Parkinson, C.L. and Cavalieri, D.J. 2002. A 21-year record of Arctic sea-ice extents and their regional, seasonal and monthly variability and trends. *Annals of Glaciology* **34**: 441-446.

Parkinson, C., Cavalieri, D., Gloersen, D., Zwally, J. and Comiso, J. 1999. Arctic sea ice extents, areas, and trends, 1978-1996. *Journal of Geophysical Research* **104**: 20,837-20,856.

Peterson, B.J., Holmes, R.M., McClelland, J.W., Vorosmarty, C.J., Lammers, R.B., Shiklomanov, A.I., Shiklomanov, I.A. and Rahmstorf, S. 2002. Increasing river discharge in the Arctic Ocean. *Science* **298**: 2171-2173.

Polyakov, I., Akasofu, S.-I., Bhatt, U., Colony, R., Ikeda, M., Makshtas, A., Swingley, C., Walsh, D. and Walsh, J. 2002a. Trends and variations in Arctic climate system. *EOS: Transactions, American Geophysical Union* **83**: 547-548.

Polyakov, I.V., Alekseev, G.V., Bekryaev, R.V., Bhatt, U., Colony, R.L., Johnson, M.A., Karklin, V.P., Makshtas, A.P., Walsh, D. and Yulin A.V. 2002b. Observationally based assessment of polar amplification of global warming. *Geophysical Research Letters* **29**: 10.1029/2001GL011111.

Polyakov, I.V., Alekseev, G.V., Timokhov, L.A., Bhatt, U.S., Colony, R.L., Simmons, H.L., Walsh, D., Walsh, J.E. and Zakharov, V.F. 2004. Variability of the intermediate Atlantic water of the Arctic Ocean over the last 100 years. *Journal of Climate* **17**: 4485-4497.

Polyakov, I.V., Bekryaev, R.V., Alekseev, G.V., Bhatt, U.S., Colony, R.L., Johnson, M.A., Maskshtas, A.P. and Walsh, D. 2003. Variability and trends of air temperature and pressure in the maritime Arctic, 1875-2000. *Journal of Climate* **16**: 2067-2077.

Przybylak, R. 1997. Spatial and temporal changes in extreme air temperatures in the Arctic over the period 1951-1990. *International Journal of Climatology* **17**: 615-634.

Przybylak, R. 2000. Temporal and spatial variation of surface air temperature over the period of instrumental observations in the Arctic. *International Journal of Climatology* **20**: 587-614.

Przybylak, R. 2002. Changes in seasonal and annual high-frequency air temperature variability in the Arctic from 1951-1990. *International Journal of Climatology* **22**: 1017-1032.

Raspopov, O.M., Dergachev, V.A. and Kolstrom, T. 2004. Periodicity of climate conditions and solar variability derived from dendrochronological and other palaeoclimatic data in high latitudes. *Palaeogeography, Palaeoclimatology, Palaeoecology* **209**: 127-139.

Schell, D.M. 1983. Carbon-13 and carbon-14 abundances in Alaskan aquatic organisms: Delayed production from peat in Arctic food webs. *Science* **219**: 1068-1071.

Schirrmeister, L., Siegert, C., Kuznetsova, T., Kuzmina, S., Andreev, A., Kienast, F., Meyer, H. and Bobrov, A. 2002. Paleoenvironmental and paleoclimatic records from permafrost deposits in the Arctic region of northern Siberia. *Quaternary International* **89**: 97-118.

Schweingruber, F.H. and Briffa, K.R. 1996. Tree-ring density network and climate reconstruction. In: Jones, P.D., Bradley, R.S. and Jouzel, J. (Eds.) *Climatic Variations and Forcing Mechanisms of the Last 2000 Years*, NATO ASI Series 141. Springer-Verlag, Berlin, Germany, pp. 43-66.

Soon, W. W.-H. 2005. Variable solar irradiance as a plausible agent for multidecadal variations in the Arctic-wide surface air temperature record of the past 130 years. *Geophysical Research Letters* **32** L16712, doi:10.1029/2005GL023429.

Stern, H.L. and Heide-Jorgensen, M.P. 2003. Trends and variability of sea ice in Baffin Bay and Davis Strait, 1953-2001. *Polar Research* **22**: 11-18.

