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# State of the Antarctic and Southern Ocean Climate System (SASOCS)

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## *Executive Summary*

This Information Paper provides a review of the key developments over the past two years in our understanding of Antarctic climate and the role of the Antarctic climate system in the global climate system. It comments on the findings of the 2007 Intergovernmental Panel on Climate Change (IPCC) that relate to the Antarctic. A follow-up paper will incorporate studies of effects of climate change on the biota.

- Antarctica and the Southern Ocean play a major role in the Earth's climate system. They are being and will continue to be affected by global climate change. Their responses to such change will have significant impact on global conditions, especially sea level.
- Modern climate in the region results from the interplay of the ice sheet – ocean – sea ice – atmosphere system and its response to past and present climate forcing.
- Superimposed on the long-term trend of post-glacial warming are millennial and finer scale oscillations whose causes are not well understood aside from those associated with the 11-year sunspot cycle.
- In the past 50 years unprecedented climatic changes cut across these trends. They include the near-surface atmospheric warming observed on the west of the Antarctic Peninsula, with associated rapid warming of the surface ocean, retreat of glaciers and the collapse of ice shelves around the Antarctic Peninsula.
- While ice is being lost from glaciers in the Peninsula and in West Antarctica, East Antarctica shows much less ice loss.
- Consistent with global warming, the Antarctic troposphere has warmed while the stratosphere has cooled. Part of the reason for stratospheric cooling is ozone depletion.
- Cooling of the stratosphere appears to have encouraged the development of polar stratospheric clouds, which may have exacerbated ozone depletion.
- The atmospheric pressure gradient between mid latitudes and Antarctica has steepened over the past 50 years, intensifying the westerlies over the Southern Ocean, and warming the Antarctic Peninsula; this change in pressure and wind has had no significant effect as yet on temperature in East Antarctica, which remains cool.
- The upper kilometer of the circumpolar Southern Ocean has warmed, as have the densest components of Antarctic Bottom Water in the Weddell Sea.
- The coastal ocean has freshened between the Ross Sea and the Southern Indian Ocean, making the Antarctic Bottom Water formed there less saline.
- Since the early 1970s sea ice has reduced west of the Antarctic Peninsula, and in the Weddell Sea. These decreases are balanced by an increase in the Ross Sea.
- Projections of Antarctic climate change over the 21$^{st}$ century with a doubling of $CO_2$ in the atmosphere indicate warming of the sea ice zone; a reduction in sea ice extent; and warming of the Antarctic interior, accompanied by increased snowfall.
- Climate models need further development to forecast change at the regional level.
- The retreat of the Antarctic ice sheet since the Last Glacial Maximum could be significantly accelerated by global warming. Ice sheet models are not yet adequate to answer pressing questions about the effect of warming on ice melt and sea level. This topic requires significant research.
- Threshold effects may have a significant impact on the ice sheet and sea ice extent. During the last glacial and current interglacial, such effects resulted in massive reorganizations of the ocean-atmosphere-cryosphere system, leading to rapid climate change events. Comprehensive sampling and modeling of the ocean-ice-atmosphere system in the region is needed to forecast such events with confidence.

The paper is a summary of a detailed review produced for submission to a scientific journal. by the SCAR Scientific Research Programme on Antarctica and the Global Climate System (S. Aoki, P.J. Barrett, N.A.N.

Bertler, T. Bracegirdle, D. Bromwich, H. Campbell, G. Casassa, A. N. Garabato, W.B. Lyons, K.A. Maasch, P.A. Mayewski, M.P. Meredith, C. Summerhayes, J. Turner, D. Vaughan, A. Worby, and C. Xiao), For access to the original paper please contact the SCAR Secretariat.

## *Setting the Stage*

Antarctica and the Southern Ocean play a significant role in the global climate system. The Southern Ocean is the world's most biologically productive ocean and a significant sink for both heat and $CO_2$ making it critical to the evolution of past climate change and present and future human-induced climate change. The Southern Ocean is the site for the production of the coldest, densest water that participates in global ocean circulation, which is of critical importance to climate change. The strong westerly winds that blow over the Southern Ocean drive the world's largest current system, the Antarctic Circumpolar Current (ACC), and are recognized to be the dominant driving force for the global overturning circulation. Today, Antarctica holds 90% of the world's fresh water as ice, and, along with its surrounding sea ice, it plays a major role in the Earth's albedo dynamics and is an important driving component for atmospheric circulation. Its unique meteorological and photochemical environment led to the atmosphere over Antarctica experiencing the most significant depletion of stratospheric ozone on the planet, in response to the stratospheric accumulation of man-made chemicals produced largely in the Northern Hemisphere.

