



CLIMATE CHANGE AND THE CRYOSPHERE

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What is the cryosphere?

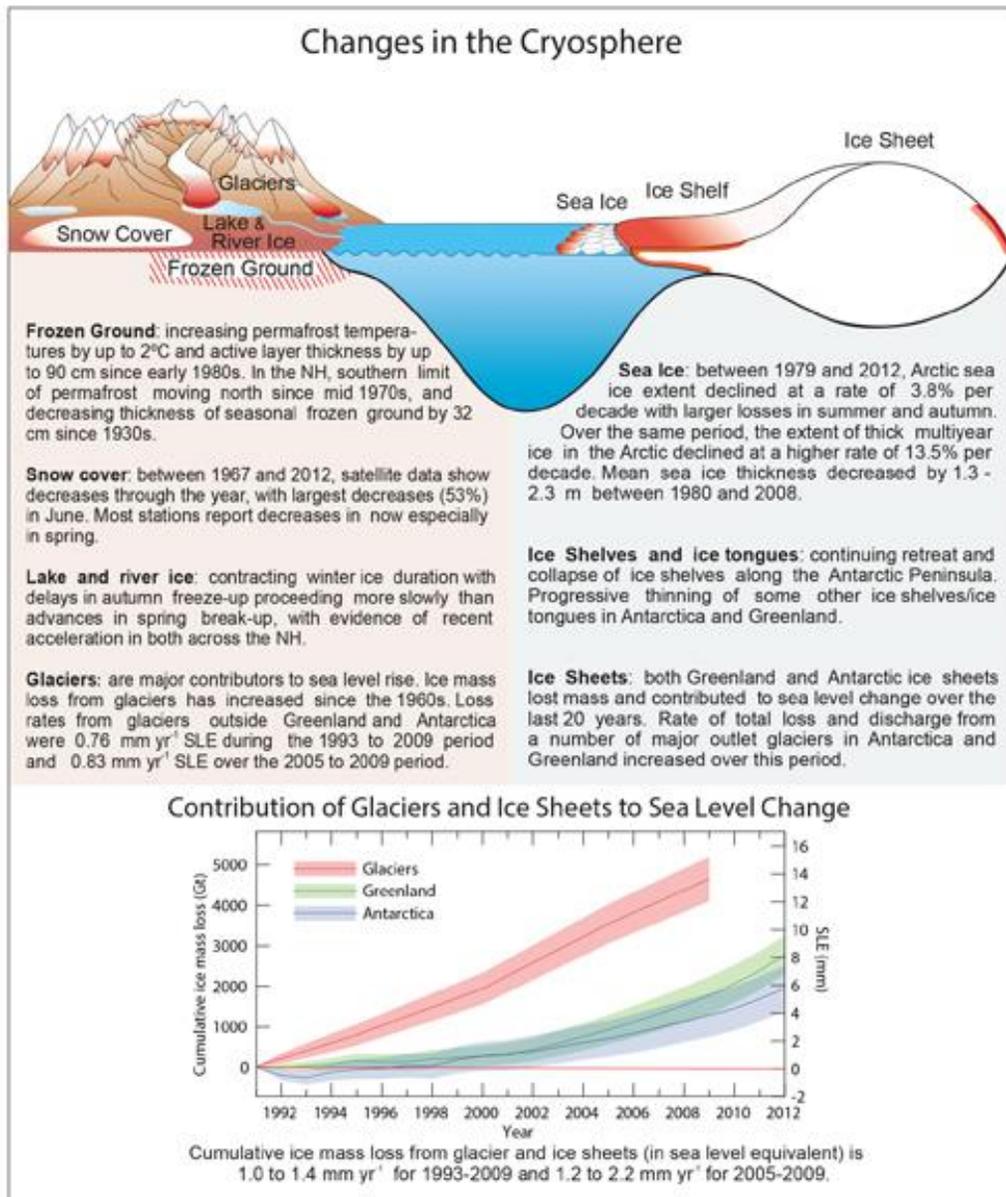
The word 'cryosphere' gets its meaning from the Greek word "kryos," which means cold. By cryosphere, we mean the places on Earth that are cold enough that they contain frozen water. The frozen water may be in the form of snow, ice (glaciers, ice shelves, ice caps, icebergs or sea ice), frozen ground, and/or methane hydrate, a co-crystallized form of water and methane.¹

How is the cryosphere changing?

