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The Arctic and Antarctic: Two Faces of Climate Change

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Although both the Arctic and Antarctic are subject to a similar annual cycle of solar radiation and the same increasing greenhouse gas concentrations, over the previous two decades the two regions have experienced dramatically different changes in sea ice extent, temperature, and other climatic indicators. While these differing responses suggest a paradox, they are largely consistent with known climate dynamics. This conclusion was drawn by scientists participating in the Second Workshop on Recent High Latitude Climate Change, in Seattle, Wash., in October 2007, against the dramatic backdrop of major Arctic sea ice reductions 1 month earlier [*World Climate Research Programme*, 2007].

In 2007, the summer minimum sea ice extent in the Arctic was 40% below the minimum sea ice extents of the 1980s and more than 20% below the previous record minimum of 2005 (Figure 1, left). Autumn temperature anomalies were greater than +6°C relative to the 1958–1998 mean. In contrast, within the past two decades sea ice extent and temperatures in the Antarctic have not been unusual in any season, except along the Antarctic Peninsula, which experienced the largest positive temperature anomalies of anywhere in the Southern Hemisphere, e.g., a 2°C increase since 1980 at the Faraday (Vernadsky) Antarctic research station.

Workshop participants concluded that the dramatic Arctic sea ice reduction in 2007 was caused by a combination of increased temperatures in response to greenhouse gas increases, fortuitous timing in the natural variability of the atmospheric general circulation, and positive feedbacks associated with a reduction in sea ice. In the Antarctic, a strengthening of the atmospheric circulation around the continent has occurred in recent decades due to seasonal stratospheric ozone depletion and greenhouse gas increases. As levels of stratospheric ozone recover, increased temperatures are expected on the central plateau and coastal areas of Antarctica.

Anthropogenic Influences

While formal attribution of ongoing changes in the Arctic is difficult because natural variability is large, evidence of an anthropogenic influence is emerging. Model simulations provided to the Intergovernmental Panel on Climate Change (IPCC) show that the inclusion of increasing greenhouse gases is essential to realistically representing observed Arctic temperature increases during recent decades. This anthropogenic influence contrasts with the causes of the warm period during the 1930s, which *Wang et al.* [2007] argue was due to internal climate variability.

Other evidence of climate change in the Arctic is a consilience of indicators including increased temperatures, diminished sea ice, degraded permafrost, enlarged melt area on Greenland, increased water vapor, decreased snow extent, increased river discharge, and resulting ecosystem impacts.

In the Antarctic, the attribution story is different. A poleward contraction and increase in circumpolar westerly winds, corresponding to a positive trend in the climate pattern known as the Southern Annular Mode (SAM), is consistent with the simulated response to external forcing from stratospheric ozone depletion and greenhouse gas increases.

Marshall et al. [2004] demonstrated that the upward trend in the summer SAM index during recent decades is inconsistent with simulated internal variability in the Hadley Centre general circulation model, suggesting an external cause. Figure 1 (right) shows the estimated regional contrasts in Antarctic near-surface temperatures for 1957–2004 due to the upward trend in the SAM index. The positive phase of the SAM is associated with strong westerly winds over the Southern Ocean, weakened descent and colder temperatures over most of Antarctica, and increased coastal sea ice production. Along the Antarctic Peninsula and through the Drake Passage, however, a positive SAM promotes warming, due primarily to enhanced temperature advection from the

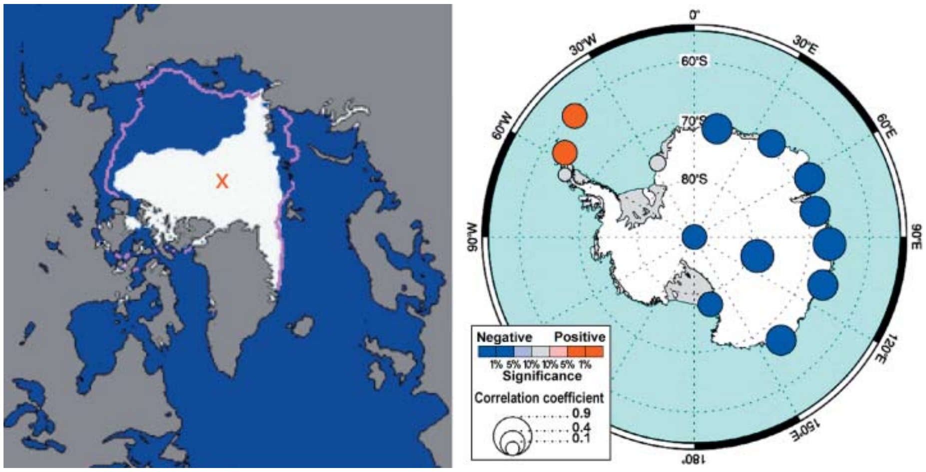

Fig. 1. (left) September 2007 Arctic sea ice extent. The pink line shows the median ice extent for September from 1979 to 2000. From National Snow and Ice Data Center. (right) Estimated change in Antarctic near-surface temperatures in autumn for 1957–2004 due to the upward trend in the Southern Annular Mode (SAM) index; red dots indicate increased temperatures with increases in SAM, blue dots indicate decreasing temperatures with increases in SAM. Similar patterns are seen in other seasons. The SAM contribution exceeds 1.0°C at seven of 14 stations. Note the different response of the Antarctic Peninsula relative to the continental stations.