The climate of the Antarctic region is profoundly influenced by its ice sheet, which reaches elevations of over 4000 m. This ice reduces Southern Hemisphere temperatures and stabilizes the cyclone tracks around the continent. The ice sheet is a relatively recent feature geologically, developing as Antarctic climate changed from temperate to polar, and from equable to strongly cyclic, over the last 50 million years (Ma). In the high $CO_2$ world of Cretaceous and early Cenozoic times, when atmospheric $CO_2$ stood at between 1000 and 3000 ppm, global temperatures were 6 or 7ºC warmer than present, peaking around 50 million years ago with little or no ice on land anywhere.

Modern climate over the Antarctic and the Southern Ocean results from the interplay of the ice sheet – ocean – sea ice – atmosphere system and its response to past and present climate forcing. This system first established itself with the first big ice sheets 34 Ma ago as global $CO_2$ levels fell, but developed into a well established "icehouse" world just 14 Ma ago. Ice cores and geological studies show how temperature and greenhouse gases have oscillated within a well-defined band through out this time, though atmospheric $CO_2$ levels have now risen above the normal limit. Distinguishing between naturally forced climate events and those responding to greenhouse gas forcing, and projecting future responses, are the twin key challenges for Antarctic climate scientists.

Following the Last Glacial Maximum around 20,000 years ago, ice core records from East Antarctica exhibit an early Holocene climatic optimum from 11,500 to 9,000 years ago, followed by a cold event about 8,000 years ago then a return to mid-Holocene 'warm' conditions followed by a slow cooling that ended with the rise in $CO_2$ post 1850. Superimposed on these long-term trends are millennial scale and faster oscillations, some of which may involve relatively abrupt change, like the one around 1000 years ago that saw intensification of the westerlies and development of a massive Amundsen Sea Low in the South Pacific, accompanied by relatively cooler temperatures over East Antarctica. Detailed examinations of ice cores from the past 700 years show that the climate tends to seesaw between one state with a strong East Antarctic High pressure system and a deep Amundsen Sea Low, and another with a weak East Antarctic High and a shallow Amundsen Sea Low. At times the climate may change mode for an extended period, forced by climate change elsewhere, for instance ENSO style forcing from the Pacific Ocean. One of the most recent switches in climate that may have affected the South Pacific, the Southern Ocean and Antarctica is evident between AD 1700 and AD 1850. The causes of this and other decadal to millennial scale changes are not well understood. Superimposed on these longer-term trends it can be shown (by using the isotope $^{10}Be$ as a proxy for solar activity) that increased solar output leads to intensification of zonal winds over much of the Southern Ocean and around Antarctica. Thus wind strength and associated climatic effects tend to fluctuate with the 11-year and longer cycle. Cutting across these trends, in recent times we see evidence for rapid and unprecedented climatic changes, such as the near-surface atmospheric warming observed on the west of the Antarctic Peninsula (annual mean 3ºC and winter mean 5ºC in the past 50 years), and the massive collapse of ice shelves around the Antarctic Peninsula (e.g. Larsen B in 2002).

## *The Last 50-200 Years*

***Mass balance:*** The mass balance is defined as the difference between mass losses (by basal melting, surface sublimation and melting, and ice calving) and mass gains (by net snow/ice accumulation at the surface by precipitation, drifting snow, and solid deposition from water vapor, subsurface accumulation by superimposed ice, and basal accretion in the case of ice shelves). Overall the Antarctic ice sheet appears to have a mass balance that is slightly negative (i.e. a little ice is being lost) over the past decade, although error limits indicate that the loss may not be significantly different from zero. The picture is complicated by our inability accurately to measure snowfall across the continent. It is imperative to reduce this uncertainty in future work.

The mass balance picture is different for the Antarctic Peninsula, which extends well to the north of the rest of Antarctica, and where ice shelves are collapsing and most glaciers (87%) are receding at rates that have accelerated over the last two decades. Much the same is true of the Sub-Antarctic islands, New Zealand, and southern South America. The 20$^{th}$ century recession of mountain glaciers in the region is outside the range of variability of the last few millennia. At the same time a few glaciers in southern South America and New Zealand, to which intensified westerlies bring more moist oceanic air, have increased snow accumulation and are advancing (or were until recently).

