.

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 2 °C, the "safe guardrail for dangerous climate change" identified by the IPCC and introduced by the UNFCCC at Copenhagen in 2009. 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

Fig 1: The historic rate of carbon dioxide emissions and the budget available before Earth's surface temperature reaches 2 °C average warming above preindustrial levels. *Source: Ministry for the Environment.*

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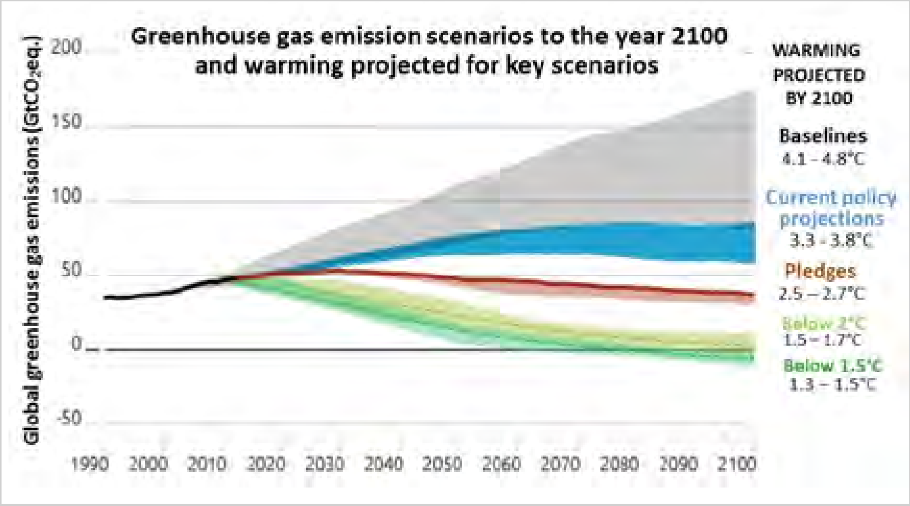

Fig 2: Global greenhouse gas emission scenarios and global average temperatures to the year 2100 for "business as usual" (baseline), an assessment of current global policy settings, the Paris Agreement pledges, and the 2 °C and 1.5 °C stabilisation scenarios. *Source: Climate Action Tracker http://climateactiontracker.org.*

charged with producing a Special Report on what impacts would be avoided by achieving this, including possible greenhouse gas emissions pathways. The Paris Climate Agreement was subsequently signed by 194 countries in New York on Earth Day, 22 April 2016, and went into force on 7 November 2016.

The Agreement is challenging, especially since the current rate of global emissions (40 billion tonnes per year) could take Earth's surface temperature to 1.5 °C in 5–10 years and 2 °C in 15–20 years. (Fig. 1). The NDCs tabled in Paris, if successfully implemented, will restrict global warming to ~2.7 °C (Fig. 2). This is still above the UNFCCC safe guardrail. Current policy settings would see global temperatures stabilising closer to 3.5 °C. To be on track to meet the Paris target, collectively parties need to commit to a 40% reduction in global greenhouse gas emissions with respect to 1990 levels by 2030. This is the EU commitment, but the NDCs of many nations, including New Zealand, fall well short of this. Time is short, so action should begin right away for us to have a chance of success. The Agreement requires parties to increase their commitments during 5-yearly global stocktakes to achieve the target.

How are the ATS and SCAR interacting with the UNFCCC and the IPCC?

While the ATS has no status within the UNFCCC, SCAR does have observer status within the IPCC through its membership of the International Council of Scientific Unions (ICSU) (Fig. 3). 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. Five of the six science priorities developed in the SCAR Horizon Scan process held in New Zealand in 2014 are of direct relevance and interest to the IPCC, now preparing for its sixth 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 Fifth Assessment Report from the legacy of several large IPY research initiatives, and are positioning themselves to make even more significant contributions to the Sixth Assessment Report.