Treshnikov, A.F. (Ed.) 1985. *Atlas Arktiki*. Glavnoye Upravlenye Geodeziy i Kartografiy, Moskva.

Vaganov, E.A., Briffa, K.R., Naurzbaev, M.M., Schweingruber, F.H., Shiyatov, S.G. and Shishov, V.V. 2000. Long-term climatic changes in the arctic region of the Northern Hemisphere. *Doklady Earth Sciences* **375**: 1314-1317.

Vaganov, E.A., Shiyatov, S.G. and Mazepa, V.S. 1996. *Dendroclimatic Study in Ural-Siberian Subarctic*. Nauka, Novosibirsk, Russia.

Yoo, J.C. and D'Odorico, P. 2002. Trends and fluctuations in the dates of ice break-up of lakes and rivers in Northern Europe: the effect of the North Atlantic Oscillation. Journal of Hydrology **268**: 100-112.

Zeeberg, J. and Forman, S.L. 2001. Changes in glacier extent on north Novaya Zemlya in the twentieth century. Holocene **11**: 161-175.

3.7. Antarctica

The study of Antarctic temperatures has provided valuable insight and spurred contentious debate on issues pertaining to global climate change. Key among the pertinent findings has been the observation of a large-scale correlation between proxy air temperature and atmospheric CO_2 measurements obtained from ice cores drilled in the interior of the continent. In the mid- to late-1980s, this broad

correlation dominated much of the climate change debate. Many jumped on the global warming bandwagon, saying the correlation proved that changes in atmospheric CO_2 concentration caused changes in air temperature, and that future increases in the air's CO_2 content due to anthropogenic CO_2 emissions would therefore intensify global warming.

By the late 1990s and early 2000s, however, ice-coring instrumentation and techniques had improved considerably and newer studies with finer temporal resolution began to reveal that increases (decreases) in air temperature precede increases (decreases) in atmospheric CO_2 content, not vice versa (see Indermuhle *et al*. (2000), Monnin *et al.* (2001)). A recent study by Caillon *et al*. (2003), for example, demonstrated that during Glacial Termination III, "the CO_2 increase lagged Antarctic deglacial warming by 800 ± 200 years." This finding, in the authors' words, "confirms that CO_2 is not the forcing that initially drives the climatic system during a deglaciation."

A second major blow to the CO_2-induced global warming hypothesis comes from the contradiction between observed and model-predicted Antarctic temperature trends of the past several decades. According to nearly all climate models, CO_2-induced global warming should be most evident in earth's polar regions, but analyses of Antarctic near-surface and tropospheric air temperatures contradict this prediction.

Doran *et al*. (2002) examined temperature trends in the McMurdo Dry Valleys of Antarctica over the period 1986 to 2000, reporting a cooling rate of approximately 0.7°C per decade. This dramatic rate of cooling, they state, "reflects longer term continental Antarctic cooling between 1966 and 2000." In addition, the 14-year temperature decline in the dry valleys occurred in the summer and autumn, just as most of the 35-year cooling over the continent as a whole (which did not include any data from the dry valleys) also occurred in the summer and autumn.

Comiso (2000) assembled and analyzed Antarctic temperature data obtained from 21 surface stations and from infrared satellites operating since 1979. He found that for all of Antarctica, temperatures had declined by 0.08°C and 0.42°C per decade, respectively. Thompson and Solomon (2002) also report a cooling trend for the interior of Antarctica.

In spite of the decades-long cooling that has been observed for the continent as a whole, one region of Antarctica has actually bucked the mean trend and *warmed* over the same time period: the Antarctic Peninsula/Bellingshausen Sea region. But is the temperature increase that has occurred there evidence of CO_2-induced global warming?

According to Vaughan *et al.* (2001), "rapid regional warming" has led to the loss of seven ice shelves in this region during the past 50 years. However, they note that sediment cores from 6,000 to 1,900 years ago suggest the Prince Gustav Channel Ice Shelf—which collapsed in this region in 1995—"was absent and climate was as warm as it has been recently," when, of course there was much less CO_2 in the air.

Although it is tempting to cite the twentieth century increase in atmospheric CO_2 concentration as the cause of the recent regional warming, "to do so without offering a mechanism," say Vaughan *et al*., "is superficial." And so it is, as the recent work of Thompson and Solomon (2002) suggests that much of the warming can be explained by "a systematic bias toward the high-index polarity of the SAM," or Southern Hemispheric Annular Mode, such that the ring of westerly winds encircling Antarctica has recently been spending more time in its strong-wind phase.