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stronger westerly winds. Ozone depletion has cooled the upper atmosphere and strengthened the Antarctic polar vortex during austral spring, and models show a maximum surface response during summer [*Keeley et al.*, 2007].

Arctic Summer of 2007

The loss of sea ice on the Pacific side of the Arctic in 2007 resulted from an unusually persistent high-surface-pressure/southerly wind pattern from June through August that transported heat and altered cloud distributions. The winds also advected sea ice across the central Arctic toward the Atlantic sector [*Gascard et al.*, 2008]. A similar pressure pattern also occurred in 1987 and 1977 with no remarkable effect on sea ice extent. The 2007 event, however, followed the steady preconditioning of the ice pack by two decades of thinning and area reduction [*Nghiem et al.*, 2007].

The Arctic is influenced by two main patterns of climate variability: the Northern Annual Mode (NAM) (also known as the Arctic Oscillation) and a Pacific pattern associated with the Aleutian low pressure center. The NAM was particularly strong and positive from 1989 to 1995, which advected a considerable amount of multiyear ice out of the Arctic into the Atlantic. Since then, a more meridional circulation pattern (southerly wind anomalies from the Pacific sector) has been present. These NAM and meridional flows persisted for multiple years, contributing to large-scale changes in Arctic Ocean and sea ice conditions [*Shimada et al.*, 2006; *Steele et al.*, 2008].

Many scientists who track Arctic change recognized that an abrupt decline in sea ice was possible, but nearly all were surprised that a dramatic sea ice decline could occur within this decade. Although it is difficult to attribute a single event to anthropogenic climate change, there are several lines of evidence that support this conclusion. The 2007 ice loss greatly exceeded that in any other year in the observational record. Control runs of global climate models (with no anthropogenic forcing) do not exhibit similar sea ice loss, but large year-on-year decreases are simulated in some ensemble members with anthropogenic forcing.

While we would not claim that the chain of events in the National Center for Atmospheric Research (NCAR) model shown in Figure 2 is identical to those leading up to the 2007 sea ice minimum, several features are similar. The large drop in the model projection of sea ice extent near 2013 in one ensemble member (black curve), along with the range of ensemble members (other colors), implicates long-term anthropogenic forcing combined with large intrinsic atmospheric variability and sea-ice-related feedbacks. The modeled minimum sea ice cover rebounds in subsequent years from its low value of 4 million square kilometers—comparable to the observed 2007 minimum extent—but it never recovers to 1980–1990 values. It appears that the real world is on a faster trajectory of sea ice loss than the expected value projected by IPCC models. Thus, it is important to understand that while many of the IPCC projections were based on averages of model runs, reality is but a single realization. This fast track is consistent with an ice-free summer Arctic before 2030, as suggested by *Stroeve et al.* [2008].

Future of the Poles

The future, no doubt, holds more surprises in polar climate research. The states of the Arctic and Antarctic climates are the result of complex interactions between external forcing, large-scale nonlinear climate dynamics, and regional feedbacks. However, given the recent dramatic loss of multiyear sea ice in the north and the projections of continued global warming, it seems nearly impossible for summer Arctic sea ice to return to the climatological extent that existed prior to 1980.

In the south, future recovery of stratospheric ozone concentrations will weaken or perhaps reverse the positive trend in the SAM index and provide less of a mask to direct greenhouse gas impacts on temperatures and sea ice loss. Scientists at the Seattle workshop speculated that without ozone reductions, Antarctic warming would likely have been more extensive. Thus, the recent and potential future changes at both poles, while different, are consistent with known impacts from shifts in atmospheric circulation and from thermodynamic processes that are, in turn, a consequence of anthropogenic influences on the climate system.

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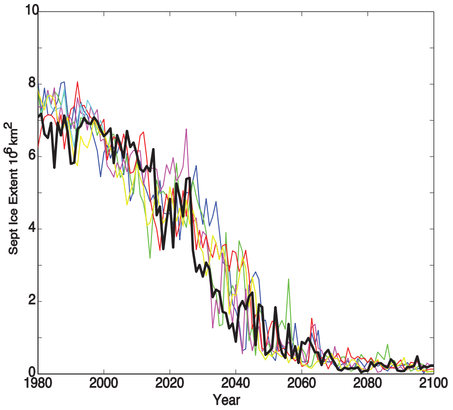

Fig. 2. Projections of Arctic sea ice extent from multiple National Center for Atmospheric Research model ensemble members. Redrawn from Holland et al. *[2006].*

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