

Climate Change and the Cryosphere

BY DANIEL BEDFORD

The cryosphere is the frozen-water component of the Earth system, comprising snow, ice, and permafrost. It sculpts the Earth's surface, leaving distinctive landforms as evidence of past glacial conditions. It also affects and is affected by a range of atmospheric processes: a blanket of snow makes the ground reflect more sunlight; warmer conditions cause melting. Humans interact with the cryosphere deliberately, using it as a water source and a playground, and coincidentally, as (for instance), shipping is diverted around icebergs, or road and rail traffic is disrupted by avalanches.

Especially in recent decades, we have also used the cryosphere to understand the causes and consequences of global climatic changes, both natural and anthropogenic. Numerous scientific organizations focus their work on the cryosphere because of its importance, including the National Snow and Ice Data Center (<http://www.nsidc.org>), Institute of Arctic and Alpine Research (<http://instaar.colorado.edu>), Byrd Polar Research Center at Ohio State University (<http://bprc.osu.edu>), British Antarctic Survey (<http://www.antarctica.ac.uk>), Association of American Geographers' Cryosphere Speciality Group (<http://www.cryoaaag.org>), and American Geophysical Union's Cryosphere Focus Group (http://www.agu.org/focus_group/cryosphere). In addition, a community of cryosphere scientists share findings and other information via the listserv CRYOLIST (<http://www.cryolist.org>).

The cryosphere has been central to scientific understanding of global climate change since at least 1837, when Swiss-American scientist Louis Agassiz first presented his ideas about a past "Ice Age" (<http://earthobservatory.nasa.gov/Features/Paleoclimatology>). Subsequent research has shown that for the last few million years, Earth has experienced multiple cold (glacial) and warm (interglacial) climatic intervals over a roughly 100,000-year cycle. This process is driven by fluctuations in Earth's orbit amplified by mechanisms internal to Earth's climate system, such as changes in atmospheric carbon dioxide. Agassiz's "Ice Age" was just the most recent glacial period, which peaked around 18,000 years ago (<http://www.ncdc.noaa.gov/paleo/ctl/100k.html>).

Cryosphere research contributes to our understanding of these cycles through ice core data. Because ice sheets build up from accumulated snow compressing into ice, drilling downward is the equivalent of going back in time. Scientists can analyze the ice's isotopic composition and the chemical composition of tiny bubbles of air trapped when the ice formed

to reveal the pattern of past climate change. Ice core data are centralized at the World Data Center for Paleoclimatology (<http://www.ncdc.noaa.gov/paleo/icecore.html>).

The record of climate change over hundreds of thousands of years gives a context for more recent climatic events. Skeptics' claims that global warming is simply part of a natural cycle can be evaluated more easily when the natural cycles are understood. Britain's Natural Environment Research Council summarizes these claims at <http://www.nerc.ac.uk/about/consult/debate/climatechange/summary.asp>, and Real Climate, where scientists offer commentary on climate science (<http://www.realclimate.org>), addresses new versions of these claims as they arise. Ice cores also show that current atmospheric concentrations of carbon dioxide are higher than at any time in the last 800,000 years (see the European Project for Ice Coring in Antarctica ice core results, <http://www.nature.com/nature/journal/v453/n7193/full/nature06949.html>). Findings like this have been major contributors to the scientific consensus on global warming. (See http://www.agu.org/sci_soc/policy/positions/climate_change2008.shtml, [**The cryosphere has been central to scientific understanding of global climate change since at least 1837, when Swiss-American scientist Louis Agassiz first presented his ideas about a past "Ice Age."**](http://www</p>
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www.ametsoc.org/policy/2007climatechange.html, and <http://www.ipcc.ch/> for typical consensus statements.)

Recent changes in the cryosphere, observed at the surface and from satellites, add to this consensus. Measurements of glacier length and mass changes (<http://www.geo.unizh.ch/wgms>, <http://glaciology.ethz.ch/messnetz/index.html>, <http://www.nichols.edu/departments/glacier>, and <http://www.glims.org>) complement striking rephotography images, taken from the same location many years apart and showing general glacier recession (http://www.swisseduc.ch/glaciers/earth_icy_planet/glaciers04-en.html). Monitoring of the Greenland ice sheet shows increased melt area and rapidly receding outlet glaciers (<http://cires.colorado.edu/science/>

groups/steffen and <http://bprc.osu.edu/MODIS>). Several Arctic ice shelves have collapsed (<http://ice.ec.gc.ca/WsvPageDsp.cfm?Lang=eng&lnid=40&ScndLvl=no&ID=11893>), and Arctic sea ice extent reached a record low in 2007, with 2008 a close second (<http://www.nsidc.org/arcticseaicenews>, “2008 Year in Review”; see also <http://igloo.atmos.uiuc.edu/cgi-bin/test/print.sh?fm=09&fd=15&fy=1980&sm=09&sd=15&sy=2007> for satellite image comparisons of 2007 and 1980). Mountain snowpack across the western United States, measured manually (<http://www.wcc.nrcs.usda.gov/snowcourse/sc-hist.html>) and with automated snowpack telemetry stations (<http://www.wcc.nrcs.usda.gov/snotel> and <http://www.wrcc.dri.edu/snotel.html>), has been melting earlier and faster in recent years. These worrying trends are summarized by the National Snow and Ice Data Center (<http://www.nsidc.org/sotc>) and the Intergovernmental Panel on Climate Change (<http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter4.pdf>). Although not every location on Earth is experiencing the same trend, the global average picture is one of melting.

