The Antarctic Ice Sheet and Climate Change
A Brief Bibliography of Research Papers

The meteorological viewpoint

Turner, J., et al. 2005. Antarctic climate change during the last 50 years. *International Journal of Climatology*, 25(3), 279 - 294. (Authors' abstract, modified.)

Near-surface temperatures have been recorded over the last 50 years at 19 Antarctic stations. Eleven of these had warming trends and seven had cooling trends in their annual data (one station had too few data to allow an annual trend to be computed), indicating the spatial complexity of change that has occurred across the Antarctic in recent decades. The Antarctic Peninsula has experienced a major warming over the last 50 years, with temperatures having increased at a rate of half a degree C per decade. At most of the coastal stations around the continent the warming trend decreased (or the cooling trend increased) between the 1960's and the 1990's.

Doran, P.T., et al. 2002. Antarctic climate cooling and terrestrial ecosystem response. *Nature*, 415(6871), 517 - 520. (Authors' abstract, modified.)

The average air temperature at the Earth's surface has increased by 0.06 °C per decade during the 20th century, and by 0.19 °C per decade from 1979 to 1998. Climate models generally predict amplified warming in polar regions, as observed in the Antarctica Peninsula region over the second half of the 20th century. However, on average, the Antarctic continent cooled between 1966 and 2000, particularly during summer and autumn. The unglaciated McMurdo Dry Valleys have cooled by 0.7 °C per decade between 1986 and 2000, with similar pronounced seasonal trends. Summer cooling has marked affects on Antarctic terrestrial ecosystems, including decreased primary productivity of lakes (6–9% per year) and declining numbers of soil invertebrates (more than 10% per year). Continental Antarctic cooling, especially the seasonality of cooling, poses challenges to models of climate and ecosystem change.

Gillett, N.P., and D.W.J. Thompson. 2003. Simulation of Recent Southern Hemisphere Climate Change. *Science*, 302(5643), 273-275. (Authors' abstract, modified.)

Recent observations indicate that climate change over the high latitudes of the Southern Hemisphere is dominated by a strengthening of the circumpolar westerly flow that extends from the surface to the stratosphere. The characteristics of the observed climate trends can be simulated by a model that is forced solely by stratospheric ozone depletion. The results provide evidence that anthropogenic emissions of ozone depleting gases have had a distinct impact on climate not only at stratospheric levels but at Earth's surface as well.

Huybrechts, P., et al. 2004. Modelling Antarctic and Greenland volume changes during the 20th and 21st centuries forced by GCM time slice integrations. *Global and Planetary Change*, 42(1-4), 83-105. (Authors' abstract, modified.)

Current and future volume changes of the Greenland and Antarctic ice sheets depend on modern mass balance changes and on the ice-dynamic response to environmental forcings back to the last ice age. Model predictions of response to a range of possible climatic changes for the 20th and 21st centuries generally show increased precipitation on Antarctica and increased melting on Greenland; the two ice sheets combined would gain mass in the 21st century. Combining these results with the long-term background trend yields a 20th and 21st century sea-level trend from polar ice sheets that is not significantly different from zero.

Wild, M., et al. 2003. Effects of polar ice sheets on global sea level in high-resolution greenhouse scenarios. *Journal of Geophysical Research*, 108(D5), 4165, doi:10.1029/2002JD002451. (Authors' abstract, modified.)

Projections of future global sea level critically depend on reliable estimates of mass balance changes on the polar ice sheets. A model of greenhouse warming with doubled carbon-dioxide concentration suggests an increase in snow accumulation on both Greenland and Antarctic ice sheets. There is an increase in summertime melting on Greenland, but it amounts to less than the snowfall increase. Antarctica is still too cold for significant melting. The experiment with doubled carbon-dioxide concentration thus suggests a mass gain in both Antarctica and Greenland. These mass balance shifts correspond to a net sea level lowering of 1.2 millimeters per year at the time of doubled carbon-dioxide. This may compensate for a substantial fraction of the melt-induced sea level rise from smaller glaciers and ice caps, leaving thermal expansion of the ocean as the dominant factor for sea level rise over the coming decades. The compensating effect, however, could fade if carbon-dioxide concentrations in the atmosphere continue to rise above double the present values, since the additional climatic warming could then induce significant melting of the Antarctic ice sheet.

<u>The past record from ice cores</u>

Augustin, L., et al. 2004. Eight glacial cycles from an Antarctic ice core. *Nature*, 429(6992), 623-628. (Authors' abstract, modified.)

