# STATE OF THE ANTARCTIC CLIMATE SYSTEM
## *Excerpts from SASOCS (*Mayewski *et al.* 2009*)*

## ESTADO DEL SISTEMA CLIMATICO ANTARTICO
### *Extractos de SASOCS (*Mayewski *et al.* 2009*)*

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## RESUMEN

Dos informes recientemente publicados, documentan el pasado y presente, y las predicciones futuras para el clima sobre la Antártica y el Océano Austral. De éstas síntesis es claro que Antártica juega un rol crítico en el cambio climático sufrido a nivel hemisférico y regional, y que las actividades humanas en tiempos recientes, están empezando a tener un marcado impacto sobre la temperatura, precipitación circulación atmosférica, circulación oceánica, extensión del hielo marino y química de la atmósfera en la Antártica.

Palabras clave: Antártica, cambio climático, Océano Austral.

## ABSTRACT

Two recently released reports document the past, present and future predictions for climate over the Antarctic and the Southern Ocean. From these syntheses it is clear that the Antarctic plays a critical role in hemispheric to regional climate change and that in recent times human activities are beginning to have a marked impact on Antarctic temperature, precipitation, atmospheric circulation, ocean circulation, sea ice extent and chemistry of the atmosphere.

Key words: Antarctica, climate change, Southern Ocean.

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## EXCERPT SUMMARY

The Antarctic and Southern Ocean play a significant role in the global climate system. Antarctica is the largest reservoir of fresh water on the planet, a major site for the production of the cold deep water that drives ocean circulation, a major player in Earth's albedo dynamics, and an important driving component for atmospheric circulation. Further, its unique meteorological and photochemical environment led to the atmosphere over Antarctica experiencing the most significant depletion of stratospheric ozone on the planet, as a consequence of humanly engineered chemicals produced largely in the Northern Hemisphere. 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 human-induced climate change.

The context for understanding modern climate over Antarctica and the Southern Ocean clearly requires an understanding of multi-millennial to seasonal scale variability because of the climate complexity introduced by the large range in response times of the ice sheet – ocean – sea ice – atmosphere system to climate forcing. Deep ice cores recovered from Antarctica demonstrate the continent has experienced successive glacial/interglacial cycles over more than the past 850,000 years during which changes in temperature have been associated with changes in greenhouse gas content of the atmosphere and changes in orbital insolation patterns (EPICA, 2004). Knowledge of the phasing of climate events on regional to hemispheric scales is essential to the understanding of Earth's dynamic climate system. Recent ice core studies suggest a coupled association between glacial age millennial to multi-centennial hemispheric scales whereby Antarctic warm events and Greenland cold events change in response to deep meridional overturning of ocean circulation (MOC) (EPICA, 2006).

Demonstration that the climate system can experience abrupt change on the order of seasons to years to decades comes from both past climate records recovered from ice cores and modern observations such as the massive calving of ice shelves in West Antarctica. A climate change event commencing ~1000 years ago is the most significant climate event of at least the last ~5000 years for the Antarctic (Mayewski *et al.*, 2004a). It is characterized by intensification of major circulation features such as the westerlies and the Amundsen Sea Low and in general cooler temperatures over East Antarctica (Masson *et al.* 2000; Mayewski and Maasch 2006). The most recent, pre-instrumental era, abrupt change event occurred ~AD1700-1850 in the form of a temperature and atmospheric reorganization generally coincident with an increase in solar output and in its latter stages with the modern rise in $CO_2$ (Mayewski *et al.* 2004b).

The largest modern annual warming of the surface atmosphere is over the western and northern parts of the Antarctic Peninsula (Turner *et al.* 2005). The large winter component of this warming is associated with an atmospheric circulation induced decrease in winter sea ice. Summer warming is greatest on the eastern side of the Peninsula where strengthening of the westerlies results in maritime air masses reaching this region (Marshall *et al.*, 2006). Much of the remainder of coastal and interior Antarctica shows little change in surface temperature except possibly for a recent cooling at South Pole and a slight warming in some sectors of West Antarctica (Schneider *et al.* 2006; Monaghan *et al.* 2006; Steig *et al.* 2009). Over the last 30 years there has been winter warming (0.5 – 0.7° C $dec^{-1}$) in the mid-troposphere and cooling of the stratosphere (Turner *et al.* 2006).

Overall the Antarctic ice sheet has a mass balance that is up to now insignificantly different from zero to slightly negative (Rignot *et al.* 2008). However, several thousand-year-old ice shelves on the Antarctic Peninsula are undergoing rapid collapse and widespread glacier recession, in places accelerating over the last two decades, exists over the Antarctic Peninsula, the sub-Antarctic islands, New Zealand, and southern South American glaciers (Vaughan *et al.* 2003; Domack *et al.* 2005). New evidence suggests notable thinning along coastal sectors of the Amundsen Sea embayment (Pritchard *et al.* 2009). The $20^{th}$ century recession of mountain glaciers in the Southern Ocean region is outside the range of variability of the last few millennia. Alternately some glaciers in southern South America and New Zealand that are impacted by the intensification of the westerlies have increased snow accumulation and are advancing (Rivera *et al.* 2007; Casassa *et al.* 2007).

