



Current Understanding of Antarctic Climate Change

At a time of dramatic warming and rapid sea ice decline in the Arctic, Antarctica has cooled slightly and sea ice has increased around it. Recent scientific progress in understanding how two distinct processes affect Antarctic climate reconciles these seemingly contradictory trends at the Earth's poles. In a nutshell, the difference arises from (1) a weak response to increasing greenhouse gases and (2) a cooling effect of the stratospheric ozone hole—both unique to the southern hemisphere.

That is not to say that the southern hemisphere is exempt from global warming. As in the north, the southern hemisphere as a whole has warmed over the past half century, but at a slower rate than in the north (Trenberth et al. 2007). The southern hemisphere has much less land surface and more ocean surface than the northern hemisphere; ocean surfaces warm more slowly than land because more energy is required to heat water, and because ocean mixing transports much of the heat downward away from the surface (Parkinson 2004; Levitus et al. 2005). In fact, the signal of human-induced ocean warming has been detected to a depth of at least 700 meters (Barnett et al. 2005). As in the north, southern-hemisphere warming has been greater at mid-latitudes than at the equator, but the high latitudes around Antarctica have cooled over the past four decades (Chapman and Walsh 2007; Parkinson 2006). Because Antarctica occupies only five percent of the surface area of the southern hemisphere, there is no contradiction in this relatively small region cooling as the hemisphere warms overall. Antarctica is among a minority of regions with unique local climate conditions that currently override the global warming trend, although this situation is likely to change in the future if greenhouse gas concentrations continue to rise (Shindell and Schmidt 2004).

In spite of a moderate overall cooling trend, recent Antarctic climate change results from a mix of countervailing signals. A rapid net loss of sea ice occurred during the 1970s, followed by a slow gain. The geographic distribution of sea ice has changed, with the east gaining and the west losing sea ice. The gains and losses are each larger than the overall trend, indicating a high degree of variability and change in the Antarctic sea ice (Parkinson 2006). Scientists were surprised to discover recently that the land-based Antarctic ice sheet, which stores 60 percent of the earth's fresh water—the equivalent of 70 meters (228 feet) of sea level rise—has been losing slightly more ice each year than it is gaining (Shepherd and Wingham 2007). Most of the ice loss is from the West Antarctic Ice Sheet, the margins of which lie in the ocean (Velicogna and Wahr 2006). Warming of the ocean appears to be eroding this ice sheet at its edges (Shepherd et al. 2004; Rignot and Kanagaratnam 2006). Reaching northward from West Antarctica into the mid-latitudes, the Antarctic Peninsula has experienced the most dramatic warming in the region (Chapman and Walsh 2007; Turner et al. 2005). In a preview of the possible consequences of ice sheet erosion by the warming Southern Ocean, the Larsen B ice shelf, which was attached to the peninsula, disintegrated suddenly in February 2002; as a result, the land-based ice behind the shelf began to flow more quickly into the sea (Scambos et al. 2004). Scientists infer that widespread warming in West Antarctica could lead to many such events in the future, potentially leading to dramatic acceleration of global sea level rise (Alley et al. 2005). Clearly, the Antarctic climate is not changing monotonically in a single direction.

Still, while every other continent on Earth has experienced a clear warming trend over the past five decades (Trenberth et al. 2007), Antarctica—the fifth largest continent—has shown no clear trend

(Chapman and Walsh 2007). There are several key differences between the Arctic and the Antarctic that act in concert to explain the climatic departure between the two regions. Two of the most important factors are the predictably weak warming signal in the Antarctic compared to the Arctic, and the cooling effect of the human-induced stratospheric ozone hole above Antarctica.

As predicted by climate models, the southern hemisphere has warmed less than the northern hemisphere. The warming has occurred predominantly during the winter, and even Antarctica has warmed slightly during the winter, despite its average cooling across all seasons (Chapman and Walsh 2007). Winter is the time of year that climate models show the largest response to increasing greenhouse gas concentrations. So, even though the warming signal is weak, the seasonal pattern is consistent with the human-enhanced greenhouse effect. Since Antarctic winters are much colder than necessary to freeze seawater, a little wintertime warming is insufficient to induce large-scale losses of sea ice without concurrent warming during the summer. In an experiment using a climate model to simulate global sea ice change over a century as a result of increasing atmospheric greenhouse gases, antarctic sea ice decreased by only 10%, while arctic sea ice decreased by 60% (Parkinson 2004). It is not surprising, therefore, that Antarctic sea ice has not mirrored the rapid decline of arctic sea ice.

But Antarctica is cooling and antarctic sea ice is expanding—something more than regionally weak global warming is afoot. That other factor is the ozone hole in the upper atmosphere (stratosphere) above Antarctica. Over the past four decades, the southern Westerlies—a ring of wind that encircles the southern hemisphere between 30° and 60° latitude—have become more intense and have moved closer to the South Pole in an ever-tighter ring around Antarctica. Whenever the Westerlies intensify—regardless of the cause—Antarctica tends to cool because surface air pressure inside the ring decreases (Marshall 2006). This is called adiabatic cooling and is the same reason that the temperature drops as one climbs a mountain. Although scientists are just beginning to study the physical mechanisms by which changes in the stratosphere affect ground-level climate (Baldwin et al. 2007), observations and model results both indicate that the greater amount of stratospheric ozone depletion over the South Pole compared to mid-latitudes has caused the southern Westerlies to shift poleward and intensify (Gillett and Thompson 2003; Shindell and Schmidt 2004). Since ozone depletion is strong over Antarctica but weak over the Arctic (Solomon et al. 2007), this strong cooling effect is unique to Antarctica.