That is also the conclusion of Kwok and Comiso (2002), who report that over the 17-year period 1982-1998, the SAM index shifted towards more positive values (0.22/decade), noting that a positive polarity of the SAM index "is associated with cold anomalies over most of Antarctica with the center of action over the East Antarctic plateau." At the same time, the SO index shifted in a negative direction, indicating "a drift toward a spatial pattern with warmer temperatures around the Antarctic Peninsula, and cooler temperatures over much of the continent." Together, the authors say the positive trend in the *coupled* mode of variability of these two indices (0.3/decade) represents a "significant bias toward positive polarity" that they describe as "remarkable."

Kwok and Comiso additionally report that "the tropospheric SH annular mode has been shown to be related to changes in the lower stratosphere (Thompson and Wallace, 2000)," noting that "the high index polarity of the SH annular mode is associated with the trend toward a cooling and strengthening of the SH stratospheric polar vortex during the stratosphere's relatively short active season in November," which is pretty much the same theory that has been put forth by Thompson and Solomon (2002).

In another slant on the issue, Yoon *et al*. (2002) report that "the maritime record on the Antarctic Peninsula shelf suggests close chronological

correlation with Holocene glacial events in the Northern Hemisphere, indicating the possibility of coherent climate variability in the Holocene." In the same vein, Khim *et al*. (2002) say that "two of the most significant climatic events during the late Holocene are the Little Ice Age (LIA) and Medieval Warm Period (MWP), both of which occurred globally (Lamb, 1965; Grove, 1988)," noting further that "evidence of the LIA has been found in several studies of Antarctic marine sediments (Leventer and Dunbar, 1988; Leventer *et al*., 1996; Domack *et al*., 2000)." To this list of scientific journal articles documenting the existence of the LIA in Antarctica can now be added Khim *et al*.'s own paper, which also demonstrates the presence of the MWP in Antarctica, as well as earlier cold and warm periods of similar intensity and duration.

Further evidence that the Antarctic as a whole is in the midst of a cooling trend comes from Watkins and Simmonds (2000), who analyzed region-wide changes in sea ice. Reporting on trends in a number of Southern Ocean sea ice parameters over the period 1987 to 1996, they found statistically significant increases in sea ice area and total sea ice extent, as well as an increase in sea ice season length since the 1990s. Combining these results with those from a previous study revealed these trends to be consistent back to at least 1978. And in another study of Antarctic sea ice extent, Yuan and Martinson (2000) report that the net trend in the mean Antarctic ice edge over the past 18 years has been an equatorward expansion of 0.011 degree of latitude per year.

The temperature history of Antarctica provides no evidence for the CO_2-induced global warming hypothesis. In fact, it argues strongly against it. But what if the Antarctic *were* to warm as a result of some natural or anthropogenic-induced change in earth's climate? What would the consequences be?

For one thing, it would likely help to increase both the number and diversity of penguin species (Sun *et al*., 2000; Smith *et al*., 1999), and it would also tend to increase the size and number of populations of the continent's only two vascular plant species (Xiong *et al*., 2000). With respect to the continent's great ice sheets, there would not be much of a problem either, as not even a warming event as dramatic as 10°C is predicted to result in a net change in the East Antarctic Ice Sheet (Näslund *et al*., 2000), which suggests that predictions of catastrophic coastal flooding due to the melting of the world's polar ice sheets are way off the mark.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/a/antarcticatemp.php.

References

Caillon, N., Severinghaus, J.P., Jouzel, J., Barnola, J.-M., Kang, J. and Lipenkov, V.Y. 2003. Timing of atmospheric CO_2 and Antarctic temperature changes across Termination III. *Science* **299**: 1728-1731.

Comiso, J.C. 2000. Variability and trends in Antarctic surface temperatures from *in situ* and satellite infrared measurements. *Journal of Climate* **13**: 1674-1696.

Domack, E.W., Leventer, A., Dunbar, R., Taylor, F., Brachfeld, S. and Sjunneskog, C. 2000. Chronology of the Palmer Deep site, Antarctic Peninsula: A Holocene palaeoenvironmental reference for the circum-Antarctic. *The Holocene* **11**: 1-9.

