A cold look at planet Earth: Learning from the world's frozen places

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Water, the key to life, is also a key to understanding the way the natural world works. Water in the form of ice is especially instructive.

Water moves through the hydrologic cycle, one of the most basic and vital processes of Earth's systems, in three forms—as a liquid in seas and streams; as a vapor in clouds and fog; and as a solid in ice. Found predominately in glaciers, the world's ice is, by nature, temperature dependent. Thus the presence or absence of glaciers and their geographic distribution around the globe are closely linked to Earth's historical and current climate conditions and to changes in global sea level.

The recently published "State of the Earth's Cryosphere at the Beginning of the 21st Century" summarizes past and present-day changes in the Earth's cryosphere (the whole of its frozen water) and describes the ongoing and potential effects of those changes. Extensively illustrated in print and connected to a companion online image gallery, this volume supplies a synthesis for 10 other geographically-based volumes in the 11-volume Satellite Image Atlas of Glaciers of the World.

"Evidence from a wide range of satellite and field observations over the last 30 years shows that nearly all glaciers, snowpack, sea ice, and permafrost are in retreat around the globe,"□ said USGS Director Marcia McNutt. "That this worldwide phenomenon can be readily observed by a non-specialist without any sophisticated data processing or image enhancement is strong evidence that our rapidly warming planet is causing major changes in one of the key Earth systems."

Glaciers as climate indicators

Glaciers cover about 15.9 million square kilometers of Earth's land surface (2009 figures), slightly less than the size of Russia. Ice sheets in Antarctica and in Greenland store most of the glacier ice on Earth, occupying 95.5 percent of glacier area and containing 99.4 percent of glacier volume. Other glaciers are located on all of Earth's continents except Australia. (The term glacier in the Satellite Image Atlas includes ice sheets, a long-held definition also used by the Scott Polar Research Institute and the American Geosciences Institute.)

Glaciers have waxed and waned throughout the history of Earth in response to several factors: the global climate, the latitudinal position of the continents, the geographic position and elevation of mountain ranges, and slight changes in the Earth's orbit. Presently, glaciers around the world are responding to natural warming after the end of the Little Ice Age in the late 1800s, as well as to the warming that human activity has caused through increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere.

For example, since the late 19th century, all of Iceland's glaciers have decreased in area and thickness. Although Iceland's glaciers retreated from 1930 through 1970, they advanced during 1970 to 1995. Since 1995, however, the decrease has been quite dramatic. If the climate continues to warm, glaciers in Iceland will probably decrease by 40 percent during the 21st century and will virtually disappear by 2200.

The overwhelming scientific consensus is that burning of fossil fuels and deforestation, both of which are human activities, are critical factors in the Earth's observed warming.

Melting glaciers—rising seas

Water covers 70 percent of the Earth's surface. Of all the world's water, water in the oceans makes up 97 percent while frozen water in glaciers accounts for just 2 percent.

Although 2 percent seems like a small ratio, it is the long-term exchange between glacier ice and the oceans that principally determines global sea level. Warming of the Earth alters the relationship between global sea level and the volume of glacier ice on land, as frozen water is converted to meltwater and transferred from land to the oceans. The warming of the Earth's oceans also serves to increase the volume of the water and add to global sea rise.

In response to variations in the volume of glacier ice on the continents, sea level has repeatedly fallen and risen between glacial and interglacial periods of Earth's geologic history. Approximately 20,000 years ago, for example, sea level was about 125 meters (410 feet) lower than at present (2009 figures). If all of the present glacier ice on land were to melt, sea level would rise an additional 75 meters (246 feet).

The present rate of the global rise in sea level is now about 3-4 mm each year, equivalent to a stack of three to four U.S. pennies.

The cryosphere: Beyond glaciers

The cryosphere (from Greek, cryos, "cold"□) is the term that describes the portions of the Earth's surface where water is in solid form. It includes glaciers, snow cover, floating ice, and permafrost, although glaciers are the dominant component.

Global snow cover is measured on a daily basis, and snow-cover trends can be measured over decades. These advances have important applications to hydrological forecasting, enabling us to predict flooding and water supply.

Sea ice covers vast areas of the polar oceans, affecting the atmosphere, the oceans, and terrestrial and marine ecosystems of the polar regions. Changes in the ice, if sufficiently large, can initiate regional and global climatological and ecological consequences. This publication notes that 2007 was a record low year for Arctic sea ice extent, but an even lower minimum was recorded more recently in September 2012.

Permafrost or perennially frozen ground includes northern peatlands and frozen, organic-rich sediments that contain large amounts of carbon. Deep, perennially frozen sediments, both onshore and beneath the Arctic shelves, contain methane hydrates. These carbon-rich deposits are potential sources of greenhouse gases, especially methane, if climate warming continues.

The cryosphere in education

A substantial section of the new volume is designed for use by teachers and students in the classroom to improve the understanding of major aspects of global environmental change. The print version of this section contains a wall-size plate, "Earth's Dynamic Cryosphere,"□ and eight Supplemental Cryosphere Notes (two-page summaries of topics included in the report). These materials support a major national effort to increase higher-education student enrollment in the Earth sciences.

Global collaboration and space-based views

The State of the Earth's Cryosphere represents an extensive collaboration among 20 glaciologists from the United States and three other nations (Canada, Denmark, and Norway) who represent 14 scientific institutions. Since 1988, more than 110 scientists from 24 countries have contributed to the 11-volume series, Satellite Image Atlas of Glaciers of the World (USGS Professional Paper 1386A-K).

The goal of Satellite Image Atlas of Glaciers is to establish a comprehensive baseline of glacier conditions on all continents so that subsequent change can be readily seen and investigated. The advent of spaced-based Earth observation satellites—beginning with the first Landsat satellite in 1972 and continuing with the forthcoming launch of Landsat 8—made that sweeping objective feasible.

More information: Williams, R.S., Jr., and Ferrigno, J.G., 2012, State of the Earth's Cryosphere at the Beginning of the 21st Century: Glaciers, Global Snow Cover, Floating Ice, and Permafrost and Periglacial Environments: *U.S. Geological Survey Professional Paper* 1386-A, 496 p.

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