The collapse of Antarctic ice shelves in itself contributes nothing directly to sea-level change, as they are already floating. However, their disappearance can cause previously dammed glaciers to accelerate, which may lead to sea-level rise. As warming spreads south, the Larsen C ice shelf is beginning to thin and may be the next to collapse.

***Atmospheric temperature:*** The largest modern annual warming of the near-surface atmosphere is over the western and northern parts of the Antarctic Peninsula, especially in winter. The large winter component of this warming (5ºC in 50 years) is associated with a concomitant decrease in winter sea ice. Summer warming has been greatest on the eastern side of the Peninsula, because strengthening of the westerlies resulted in 'warm' maritime air masses reaching the Weddell Sea, where they contributed to the collapse of the Larsen B ice shelf. Much of the rest of coastal and interior Antarctica shows little change in surface air temperature except for a recent slight cooling at the South Pole. Over the last 30 years there has been winter warming (0.5 – 0.7° C per decade) in the mid-troposphere (some 5km above sea-level), and cooling of the stratosphere. The pairing of tropospheric warming and stratospheric cooling may be a reflection of the growing storage of greenhouse gases in the troposphere, which prevents radiation from the Earth's surface from warming the stratosphere.

***Atmospheric circulation:*** The meridional circulation of the Earth's atmosphere results from the movement of warm air from the tropics towards the poles. There are a number of cells in the atmospheric circulation that give low pressure close to the Equator (the Doldrums), high pressure in the sub-tropics, and low pressure in the belt of storms in the mid-latitudes over 40º S – 60º S (the westerlies). The pressure gradient between the mid-latitude higher pressure zone at 40º S and the high latitude low-pressure zone at 65º is known as the Southern Hemisphere Annular Mode (or SAM) (also referred to as the Antarctic Oscillation). The gradient steepens when pressures increase at mid-latitudes and decrease at high latitudes. At these times the SAM index is said to be in its positive phase, and the westerlies are at their strongest. The SAM index, which is the principal mode of variability of the atmospheric circulation of the high latitudes, fluctuates throughout the year and from year to year. Over the last 50 years it has shifted to its positive phase during the summer and autumn, intensifying the westerlies over the Southern Ocean, warming the Antarctic Peninsula and cooling East Antarctica by a small amount. Some modeling studies attribute the development of a positive SAM in the summer in recent years to strengthening of the ozone hole, while others suggest that it is caused by greenhouse gas increases. Alternatively it may be a response to both types of forcing.

The El Niño–Southern Oscillation (ENSO) can also affect Antarctica and the Southern ocean, especially in the region of West Antarctica and the Antarctic Peninsula. Instrumental records reveal that ENSO warm events are associated with enhanced precipitation in West Antarctica. West Antarctic precipitation was positively correlated with the Southern Oscillation Index (SOI)(a measure of ENSO events) until about 1990, after which the two became strongly anti-correlated. The decadal variability of the high latitude ENSO teleconnection to the South Pacific is governed by the phase of the SAM. When both are in the same phase (i.e., La Niña occurring with positive phases of the SAM and vice-versa), the teleconnection is amplified; the connection is much weaker when these two main climate modes are out of phase.

During El Niño events (warm Pacific equator), which recur about every 4 years, high air pressure, warm sea surface temperature and less sea ice often occur west of the Antarctic Peninsula in the Pacific sector, while cold sea surface temperature and more sea ice occur east of the Peninsula in the Atlantic sector. It is also stormier east of the Peninsula than to the west. The opposite conditions apply during intervening La Niña events (cold Pacific equator).

Ice core studies reveal that the range of variability in modern atmospheric circulation features like the westerlies and the Amundsen Sea Low is within that of the last few hundred years. Ice cores have also been used to infer a recent increase in inland penetration of marine tropospheric air masses in the Amundsen Sea sector of West Antarctica during summer, which may be a reflection of the warming that was previously largely confined to the Antarctic Peninsula.