A deep ice core from Dome C, Antarctica provides a climate record for the past 740,000 years (8 glacial cycles). The transition from glacial to interglacial conditions about 430,000 years ago resembles the transition into the present interglacial period in the magnitude of change in temperatures and greenhouse gases, but it was exceptionally long -- 28,000 years, compared to 12,000 years recorded so far in the present interglacial period. Given the similarities between that earlier warm period and today, our results may imply that without human intervention, a climate similar to the present one would extend well into the future.

Taylor, K.C., et al. 2004. Abrupt climate change around 22 ka on the Siple Coast of Antarctica. *Quaternary Science Reviews*, 23(1-2), 7-15. (Authors' abstract, modified.)

A new ice core from Siple Dome, Antarctica suggests the surface temperature increased by about 6 degrees C in just several decades approximately 22,000 years ago. This abrupt change did not occur in another ice core collected only 500 km away (at Byrd Station). This demonstrates there was significant spatial heterogeneity in the response of the Antarctic climate during the last deglaciation and draws attention to unexplained mechanisms of abrupt climate change in Antarctica.

<u>The collapse of the Larsen Ice Shelf (east side of Antarctic Peninsula)</u>

News Release from the Union of Concerned Scientists' Sound Science Initiative:

The collapse of more than 3000 square kilometers of the Larsen-B ice shelf occurred over a 35-day period between January 31st and March 7th, 2002. Following the first dramatic collapse of the Larsen A Ice Shelf in 1995, scientists at the British Antarctic Survey have been monitoring the remaining ice shelf and had predicted its disintegration. The speed with which this last part of the ice sheet disintegrated, however, has astounded scientists. The breakup is directly attributed to regional warming in this part of Antarctica. Over the last 50 years, average temperatures in the Antarctica Peninsula have risen by 2.5 degrees Celsius, five times the global average. This unprecedented warming has led to a pattern of retreat of ice shelves on the eastern side of the Peninsula.

Rignot, et al. 2004. Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf. *Geophysical Research Letters*, 31(18), L18401, doi:10.1029/2004GL020697. (Authors' abstract, modified.)

Antarctic Peninsula glaciers that fed the former Larsen B ice shelf sped up by factors of two to eight following the collapse of the ice shelf in 2002. In contrast, glaciers further south did not accelerate as they are still buttressed by an ice shelf. The mass loss associated with the flow acceleration exceeds 27 cubic kilometers per year and ice is thinning at rates of tens of meters per year. We attribute this abrupt evolution of the glaciers to the removal of the buttressing ice shelf. The magnitude of the glacier changes illustrates the importance of ice shelves on ice sheet mass balance and contribution to sea level change.

Scambos, T.A., et al. 2004. Glacier acceleration and thinning after ice shelf collapse in the Larsen B embayment, Antarctica. *Geophysical Research Letters*, 31(18), L18402, doi:10.1029/2004GL02067. (Authors' abstract, modified.)

Ice velocities acquired between January 2000 and February 2003 show a two- to six-fold increase in centerline speed of four glaciers flowing into the now-collapsed section of the Larsen B Ice Shelf. The surface of one glacier lowered by up to 38 meters in a six-month period beginning one year after the break-up in March 2002. Smaller elevation losses were observed for two other glaciers over a later 5-month period. Two glaciers south of the collapse area show little change in speed or elevation. Data suggest that both summer melt percolation and changes in the stress field due to shelf removal play a major role in glacier dynamics.

Domack, E., et al. Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch. *Nature,* Vol. 436, 681-685, 4 August 2005 doi:10.1038/nature03908. (Authors' abstract, modified.)

The stability of the Antarctic ice shelves in a warming climate has long been discussed, and the recent collapse of a significant part of the Larsen ice shelf off the Antarctic Peninsula has led to a refocus on the implications of ice shelf decay for the stability of Antarctica's grounded ice. Records from six marine sediment cores in the vicinity of the Larsen ice shelf demonstrate that the recent collapse of the Larsen B ice shelf is unprecedented during the Holocene [i.e. since the end of the last ice age]. We infer from our measurements that the Larsen B ice shelf has been thinning throughout the Holocene, and we suggest that the recent prolonged period of warming in the Antarctic Peninsula region, in combination with the long-term thinning, has led to collapse of the ice shelf.

The West Antarctic Ice sheet (WAIS): the Amundsen Sea (Pine Island Bay) sector

Thomas, R., et al. 2004. Accelerated Sea-Level Rise from West Antarctica. *Science*, 306(5694), 255-258. (Authors' abstract, modified.)