The range of variability of modern atmospheric circulation patterns such as the westerlies and the Amundsen Sea Low, assessed using ice core proxies, is still within the range of variability of the last few thousands of years (Mayewski and Maasch, 2006). Instrumental records reveal that over the last 50 years the Southern Hemisphere Annular Mode (SAM), the principle mode of variability of atmospheric circulation of the extra-tropics and high latitudes, has shifted to its positive phase resulting in intensification of the westerlies over the Southern Ocean and consequent changes in temperature and precipitation (Thompson and Solomon, 2002). The El Niño–Southern Oscillation (ENSO) has a profound effect on the high latitudes of the Southern Hemisphere, notably in the South Pacific where it impacts, for example West Antarctic precipitation minus evaporation (Bromwich *et al.* 2000). It also impacts upper-level divergence, exerted in a great circle trajectory, in for example the form of the Pacific South American (PSA) pattern of positive and negative geopotential height anomalies (Revell *et al.* 2002). Recent inland penetration during summer of marine tropospheric air masses into the Amundsen Sea portion of West Antarctica is inferred from ice core reconstructions of past atmospheric circulation (Dixon *et al.* 2005).

Increases in $CO_2$, $CH_4$, $N_2O$, radionuclides, and trace metals such as Pb in addition to decreases in stratospheric ozone over Antarctica are attributed to anthropogenic activity. The recent positive phase of the SAM is associated with stratospheric ozone depletion and tropospheric greenhouse gas increases (Thompson and Solomon 2002). Recent work demonstrates that reduction in ozone killing CFCs has been highly successful but that human source increases in nitrous oxide still pose problems for ozone recovery (Ravishankara *et al.* 2009).

Large-scale warming within the Antarctic Circumpolar Current (ACC) of around 0.2°C (exceeding that of the global ocean) associated with greenhouse gas warming is apparent over the last few decades Gille 2002, 2003). Some of this warming could be related to a redistribution of heat related to southward shift of the ACC. Upper water column warming trends are noted near 40°S while closer to the Antarctic cooling below 1000m and above 600m is linked to the formation sites of bottom and shelf waters (Levitus *et al.* 2005). Large decreases in salinity are found south of 70°S in the Pacific Sector of the Southern Ocean and in the Weddell Sea and freshening of the Ross Sea and other coastal fringes related to melting of freshwater source glacial ice (Jacobs *et al.* 2002). Strong surface-intensified warming and coincident increase in salinity are associated with a reduction in sea ice to the west of the Antarctic Peninsula (Meredith and King 2005).

Variability and change in ocean circulation is still poorly understood despite its apparent significance as a driver of past climate. Impact of changes in the SAM are expected to contribute to latitudinal shifts and changes in transport of the ACC, changes in circumpolar eddy activity, rates of upwelling of Circumpolar Deep Water, rate of formation and export of Subantarctic Mode Water and Antarctic Intermediate Water at the northern edge of the ACC, variability in the strength of the Southern Hemisphere subtropical and subpolar gyres although details are as yet unclear, and changes in the heat holding and carbon sink/source capacity of the Southern Ocean (*e.g.* Hall and Visbeck 2002; Toggweiller *et al.* 2006)

At present there is no compelling evidence that the sea ice edge around Antarctica has deviated much over the past 200 years based on a comparison of ship's logs and satellite data (Parkinson, 1990; Zwally *et al.*, 2002). There is a trend in the reduction of the length of the sea ice season by several days for the Antarctic Peninsula (Parkinson (2004). Reduction in sea ice extent associated with temperature increases induced by change in the SAM is found in the Weddell Sea/Antarctic Peninsula (Thompson and Solomon, 2002), balanced by an increase in the Ross Sea, and retreat of sea ice 80 – 140ºE in East Antarctica (Gloersen *et al.*, 1992).

Success at qualitatively reproducing the observed warming over the Antarctic Peninsula is a positive step in the model capability needed to understand future climate over Antarctica and the Southern Ocean, although uncertainties associated with climate controls and model error still require research. With an approximate doubling of $CO_2$ in the atmosphere over the next century annual mean surface temperatures in the Antarctic sea ice zone would increase by 0.2 to 0.3°C per decade (according to the Special Report on Emissions Scenarios (SRES) A1B scenario, for which predictions for 2100 are about in the middle of the range of the various scenarios in terms of effect on temperature). The projected pattern of temperature change shows strong warming over the high interior of more than 0.3°C per decade. This simulated strong warming over the continent may yield weakening of katabatic winds, especially in the summer season, an increase of 25-50% in snowfall over much of Antarctica with a resultant negative contribution to sea level, a reduction in sea ice extent and sea ice concentration, an increase in the amplitude of the seasonal cycle of sea ice extent, and an increase in westerly winds over the Southern Ocean (that may be moderated due to less rapid change of stratospheric ozone) isolating the continental interior from maritime air masses.

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