***Ozone hole and climate:*** Ozone forms a protective blanket in the stratosphere at heights of 20-40km above the Earth, protecting life from dangerous levels of ultraviolet radiation. In the polar regions this ozone is destroyed by chlorine atoms liberated from chlorine gas generated by the chemical breakdown of chlorine compounds bound to the surfaces of ice crystals in polar stratospheric clouds. The destruction takes place in the southern spring, when the sun begins to rise, heating the stratosphere and supplying UV rays that convert chlorine gas to the chlorine atoms that attack ozone molecules. The process is focused above Antarctica because there the stratosphere gets colder than anywhere else on Earth. That coldness comes about because in the southern winter strong stratospheric winds flow clockwise around the continent forming a ring of moving air named the Polar Vortex. Temperatures inside the ring drop sharply as the supply of warm air from outside is cut off. Water vapour condenses into tiny ice particles to form the polar stratospheric clouds that attract chlorine-bearing compounds derived from industrially produced chlorofluorocarbons (CFCs). Ozone destruction stops in October when the air warms up, melting the icy particles that make up polar stratospheric clouds. The molecules that were bound to their icy surfaces are free again to bind chlorine gas, stopping its breakdown into destructive chlorine atoms. In November the Polar Vortex weakens allowing ozone rich air from outside to flow in and replace the ozone that was destroyed. By year-end the ozone levels in the stratosphere are typically back to normal, until the following spring when the cycle begins again. Reductions in the emissions of CFCs have stabilized the ozone hole, which now varies in intensity from year to year in response to variability in atmospheric conditions.

Global circulation models imply that global warming should lead to cooling of the stratosphere. A cooler stratosphere may in turn lead to the development of increased polar stratospheric cloudiness, which may have two related effects: (i) to exacerbate the conditions giving rise to ozone depletion; and (ii) to provide a lid on the troposphere that would lead to further tropospheric warming. Models are not yet adequate to examine this issue.

***Ocean temperature and salinity:*** The Southern Ocean is the least explored and least understood ocean in the world, not least because of the difficulty in sampling it during the southern winter, when much of it is covered by sea-ice. Although much more needs to be done to monitor its behaviour as the basis for predicting future change, it is now well established from observations and models that since 1950 the Southern Ocean has warmed by around 0.2ϒC at depths of 700 to 1100m and between 35 and 65ºS. Recent indications are that this warming extends to the surface of the Southern Ocean, with undiminished magnitude. This rate of warming exceeds that of the global ocean, and may reflect anthropogenic global change. The cause of the ocean warming is not known unambiguously, but is likely to depend on the increasing strength of the westerly winds over the Southern Ocean and increased radiative forcing from greenhouse gases. One model study showed that if the cooling effect of volcanic aerosols is neglected, the simulated warming is nearly double, suggesting that the human impact on Southern Ocean warming is only partially realized at present.

Upper water column warming trends are noted near 40ϒS, perhaps associated with the formation and sinking of Sub-Antarctic Mode Water. Closer to the Antarctic, cooling below 1100m and above 600m is linked to the formation sites of intermediate and bottom waters. Large decreases in salinity are found south of 70ϒS in the Pacific Sector of the Southern Ocean, associated with freshening of the Ross Sea and other coastal fringes, probably due to increased melting of glacial ice. In the Weddell Sea, mid-level waters warmed markedly by 0.3ºC between the 1970s and the mid-1990s, though lately slight cooling (0.06ºC) has been noted. Whether or not this is a temporary change remains to be seen, but Weddell Sea bottom waters have also warmed, by 0.02ºC, since 1980, and that trend continues. Strong surface-intensified warming and a coincident increase in salinity since the 1950s are associated with a reduction in sea ice to the west of the Antarctic Peninsula and with the warming of the air masses over the Peninsula. The reduction in sea ice there reduces albedo and positively reinforces warming.