These observations are alarming not only because they show rapid global warming, but also because the cryosphere is itself a key component of the climate system. Snow and ice reflect sunlight (around 80–90 percent for fresh snow) and absorb heat through melting, keeping temperatures cool; air cooling as it passes over snow or ice surfaces becomes denser and flows downslope, generating distinctive wind patterns (see, for example, results from the University of Utrecht’s Morteratschgletscher project, http://www.phys.uu.nl/~oerlemns/site_Mort/mort-eratsch.html). Changes in snow and ice cover therefore can be contributors to, as well as consequences of, climate change. These effects are most apparent in the Arctic, where melting of reflective sea ice exposes more absorbent ocean water below and thawing permafrost may release greenhouse gases such as methane (<http://www.arctic.gov/files/PermafrostForWeb.pdf>). Sea ice and permafrost exemplify feedback loops between climate and the cryosphere—that is, more melting means more warming. Projects to understand the details of these processes are in progress as part of the 2007–2009 International Polar Year (<http://www.ipy.org>).

A melting cryosphere is also important to many peoples’ everyday lives. Earlier and faster melting of western U.S. snowpack prolongs the dry season, challenging water and wildfire managers (<http://www.colorado.edu> and <http://www.sciencemag.org/cgi/content/full/313/5789/940>). Ski resorts face higher snowmaking costs and shorter snow seasons and have become actively involved in efforts to reduce greenhouse gas emissions (<http://www.KeepWinterCool.org>). Shrinking glaciers threaten water supplies to mountain villages in the Peruvian Andes (<http://bprc.osu.edu/glacierchange/research.html>) and Himalayas (<http://www.theglaciertrust.org/2008/09/water-resources-management-for-nepali-hill-farmers.html>; see also recent publications at [\[www.icimod.org?page=78\]\(http://www.icimod.org?page=78\)\). Melting land ice contributes to rising sea levels, potentially inundating low-lying coastlines. With roughly 90 percent of the Earth’s land ice in Antarctica, there is an urgent need to understand the details of ice sheet stability and climate change, and two important projects are dedicated to this aim \(<http://pigiceshelf.nasa.gov> and <http://neptune.gsfc.nasa.gov/wais>\).](http://</p></div><div data-bbox=)

Thawing can also amplify the existing cryospheric hazards of high-mountain environments, such as snow avalanches (<http://www.avalanche.org> and <http://www.fsavalanche.org>). Sudden glacial outburst floods, or *jökulhlaups*, can also be a consequence of warming as fragile ice dams are destabilized (<http://www.glacierhazards.ch> and <http://www.pbs.org/wgbh/nova/mtblanc/space.html>).

Thawing can bring benefits as well as hazards. A commercial ship navigated the Northwest Passage along the Arctic coast of North America for the first time in 2008 (<http://www.cbc.ca/canada/north/story/2008/11/28/nwest-vessel.html>), suggesting greater ease of travel in a warmer world. Such benefits, however, are a matter of perspective. The Panama Canal, for example, might lose revenue if more ships take an Arctic route (see “Thinning on Top” at <http://www.economist.com/video/graphics>), and a reduction of Arctic sea ice would pose a threat to species for which ice is an important habitat, such as seals, caribou, migratory birds, and polar bears (<http://amap.no/acia>).

Polar bears in particular have become the symbol of what is at stake in the Arctic. They are magnificent animals as well as ferocious predators, and their loss would diminish the world. The cryosphere is important for its beauty as well as its role in climate change or as a water resource or habitat; for instance, the delicate patterns of snowflakes (<http://snowcrystals.com>) captivate children and adults alike. The cultural importance of snow and ice is recognized by the National Science Foundation, which includes artists and writers in its Antarctic research program (<http://www.nsf.gov/od/opp/aawr.jsp>), but the impacts of a melting cryosphere are felt most acutely by those cultures that have been shaped by cold for thousands of years, such as the Inuit (http://www.windows.ucar.edu/tour/link=/earth/polar/inuit_culture.html). A melting cryosphere has therefore become a human-rights issue, as highlighted by the Inuit Circumpolar Council (<http://www.inuit.org/index.asp?lang=eng&num=244>). Sheila Watt-Cloutier, former chair of the council, has spoken movingly on this subject (for example, at the Climate 2050 conference held in Montreal in 2007, <http://www.youtube.com/watch?v=G1Sh4XeoLBA>). Amid the reports of melting snow and ice, the aesthetic and cultural importance of the cryosphere is well worth remembering.

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