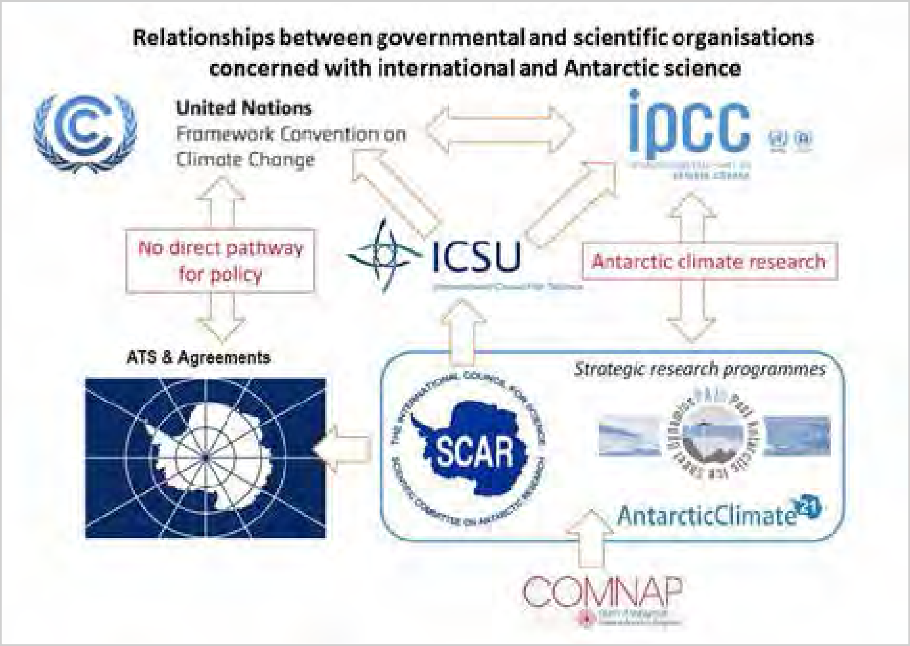

Fig 3: Relationships and interactions between the UNFCCC, IPCC, ICSU and the Antarctic Treaty System, key international governmental and scientific organisations with climate and Antarctic interests. *Source: Author.*

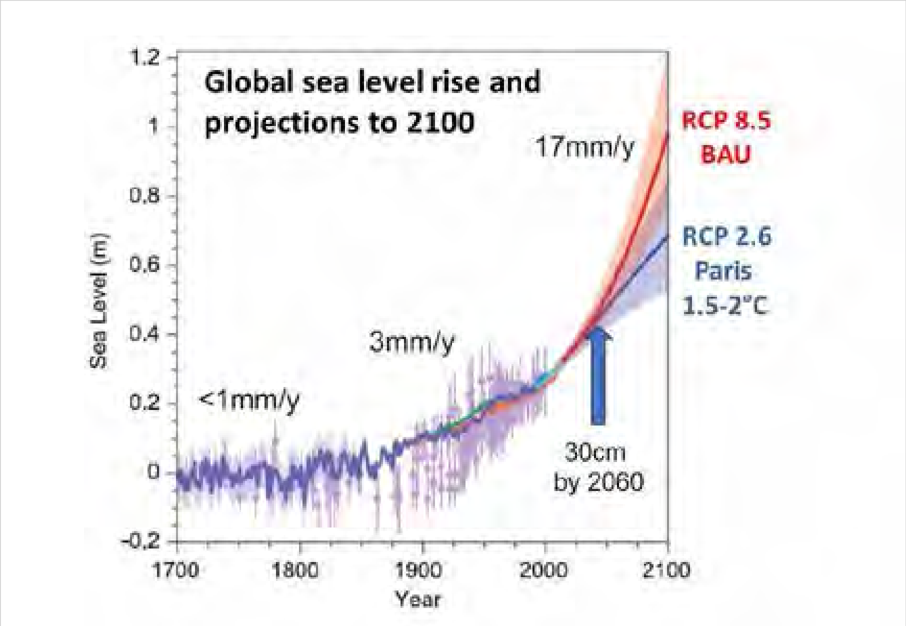

Fig 4: Historical global mean sea-level rise based on palaeoclimate reconstructions, and satellite and tide gauge measurements. This is continued on the right with projected sea-level rise for the IPCC 5th Assessment Report (2013) low (RCP 2.6) and high emission (RCP 8.5 – "Business as usual" or BAU) scenarios. *Source: IPCC.*

Antarctica's contribution to future sea-level rise

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, changes in Antarctica and the surrounding Southern Ocean have worldwide consequences. Some consequences of Antarctica's changing climate are listed in Table 1 (page 51).