***Ocean circulation:*** The ocean plays a key role in the climate system by storing heat and moving it around in the meridional overturning circulation otherwise known as the thermohaline conveyor belt. How this system works in the Southern Ocean is not well understood because that ocean is under-sampled, especially in areas covered by winter sea ice. Two main processes dominate Southern Ocean circulation. The prevailing westerly winds help to drive the Antarctic Circumpolar Current (ACC), the world's largest ocean current, which circles Antarctica from west to east between around 45 and 60ºS and connects the Atlantic, Pacific and Indian Oceans. Crossing the current is a complex system of north-south imports and exports. The products of deep convection in the North Atlantic flow south to the Southern Ocean, eventually rising up to the surface again as they cross the ACC and approach the Antarctic coast. Antarctic Bottom Water forms on the continental shelf and at the shelf break, sinks down the continental slope, and is exported north along the seabed, reaching the North Atlantic. Antarctic Intermediate Water sinks north of the Polar Front near the middle of the ACC, to permeate the global ocean at intermediate depths; and Sub-Antarctic Mode Water sinks to shallower depths and moves north away from the Sub-Antarctic Front at the northern edge of the ACC. Strengthening of the winds, induced by changes in the Southern Annular Mode, is expected to increase (i) transport in the ACC and/or circumpolar eddy activity, (ii) the upwelling of Circumpolar Deep Water, (iii) the formation and export of Sub-Antarctic Mode Water and Antarctic Intermediate Water, and (iv) the strength of the Southern Hemisphere subtropical and sub-polar gyres. Observational evidence supports some of these assertions, but many details are as yet unclear, as are the effects on climate. This is a serious problem, as Southern Ocean circulation change is thought to have played a pivotal role in driving past global climatic transitions and stands out as a key element of the oceanic response to recent and projected atmospheric trends in model simulations of climate change. Resolving the problem calls for extended observations of ocean behaviour under the winter sea ice.

***Sea ice:*** Based on a comparison between ship's logs and satellite data, there is no compelling evidence that the sea ice edge around Antarctica has changed much as a whole over the past 200 years. Satellite data confirm that there has been no statistically significant change in sea ice extent in recent decades. There is, however, strong evidence for regional changes in ice extent and area. Since the early 1970s there has been a significant reduction in the extent of sea ice and the length of the sea ice season to the west of the Antarctic Peninsula, and, to a lesser extent, in the Weddell Sea. These decreases are balanced by an increase in the Ross Sea. A possible retreat of sea ice in East Antarctica between 80 – 140ºE is the subject of debate. As far as sea ice thickness is concerned our knowledge is limited, as monitoring it year-round is currently not possible.

Because plankton release dimethyl-sulphide that is transported landward by winds and deposited in snow as sulphates, ice cores on land may contain records of periods when plankton were closer to the coast; these records could then be used to extract the past history of sea ice extent. Research on this topic is ongoing.

## The Next 100 Years

The main tools we have for predicting how the climate of the Earth will evolve in the future are coupled atmosphere-ocean climate models. Many of the current generation of climate models struggle to represent key aspects of polar climate, such as sea ice and near-surface temperature. The best of these models have recently succeeded in qualitatively reproducing the observed warming over the Antarctic Peninsula, although uncertainties associated with climate controls and model error still require research. One of the difficulties is the coarse horizontal scale of the Global Circulation Models (GCMs) used to forecast climate change (grid sizes are of the order of hundreds of square kilometers). In future we need to develop higher resolution regional models nested within the GCMs to accurately reproduce regional effects.

Here we refer to projections of Antarctic climate change over the 21$^{st}$ century from 19 of the 24 models that were submitted for the Intergovernmental Panel on Climate Change (IPCC) Assessment Report Four (AR4). Data from the Special Report on Emissions Scenarios (SRES) A1B scenario were used. This prescribes an approximate doubling of $CO_2$ in the atmosphere over the next century and compared to other SRES scenarios is middle of the range in terms of the simulated 21$^{st}$ century global temperature response to prescribed forcing. The 21$^{st}$ century projected changes (presented here as the mean and standard deviation of the projections from the different models) of the annual mean of key climate parameters over Antarctica are as follows: (i) a surface temperature increase of $0.24 \pm 0.10^oC$ per decade in the sea ice zone; (ii) an overall reduction in sea ice area of $33 \pm 9\%$ by 2100; (iii) a warming of $0.34 \pm 0.10^oC$ per decade over the interior of Antarctica; (iv) weakening of katabatic winds, especially in the summer season; (v) an increase of $25 \pm 11\%$ in annual accumulated snowfall over the grounded Antarctic ice sheet by 2100. While increased snowfall might be expected to mitigate against a rise in sea-level, that effect may be neutralized by the melting and mechanical break up of ice sheets at the coast. Ice sheet models are not yet adequate to answer this pressing question, not least in failing to take mechanical break-up into account. Warming of the interior might be expected to be higher were it not for the fact that the anticipated increase in the strength of westerly winds over the Southern Ocean is expected to isolate the continental interior, preventing extensive penetration by 'warm' maritime air masses.