To summarize, surface warming from the greenhouse effect is weaker in the southern hemisphere than in the northern hemisphere, whereas cooling from stratospheric ozone depletion is stronger in the south than in the north. Consequently, the Arctic has warmed dramatically, even as the Antarctic has experienced a small cooling trend. Climate models reproduce this pattern when they are driven by both greenhouse gas increases and stratospheric ozone depletion (Gillett and Thompson 2003; Shindell and Schmidt 2004). Hence, the present cooling of Antarctica is consistent with the rest of the Earth's surface warming in response to rising greenhouse gas concentrations.

The stratospheric ozone layer filters out harmful ultraviolet radiation from incoming sunlight. To protect public health and natural ecosystems, an international treaty—the Montreal Protocol—is phasing out the release of ozone-depleting chemicals to the atmosphere. According to climate models that correctly simulate the current cooling trend in Antarctica, if greenhouse gases continue to rise as the ozone layer recovers in future decades, the warming effect of greenhouse gases will begin to outweigh the cooling effect of ozone depletion (Shindell and Schmidt 2004). The result would be widespread warming in Antarctica, with attendant declines in sea ice and accelerated loss

of land-based ice, with the latter contributing to accelerated sea level rise.

References

- Alley, R.B., P.U. Clark, P. Huybrechts, and I. Joughin. 2005. Ice-sheet and sea-level changes. *Science* 310:456-460.
- Baldwin, Mark P., Martin Dameris, and Theodore G. Shepherd. 2007. How Will the Stratosphere Affect Climate Change? *Science* 316 (5831):1576-1577.
- Barnett, T. P., D. W. Pierce, K. M. AchutaRao, P. J. Gleckler, B. D. Santer, J. M. Gregory, and W. M. Washington. 2005. Penetration of human-induced warming into the world's oceans. *Science* 309:284-287.
- Chapman, W.L., and J.E. Walsh. 2007. A synthesis of Antarctic Temperatures. *Journal of Climate* 20:4096-4117.
- Gillett, N., and D.W.J. Thompson. 2003. Simulation of Recent Southern Hemisphere Climate Change. *Science* 302:273-275.
- Levitus, S., J. Antonov, and T. Boyer. 2005. Warming of the world ocean, 1955-2003. *Geophysical Research Letters* 32:L02604, doi:10.1029/2004GL021592.
- Marshall, G.J. 2006. Half-century seasonal relationships between the Southern Annular Mode and Antarctic temperatures. *International Journal of Climatology* 27:doi:10.1002/joc.1407.
- Parkinson, C.L. 2004. Southern Ocean sea ice and its wider linkages: insights revealed from models and observations. *Antarctic Science* 16:387-400.
- . 2006. Earth's cryosphere: Current state and recent changes. *Review of Environment And Resources* 31:33-60.
- Rignot, E., and P. Kanagaratnam. 2006. Changes in the velocity structure of the Greenland ice sheet. *Science* 311:986-990.
- Scambos, T.A., J.A. Bohlander, C.A. Shuman, and P. Skvarca. 2004. Glacier acceleration and thinning after ice shelf collapse in the Larsen B embayment, Antarctica. *Geophysical Research Letters* 31:L18402, doi:10.1029/2004GL020670.
- Shepherd, A., and D. Wingham. 2007. Recent sea level contributions of the Antarctic and Greenland ice sheets. *Science* 315:1529-1532.
- Shepherd, A., D. Wingham, and E. Rignot. 2004. Warm ocean is eroding West Antarctic Ice Sheet. *Geophysical Research Letters* 31:L23402, doi:10.1029/2004GL021106.
- Shindell, D.T., and G.A. Schmidt. 2004. Southern Hemisphere climate response to ozone changes and greenhouse gas increases. *Geophysical Research Letters* 31:L18209, doi:10.1029/2004GL020724.
- Solomon, S., R.W. Portmann, and D.W.J. Thompson. 2007. Contrasts between Antarctic and Arctic ozone depletion. *Proceedings of the National Academy of Sciences USA* 104:445-449.
- Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A.K. Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden, and P. Zhai. 2007. Observations: surface and atmospheric climate change. In *Climate Change 2007: The Physical Science Basis*, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller. Cambridge, United Kingdom and New York, N.Y., USA: Cambridge University Press.
- Turner, J., S.R. Colwell, G.J. Marshall, T.A. Lachlan-Cope, A.M. Carleton, P.D. Jones, V. Lagun, P.A. Reid, and S. Iagovkina. 2005. Antarctic climate change during the last 50 years. *International Journal of Climatology* 25:279-294.
- Velicogna, I., and J. Wahr. 2006. Measurements of time-variable gravity show mass loss in Antarctica. *Science* 311:1754-1756.