Sea-level rise (SLR) is the clearest planet-wide signal of human-induced climate change. So far global sea level has risen 20 centimetres in response to a 1 °C warming. So what does the IPCC predict future SLR will be by the end of the century? In its 2013 assessment report it said SLR could be 1 metre higher with no policy on emissions reductions and 0.5 metres with aggressive emissions reductions as outlined in the Paris Agreement (Fig. 4). No matter what we do from now on we have already committed the planet to 25–30 centimetres of SLR over the next 40 years from the greenhouse gas warming that has already occurred. This is heat already built into the system and is known as committed climate change.

Arguably, the biggest uncertainty of societal and policy relevance facing climate science today is the future contribution of the Antarctic ice sheet to global SLR. After assessing the evidence, the IPCC noted the potentially large contribution from rapid retreat of unstable parts of the Antarctic ice sheet, but did not include this in their global sea-level predictions. They argued at the time of writing (2013) 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 98 centimetres] during the 21st century".

Satellite measurements and further analysis have now shown that the rate of polar ice sheet melting is accelerating. Greenland is contributing more than Antarctica at the moment, but Antarctic ice loss is expected to overtake Greenland to become the dominant contributor by the end of the century. This is because the ocean around Antarctica is warming and the ice sheet is thinning and retreating the fastest, where these warm water currents are moving onto the continental shelf and under the ice shelves (Fig. 5a). The ice shelves are the floating extensions of the land-based ice where it flows out onto the ocean. They play an important stabilising role, holding back the ice sheet from flowing into the ocean (Fig. 5b). When the ice shelves melt as they have around the Antarctic Peninsula and along the Amundsen Sea, the ice sheet slides into the ocean up to 10 times faster. This rapid ice loss contributes to global SLR and could result in an unstoppable runaway retreat of an entire sector of the ice sheet where the bed of the ice sheet lies well below sea level.

Two studies published in 2014 said that it may already be too late for the West Antarctic Ice Sheet. However, this is still actively debated. A key issue is the threshold for Antarctic ice shelf stability, including the role of temperature. How can we determine that threshold, and how fast will sea level rise if it's crossed? New computer ice sheet models are providing key insights. The models have been developed and tested on geological evidence of warmer-than-present climates in the geological past, and these same models are now being applied to the IPCC future climate scenarios. Table 2 (page 51) summarises key insights into Antarctic ice sheet and global sea-level sensitivity that can be determined only from palaeo (past) climate evidence.

What do the latest generation of Antarctic ice sheet models show?

New projections from computer-based Antarctic ice sheet models since the 2013 IPCC report indicate higher rates and magnitudes of