Any assessment of future change using the output from climate models must include a consideration of the ability of the models to represent the processes leading to the change of interest. One example of this is the Antarctic Peninsula warming, which has strong contributions from different mechanisms in different seasons. The summer warming to the east of the Peninsula has been attributed to SAM changes, which are well represented in most climate models. The winter warming to the west of the Peninsula has been linked to other processes, such as the retreat of sea ice and changes in the frequency and intensity of El Niño events; both still represent significant modeling challenges and attributions of change should be treated with caution.

## *Notes on The IPCC Policy Makers' Summary (Working Group 1)*

The SASOCS document was prepared during the last few months in the run up to the release of the Summary for Policy Makers prepared by Working Group (WG) 1 of the Intergovernmental Panel on Climate Change (IPCC) on February 2, 2007. The full report of WG1 will not be released on line until May 2007. Given the timing of the SASOCS document, it can be taken as a more up to date version of the climate story than is presented in the Policy Makers Summary, especially as far as Antarctica and the Southern Ocean are concerned. In the text that follows, each IPCC finding (carrying our number) is followed by a SASOCS perspective.

*IPCC 1. Warming of the climate system is unequivocal. Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.*

SASOCS response to IPCC-1: – Anthropogenically induced greenhouse gas change plays a critical role in the climate over Antarctica and the Southern Ocean. Increasing levels of greenhouse gases, coupled with the presence of the Antarctic ozone hole, which have resulted in a colder stratosphere, have worked together to strengthen the westerly winds around the Antarctic, isolating the continent from warmer maritime air masses over the Southern Ocean. These factors have resulted in little change in surface temperature over recent decades for the bulk of the Antarctic, which is in contrast to the rapid increases in temperature and loss of sea ice in the Arctic.

*IPCC 2. Losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003. Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues.*

*IPCC 3. Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year.*

*IPCC 4. The warmth of the last half-century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise….. Average polar temperatures at that time were 3 to 5°C higher than present, because of differences in the Earth's orbit.*

*IPCC 5. The … pattern of tropospheric warming and stratospheric cooling is very likely due to the combined influences of greenhouse gas increases and stratospheric ozone depletion.*

SASOCS response to IPCC 2, 3,4 and 5: – Ice sheet dynamics pose a potentially alarming problem in forecasting future sea level change. Potential regions of instability that could contribute to a future massive (several meter) rise in sea level are found along the coast of West Antarctica and in several parts of East Antarctica (eg. the Lambert and Byrd Glacier drainage basins). The Antarctic ice sheet has been in a state of retreat following the Last Glacial Maximum, and that retreat could be significantly accelerated by growing greenhouse gas change impacts on sea surface temperature, on surface melting over the ice sheet, and on atmospheric circulation. This topic requires significant research.

*IPCC 6. Antarctic sea ice extent continues to show inter-annual variability and localized changes but no statistically significant average trends, consistent with the lack of warming reflected in atmospheric temperatures averaged across the region.*

SASOCS response to IPCC 6: – Studies of a network of high resolution ice cores covering up to the past 10,000 years can provide a picture of past regional climate change including the past extent of sea ice, though they will not help to determine past ice thickness.

*IPCC 7. For the next two decades a warming of about 0.2°C per decade is projected.*

*IPCC 8. Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century*

*IPCC 9. Sea ice is projected to shrink in both the Arctic and Antarctic under all scenarios.*

*IPCC 10. Model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. Net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance.*

SASOCS response to IPCC 7-10: – Much of Antarctic climate (other than Antarctic Peninsula temperature, mass balance, sea ice extent, and ice shelf extent; winter mid tropospheric temperature over Antarctica, and stratospheric ozone levels) is currently within the range of variability for temperature, mass balance, and atmospheric circulation of the last several centuries. Current models take this state as the basis for future projections. However, the possible responses of the ice sheet and of sea ice extent to future warming are poorly known. Antarctic climate is dominated by the presence of the ice sheet and any changes in its extent and thickness will solicit massive responses, as we know from our understanding of the retreat of Northern Hemisphere ice sheets. We cannot underestimate the potential impact of threshold effects on the ice sheet and sea ice extent. During the last glacial and current interglacial, threshold effects resulted in massive reorganizations of the ocean-atmosphere-cryosphere system, leading to rapid climate change events. Comprehensive sampling and modeling of the ocean-ice-atmosphere system in the Antarctic region is necessary if we are to forecast such events with any reasonable degree of confidence.

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