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) analyzed the state of the Earth's cryosphere and concluded (with high confidence) that "over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent."²

The cryosphere is changing differently in the Northern and Southern Hemispheres. The North Pole is in the Arctic Ocean and is surrounded by land; the South Pole is on land in Antarctica, which is surrounded by ocean. In the north, the westerly winds that circle the North Pole have been getting weaker while those around Antarctica are getting stronger. This leads to differences in how moisture moves through the atmosphere. Warming, thus far, has been mostly in the high- to mid-latitudes of the Northern Hemisphere, the interior of several continents, and the northernmost reaches of Antarctica.³

The National Snow & Ice Data Center (NSIDC) provides an overview of how each of the various components of the cryosphere is changing in response to global climate change.⁴ These changes are illustrated in the following figure.⁵



Northern Hemisphere: According to NSIDC, the Arctic sea ice extent was below average during each month of 2014. When averaged for the entire year, the Arctic sea ice extent was the sixth smallest on record. Winter snow cover extent has increased slightly in the 48-year record, while in spring it has decreased substantially.

Southern Hemisphere: Antarctic sea ice extent was much above average during all of 2014. When averaged for the entire year, it was the largest Antarctic sea ice extent on record.⁶

Why are changes in the cryosphere important?

(1) Loss of glaciers and ice sheets, through either melting or calving into the sea, contributes significantly to sea level rise that can endanger coastal populations, development, infrastructure, and ecosystems.⁷ Those glaciers grounded below sea level have the greatest sea level change potential for this century. Researchers, using new measurement techniques, found recently that Greenland's ocean-feeding glaciers are deeper and longer than previously thought and will thus contribute even more to sea level rise than expected.⁸ (Ice grounded below sea level, like much of the ice in West Antarctica, could cause up to about 23 feet [7 m] of sea level rise in the relatively short term. Most of the ice in Antarctica, however, is grounded on land above sea level in East Antarctica and is expected to take centuries to melt fully.)

Of particular concern is the question of how quickly these glaciers and ice sheets will melt. Will there be time to adapt? Studies of sea levels since the coldest part of the last ice age indicate that the sea level rise of about 400 feet was not smooth and gradual; indeed, during one period (Meltwater Pulse 1A), sea levels rose as much as 65 feet (20 meters) in as little as 200 years.⁹

(2) Arctic warming can influence weather and climate around the world, particularly in the Northern Hemisphere. The Arctic has been warming about twice as fast as the rest of the Northern Hemisphere (a phenomenon known as *Arctic amplification*). This in turn is affecting the jet stream, which is fueled by the temperature contrast (now less pronounced) between the frigid Arctic and the milder lower latitudes.¹⁰

Scientists are starting to see a relationship between Arctic climate change and extreme weather events in the U.S. and Europe. As enhanced Arctic warming affects the jet stream, slowing its west-to-east winds and promoting larger north-south meanders, the likelihood of extreme weather events in the Northern Hemisphere is increasing.¹¹

(3) Loss of mountain glaciers can threaten water supplies for drinking, agriculture, and industry in areas that depend on summer melt of snow and ice for water. This is a major threat to both Asia and South America.¹²

(4) When areas covered by glaciers or sea ice are reduced, a positive feedback process occurs. Snow and ice reflect much of the sun's radiant energy back into space, while darker land and water surfaces absorb more (the albedo effect). As more land and

water (darker surfaces) are exposed and absorb more radiation, the melt rate of ice increases. Black soot on snow and ice also decreases albedo and speeds melting.¹³

Another contributing factor, recently reported by scientists at the Lawrence Berkeley National Laboratory, is that open oceans are much less efficient than sea ice at emitting far-infrared radiation to space. This means that the Arctic Ocean traps more far-infrared energy than estimated previously, which is likely contributing to warming in that region.¹⁴

(5) Warming seawater and thawing land can lead to the release of methane from methane hydrates. Methane hydrates are important -- not because of the amount of ice they contain (less than 1 percent of the ice in the cryosphere) but because of the large amount of methane they hold. Earth's methane hydrates contain more carbon than all the known reserves of conventional fossil fuels. Estimates are very uncertain but go as high as 22,000 gigatons (or billions of tonnes) of carbon.¹⁵