Doran, P.T., Priscu, J.C., Lyons, W.B., Walsh, J.E., Fountain, A.G., McKnight, D.M., Moorhead, D.L., Virginia, R.A., Wall, D.H., Clow, G.D., Fritsen, C.H., McKay, C.P. and Parsons, A.N. 2002. Antarctic climate cooling and terrestrial ecosystem response. *Nature* advance online publication, 13 January 2002 (DOI 10.1038/nature710).

Grove, J.M. 1988. *The Little Ice Age*. Cambridge University Press, Cambridge, UK.

Indermuhle, A., Monnin, E., Stauffer, B. and Stocker, T.F. 2000. Atmospheric CO_2 concentration from 60 to 20 kyr BP from the Taylor Dome ice core, Antarctica. *Geophysical Research Letters* **27**: 735-738.

Khim, B-K., Yoon, H.I., Kang, C.Y. and Bahk, J.J. 2002. Unstable climate oscillations during the Late Holocene in the Eastern Bransfield Basin, Antarctic Peninsula. *Quaternary Research* **58**: 234-245.

Kwok, R. and Comiso, J.C. 2002. Spatial patterns of variability in Antarctic surface temperature: Connections to the South Hemisphere Annular Mode and the Southern Oscillation. *Geophysical Research Letters* **29**: 10.1029/2002GL015415.

Lamb, H.H. 1965. The early medieval warm epoch and its sequel. *Palaeogeography, Palaeoclimatology, Palaeoecology* **1**: 13-37.

Leventer, A. and Dunbar, R.B. 1988. Recent diatom record of McMurdo Sound, Antarctica: Implications for the history of sea-ice extent. *Paleoceanography* **3**: 373-386.

Leventer, A., Domack, E.W., Ishman, S.E., Brachfeld, S., McClennen, C.E. and Manley, P. 1996. Productivity cycles

of 200-300 years in the Antarctic Peninsula region: Understanding linkage among the sun, atmosphere, oceans, sea ice, and biota. *Geological Society of America Bulletin* **108**: 1626-1644.

Monnin, E., Indermühle, A., Dällenbach, A., Flückiger, J., Stauffer, B., Stocker, T.F., Raynaud, D. and Barnola, J.-M. 2001. Atmospheric CO_2 concentrations over the last glacial termination. *Nature* **291**: 112-114.

Näslund, J.O., Fastook, J.L and Holmlund, P. 2000. Numerical modeling of the ice sheet in western Dronning Maud Land, East Antarctica: impacts of present, past and future climates. *Journal of Glaciology* **46**: 54-66.

Smith, R.C., Ainley, D., Baker, K., Domack, E., Emslie, S., Fraser, B., Kennett, J., Leventer, A., Mosley-Thompson, E., Stammerjohn, S. and Vernet M. 1999. Marine ecosystem sensitivity to climate change. *BioScience* **49**: 393-404.

Sun, L., Xie, Z. and Zhao, J. 2000. A 3,000-year record of penguin populations. *Nature* **407**: 858.

Thompson, D.W.J. and Solomon, S. 2002. Interpretation of recent Southern Hemisphere climate change. *Science* **296**: 895-899.

Thompson, D.W.J. and Wallace, J.M. 2000. Annular modes in extratropical circulation, Part II: Trends. *Journal of Climate* **13**: 1018-1036.

Vaughan, D.G., Marshall, G.J., Connolley, W.M., King, J.C. and Mulvaney, R. 2001. Devil in the detail. *Science* **293**: 177-179

Watkins, A.B. and Simmonds, I. 2000. Current trends in Antarctic sea ice: The 1990s impact on a short climatology. *Journal of Climate* **13**: 4441-4451.

Xiong, F.S., Meuller, E.C. and Day, T.A. 2000. Photosynthetic and respiratory acclimation and growth response of Antarctic vascular plants to contrasting temperature regimes. *American Journal of Botany* **87**: 700-710.

Yoon, H.I., Park, B.-K., Kim, Y. and Kang, C.Y. 2002. Glaciomarine sedimentation and its paleoclimatic implications on the Antarctic Peninsula shelf over the last 15,000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* **185**: 235-254.

Yuan, X. and Martinson, D.G. 2000. Antarctic sea ice extent variability and its global connectivity. *Journal of Climate* **13**: 1697-1717.