Recent aircraft and satellite laser altimeter surveys of the Amundsen Sea sector of West Antarctica show that local glaciers are discharging almost 60% more ice per year to the ocean, than is added by snowfall within their catchment basins. This excess discharge is sufficient to raise sea level by more than 0.2 millimeters per year. Glacier thinning rates near the coast during 2002-2003 are much larger than those observed during the 1990s. Most of these glaciers flow into floating ice shelves over bedrock up to hundreds of meters deeper than previous estimates, providing exit routes for ice from further inland if ice-sheet collapse is under way.

Shepherd, A., et al. 2004. Warm ocean is eroding West Antarctic Ice Sheet. *Geophysical Research Letters*, 31(23), L23402, doi:10.1029/2004GL021106. (Authors' abstract, modified.)

Satellite radar measurements show that ice shelves in Pine Island Bay have thinned by up to 5.5 meters per year over the past decade. The thinning of the ice shelves, apparently from ocean currents on average 0.5°C warmer than freezing, is mirrored by the thinning of their tributaries -- Pine Island, Thwaites and Smith glaciers. The imbalance of the glaciers in response to the thinning of the ice shelves shows that Antarctica is more sensitive to changing climates than was previously considered.

Payne, A.J., A. Vieli, A.P. Shepherd, D.J. Wingham, and E. Rignot, et al. 2004. Recent dramatic thinning of largest West Antarctic ice stream triggered by oceans. *Geophysical Research Letters*, 31(23), L23401, doi:10.1029/2004GL021284. (Authors' abstract, modified.)

A growing body of observational data suggests that Pine Island Glacier in West Antarctica is changing on decadal or shorter time scales. These changes may have far-reaching consequences for the future of the West Antarctic ice sheet (WAIS) and global sea levels because of the glacier's role as one of the ice sheet's primary drainage portals. The speed at which these changes are propagated upstream implies a tight coupling between the ice-sheet interior and the surrounding ocean.

Dupont, T.K., and R.B. Alley. 2005. Assessment of the importance of ice-shelf buttressing to ice-sheet flow. *Geophysical Research Letters*, 32(4), L04503, doi:10.1029/2004GL022024. (Authors' abstract, modified.)

Reduction or loss of a restraining ice shelf will cause speed-up of flow from contiguous ice streams, contributing to sea-level rise. Loss of buttressing for an ice stream similar to Pine Island Glacier, West Antarctica is modeled to contribute at least 1 mm of sea-level rise over a few decades.

The WAIS as a whole

Oppenheimer, M., and R.B. Alley. 2004. The West Antarctic Ice Sheet and Long Term Climate Policy. *Climatic Change*, 64(1-2), 1-10. (Authors' abstract, modified.)

"Disintegration of the West Antarctic ice sheet (WAIS) has long served as a benchmark of dangerous climate change. Recent findings with implications for the future of the WAIS may be of importance to policy makers and others grappling with the meaning of Article 2 of the U.N Framework Convention on Climate Change and its injunction to avoid 'dangerous anthropogenic interference with the climate system.' These observations show acceleration of glaciers coupled to abrupt ice-shelf disintegration along the Antarctic Peninsula. The key issue is whether the main body of the ice sheet would behave similarly if its ice shelves were thinned or removed by a warming climate."

Bindschadler, R.A., and C.R. Bentley. 2002. On thin ice? *Scientific American*, December), 66-73. (Authors' text, modified.)

How soon humanity will have to move inland to escape rising sea level depends in great part on how quickly West Antarctica's massive ice sheet shrinks. For nearly three decades many Antarctic experts have warned that West Antarctica's ice sheet is in the midst of a rapid disintegration that could raise global sea level five meters in a few centuries or less. Many of those researchers now think that the ice sheet is shrinking much more slowly than they originally suspected and that sea level is more likely to rise half a meter or less in the next century. That emerging consensus is not without its caveats. The poorly understood Amundsen Sea sector of the ice sheet, containing Pine Island and Thwaites Glaciers, now appears to be shrinking much faster than previously thought. Global warming, which has so far played a negligible role in West Antarctica's fate, is bound to wield greater influence in the future.

<u>The Antarctic ice sheet as a whole</u>

Rignot, E., and R.H. Thomas. 2002. Mass balance of polar ice sheets. *Science*, 297(5586), 1502-1506. (Authors' abstract, modified.)

Recent advances in the determination of the mass balance of polar ice sheets show that the West Antarctic Ice Sheet, with thickening in the west and thinning in the north, is probably thinning overall. The mass imbalance of the East Antarctic Ice Sheet is likely to be small, but even its sign cannot yet be determined. Large sectors of ice in the Amundsen Sea Embayment of West Antarctica and the Antarctic Peninsula are changing quite rapidly as a result of processes not yet understood.