Releasing this powerful greenhouse gas can increase the rate of warming, as occurred 56 million years ago and caused what geologists call the Paleocene-Eocene Thermal Maximum (PETM) -- when the release of 2000-3000 gigatons of carbon as methane, over a period of several centuries, raised earth's average surface temperature by 9-11°F (5-6°C). Recovery took more than 150,000 years.¹⁶

Current observations have shown vast plumes of methane in the Arctic Ocean as sea ice retreats.¹⁷

(6) Loss of Arctic sea ice is opening new shipping routes between the Atlantic and Pacific Oceans, as well as providing access to previously inaccessible fossil fuels and minerals. This in turn could lead to territorial disputes and other conflicts as well as to more carbon emissions if the fossil fuels are extracted and burned. Resource extraction companies, shipping firms, and the defense and economic development sectors of Arctic-bordering countries are all starting to consider the implications of an open Arctic Ocean.¹⁸

(7) Most of the issues detailed above have been identified as national security threats: climate disruption, loss of land from sea level rise, loss of water supplies, loss of food production due to droughts and floods, and conflicts over newly available trade routes and natural resources. Adding to the picture, millions of people affected by these disasters may become environmental refugees, leaving home in order to survive.¹⁹

(8) Loss of snow pack is creating economic losses for skiing- and snow-related tourism. The Alps are warming two to three times faster than the worldwide average. Sixteen

million cubic feet of snow was stored under insulated blankets to ensure that the 2014 Sochi Winter Olympic Games would have snow.²⁰ It is likely that there will not be many places left by 2100 that can host the Winter Olympics.²¹

Have there been major changes in the cryosphere over Earth's long history?

Our planet has gone through various stages: "greenhouse," with no ice at the poles, "ice house," with some permanent ice, and "snowball," when the entire earth's surface was covered with ice. These dramatic differences are attributed primarily to changes in the atmospheric CO₂ concentration and in the planet's orbit.²²

Examination of 11,700-year old ice cores from Greenland, formed during a rapid shift from a near-glacial period to the current period of relative warmth, provides evidence that the climate can change abruptly to a new state in just a few years. The abrupt onset of the current interglacial (warm) climate was marked by a northward shift in the jet stream (the edge of the polar vortex), an abrupt decrease in North Atlantic sea ice extent, and more moisture in Greenland -- as we are seeing today.²³

What potential policy changes and actions are needed to adapt to cryosphere changes?

- Revise coastal zoning policies and flood insurance practices to encourage people to avoid placing buildings and infrastructure in low-lying areas.
- Increase the costs of federal flood insurance from the Federal Emergency Management Agency (FEMA), until the costs cover the payouts for flood damage.
- Provide international funding to help low-lying island populations relocate.
- Design better agricultural and industrial methods to reduce water use.
- Support the U.S. Department of Defense Arctic Strategy.²⁴
- Change water use regulations to protect diminished potable water supplies at local, state, and national levels.
- Implement public education campaigns about changes in the cryosphere, sea level rise, and the importance of reducing water use.

¹ For details about the components of the cryosphere, except methane hydrate, see "All About the Cryosphere," *National Snow & Ice Data Center*,

<http://nsidc.org/cryosphere/allaboutcryosphere.html>. For methane hydrate, see "Methane Hydrate," *Geology.com*, <http://geology.com/articles/methane-hydrates/>.

² "Climate Change 2013: The Physical Science Basis, Summary for Policy Makers," Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

³ To step through Earth's average regional surface temperatures by decade from 1880 to 2009 see; <http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php>

⁴ "State of the Cryosphere," *National Snow & Ice Data Center*, <http://nsidc.org/cryosphere/sotc/>

⁵ David Biello, "12 Graphics That Contain Everything You Need to Know about Climate Change," January 31, 2014, <http://blogs.scientificamerican.com/observations/2014/01/31/12-graphics-that-contain-everything-you-need-to-know-about-climate-change>. It contains the following abbreviations: NH, Northern Hemisphere; SLE, sea level equivalent; Gt, gigatonnes, or billions of metric tonnes. Note: 10 mm of SLE from glaciers is equivalent to about 3600 Gt of ice lost.