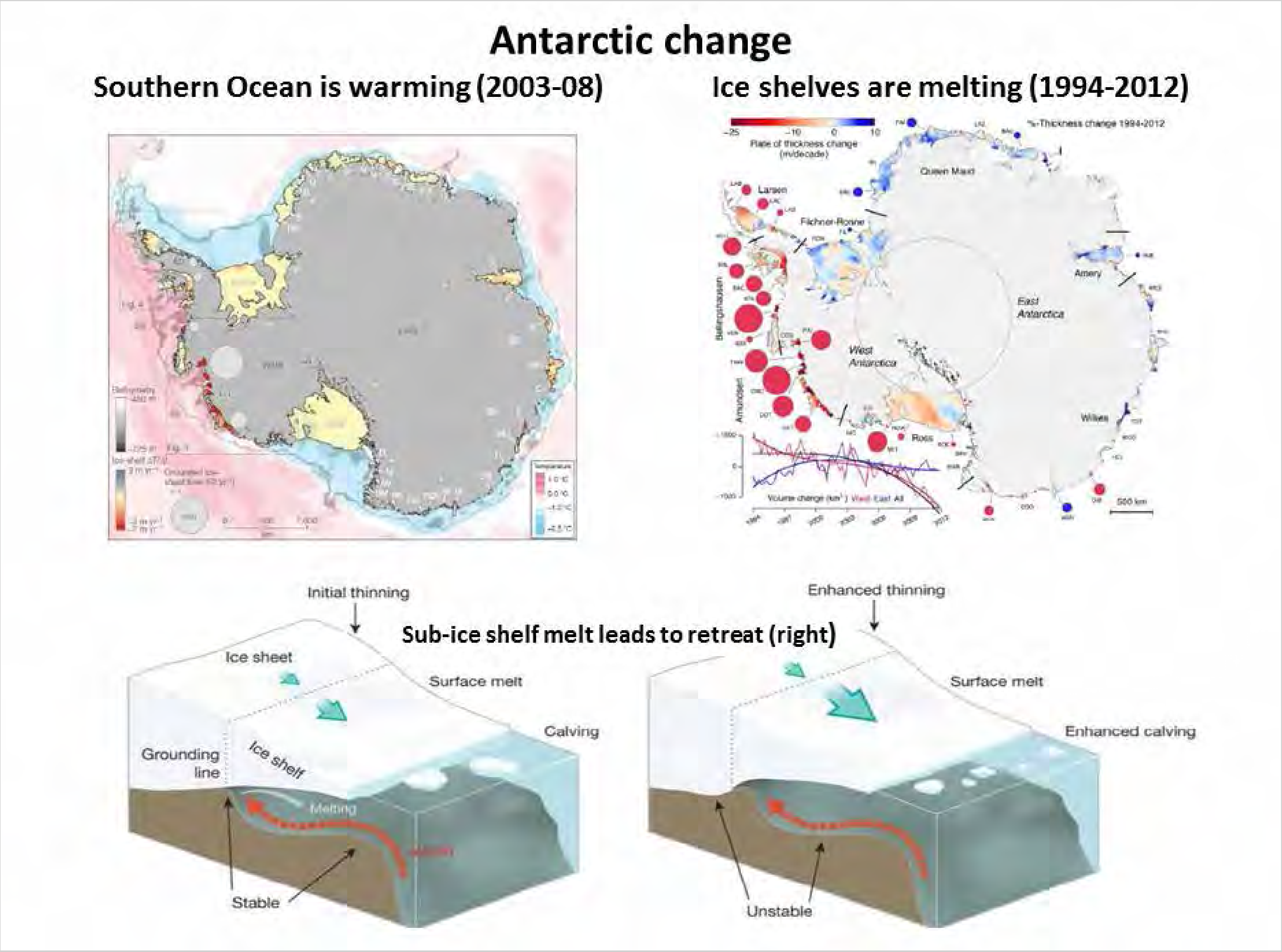

Fig 5: The two maps show the changes now taking place to the Antarctic region: on the left the warming ocean (in pink), and on the right areas where the ice shelves are thinning (red circles). In both maps changes are most marked along the Pacific coast of the West Antarctic Ice Sheet. *Sources: Pritchard et al. (2012, Nature); Paolo et al. (2015, Science).*

The two block diagrams show how warm circumpolar deep water rises up onto the continental shelf and melts the ice shelves, the diagram on the right showing the potential runaway scenario where the melting beneath leads to marine-based ice sheet retreat into deep subglacial basins. *Source: Hanna et al. (2013, Nature).*

future Antarctic ice mass loss for the higher-emission scenarios. These models now incorporate recently recognised processes that lead to rapid collapse of floating ice shelves and marine-based ice sheets. Model skill and performance have been developed and tested within the SCAR PAIS programme on past warm climate analogues constrained by geological data. These models indicate Antarctica may contribute as much as an additional 80 centimetres of global SLR by 2100 under the "business as usual", high-emissions scenario where CO_2 levels reach 800 parts per million by the end of the century (Fig. 6). The models also show that if a given CO_2 threshold is passed, Antarctica's ice sheets will continue to melt for centuries to come even after CO_2 levels and atmospheric temperatures have stabilised. This commitment to ongoing multi-metre SLR is because of the heat trapped in the ice sheet and ocean system, and the longevity of CO_2 in the Earth's atmosphere (centuries to millennia).

What if we stabilise Earth's temperature below 2 °C?