⁶ Global Snow & Ice - Annual 2014, *NOAA National Climatic Data Center*, <http://www.ncdc.noaa.gov/sotc/global-snow/2014/13>

⁷ To better understand the relationships among sea level, CO2 concentration, and global average temperature see Chad Tolman, "Rising Seas and Stronger Storms – Delaware's Response in the Face of Uncertainty," Delaware Sea Level Rise Advisory Committee, 2011, <http://www.dnrec.delaware.gov/coastal/Documents/SLR%20Advisory%20Committee/Meeting%204%20Feb.%2015%202011/TolmanSLRAdapt021511.pdf>

⁸ Mathieu Morlighem et al, as cited in "Hidden Greenland Canyons Mean More Sea Level Rise," *JPL- NASA News*, <http://www.jpl.nasa.gov/news/news.php?release=2014-155>.

⁹ Wikipedia, "Meltwater Pulse 1A," http://en.wikipedia.org/wiki/Meltwater_pulse_1A

¹⁰ Andrew Freedman, "Arctic Warming is Altering Weather Patterns, Study Shows," *Climate Central*, September 30, 2012, <http://www.climatecentral.org/news/arctic-warming-is-altering-weather-patterns-study-shows>.

¹¹ "Arctic summer wind shift could affect sea ice loss and U.S./European weather, says NOAA-led study," *NOAA*, October 11, 2012, http://www.noaanews.noaa.gov/stories2012/20121010_arcticwinds.html

¹² Dr. Paul Mayewski, personal review communication to authors, 7/18/2014.

¹³ For more on positive feedbacks and the risk of climate runaway initiated by human actions, see Chad Tolman, "Positive Feedbacks and Climate Runaway: The Need to Act without Delay," *League of Women Voters*, 2009. At: http://www.lwv.org/files/CCTF_BP_PositiveFeedback.pdf

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- ¹⁴ Dan Krotz, "Berkeley Lab Scientists ID New Driver Behind Arctic Warming," Berkeley Lab News Center, November 3, 2014, <http://newscenter.lbl.gov/2014/11/03/far-infrared-arctic/>
- ¹⁵ Barbara Maynard, "Burning Questions about Gas Hydrates," *Chemistry*, pp. 27-33 (Winter 2006), http://acswebcontent.acs.org/chemistry/winter_2006.pdf.
- ¹⁶ Robert Kunzig, "World Without Ice," *National Geographic Magazine*, October 2011, <http://ngm.nationalgeographic.com/2011/10/hothouse-earth/kunzig-text>
- ¹⁷ "SWERUS-C3: First observations of methane release from Arctic Ocean hydrates," *Department of Geological Sciences, Stockholm University*, July 2014, <http://www.swerus-c3.geo.su.se/index.php/swerus-c3-in-the-media/news/177-swerus-c3-first-observations-of-methane-release-from-arctic-ocean-hydrates>
- ¹⁸ Cameron Paquette, "Melting Sea ice could make Maine new shipping hub," *Bangor Daily News*, May 21, 2014, <http://bangordailynews.com/2014/05/22/business/melting-sea-ice-could-make-maine-hub-of-new-international-shipping-routes/?ref=search>
- ¹⁹ "National Security and the Accelerating Risks of Climate Change," *CNA Military Advisory Board*, May 2014, http://www.cna.org/sites/default/files/MAB_2014.pdf
- ²⁰ Porter Fox, "The End of Snow?", *NY Times*, February 7, 2014, http://www.nytimes.com/2014/02/08/opinion/sunday/the-end-of-snow.html?_r=0
- ²¹ Uri Friedman, "Do the Winter Olympics Have a Future in a Warming World?" *The Atlantic*, February 12, 2014, <http://www.theatlantic.com/international/archive/2014/02/do-the-winter-olympics-have-a-future-in-a-warming-world/283768/>
- ²² Michael Marshall, "The History of Ice on Earth," *New Scientist*, May 24, 2010, <http://www.newscientist.com/article/dn18949-the-history-of-ice-on-earth.html?full=true#.UxzZLVx331o>
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- ²⁴ Karen Parrish, "Hagel Announces DOD's Arctic Strategy," *Department of Defense News*, November 22, 2013, <http://www.defense.gov/news/newsarticle.aspx?id=121220>