There is, however, a good-news story. The results of the new models show that stabilisation of Earth's temperature below 2 °C, the Paris Climate Agreement goal, reduces Antarctic ice loss from melting to less than half a metre of SLR. This dramatically improves the prospects for island and low-lying coastal nations. 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-metre SLR. The threshold response is because of the stabilising role of ice shelves. 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.

Moderating the good news is the current uncertainty around the stability threshold, which could be

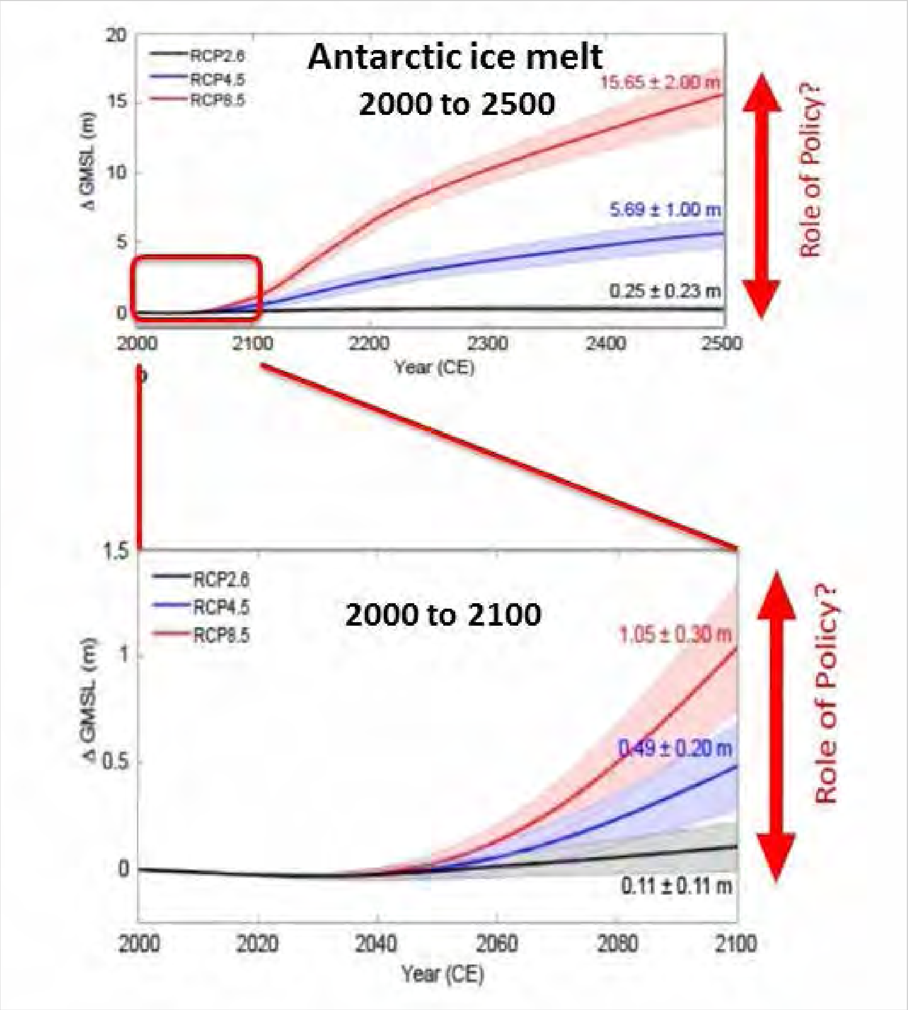

Fig 6: Antarctic contribution to global sea-level rise for high and low IPCC emission scenarios from a recent model that includes recently recognised processes of rapid ice shelf and runaway marine ice sheet retreat, and is calibrated by palaeoclimate reconstructions. The model shows that low emissions policies provide the only opportunity for preserving the ice sheets and limiting sea level rise.
Source: DeConto & Pollard (2016, Nature).

as low as 1.5 °C. If global warming is stabilised between 1.5 and 2 °C, we are still committed to global SLR of about half a metre, mostly from unstoppable ice loss in the Amundsen Sea sector. However, large ice shelves will likely stay intact and seasonal sea ice will likely decline by only 10–20%.

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 (CEP and CCAMLR) 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 Fifth Assessment Report, through strategic assessments carried out by national Antarctic programmes and funding agencies, and the SCAR Horizon Scan process. There are many areas, such as conservation and 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 the ice sheet's contribution to global SLR. The urgency and scale of these strategic research priorities require:

- Multi-disciplinary international collaboration including expertise and alignment of resource
- Access to new satellite data, autonomous vehicles, 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 for 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 Programs (COMNAP) has undertaken the Antarctic Roadmap Challenges (https://www.comnap.aq/Projects/SitePages/ARC.aspx), which identifies the resources, infrastructure, logistics, and supporting technologies needed to enable priority science objectives to be achieved over the coming decade.

The bottom line

My parting comment to the 45th ATCM was that the clock is ticking and time is short. Many knowledge gaps on Antarctica's response to global warming will have wide-reaching impacts, and it is vital that we can anticipate and manage them. The ATS and its Agreements are key stakeholders whose functions will be impacted by climate change, but the Parties also have a collective responsibility to address these knowledge gaps for the sake of both humanity and the ecosystem on which we depend.

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Table 1: Global and Antarctic consequences of anthropogenic warming

Global	Warming of the climate system is unequivocal, and the human influence is clear.
Global	The clearest global response is global sea-level rise (SLR). 20 cm SLR observed since 1850; 15 cm of SLR occurred in the last 30 years.
Global	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.
Ice sheet	The Antarctic ice sheet holds 90% of the world's ice and if returned to the ocean would raise sea level by 58 m. East Antarctic Ice Sheet contains 54 m SLR; West Antarctic Ice Sheet contains 4 m SLR.
Ice sheet	The ice mass loss is contributing to global SLR at an accelerating rate and by mid-century may be the single biggest factor contributing to global SLR.
Sea level	The largest uncertainty in predicting global future SLR is predicting the response of the Antarctic ice sheet to continued warming in the ocean and atmosphere.
Southern Ocean	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 have gone into the ocean.
Atmosphere & ocean	The tug of war between ozone hole and global greenhouse gases that acts to cool Antarctica while warming the rest of the planet, steepens the pole–equator temperature gradient of the Southern Hemisphere, invigorating zonal atmospheric circulation and causing warm circumpolar deep waters to upwell along the coast of Antarctica. This increased heat flux to the marine margins of the ice sheet is causing collapse of stabilising ice shelves and rapid thinning and retreat of the ice sheet.
Atmosphere & ocean	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.
Ocean productivity	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.

Table 2: Information from palaeoclimate archives on the sensitivity of Antarctica's ice sheets and implications for global sea level

Sensitivity	Climate reconstructions from the geological past show that the Antarctic ice sheet is highly sensitive to relatively small increases in Earth's average temperature.
Polar amplification	This sensitivity is because amplifying feedbacks and processes cause the polar regions to warm two to three times more than the global average.
2–3 °C warmer	The last time Earth experienced atmospheric CO_2 concentrations of 400 ppm (today's concentration) was three million years ago. Global temperature equilibrated at 2–3 °C warmer, polar temperatures were 6–7 °C warmer, and Antarctica lost marine-based ice from its more vulnerable subglacial basins, contributing +13 m to global sea level. Greenland melting also contributed another +7 m.
3–4 °C warmer	400–600 ppm atmospheric CO_2 (3–4 °C global warming, ~15–17 million years ago) appears to be a threshold for loss of the mostly marine-based parts of the West Antarctic Ice Sheet (+3 m SLR), and marine-based sectors of the East Antarctic Ice Sheet (+17 m SLR).
4–5 °C warmer	600–700 ppm atmospheric CO_2 (4–5 °C global warming, ~25–34 million years ago) appears to be a threshold for loss of Antarctica's land-based ice, and at 1000 ppm CO_2 Antarctica has no ice.
Rates of change	After the last ice age sea level rose 120 m due to Northern Hemisphere (+100 m SLR) and Antarctic (+20 m SLR) ice melt from ~18,000 to ~8000 y BCE), a rate of 1.2 m/century or 12 mm year. For a few hundred years around 14,500 years ago the rate reached 4 m/century. Antarctica on its own contributed to SLR at between 1 and 1.5 m/century at this time.