The Earth's Dynamic Cryosphere and the Earth System

Glaciers

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Glaciers are the dominant component of the cryosphere, which also includes snow cover, floating ice, and permafrost. Glaciers now (2009) cover about 15.9 million square kilometers of Earth's land surface, and their estimated volume is 33 million cubic kilometers. The two remaining ice sheets in Antarctica (fig. 1) and in Greenland (fig. 2) store most of the glacier ice on Earth, occupying 95.5 percent of glacier area and 99.4 percent of glacier volume. Glaciers that are not ice sheets, such as ice caps (fig. 3) and ice fields (and their outlet glaciers), valley glaciers, cirque glaciers, and other mountain glaciers are located on all of Earth's continents except Australia.

Glaciers have waxed and waned throughout the history of Earth whenever global climate (including concentration of greenhouse gases in the atmosphere), latitudinal position of the continents, latitudinal position and elevation of mountain ranges, and the Earth's position and obliquity in its orbit have been conducive to their growth or retreat.

The position and dating of outer glacial moraines offer proof that glaciers expanded in volume and area throughout the Northern Hemisphere during the Little Ice Age (13th to late 19th centuries). Evidence from the Southern Hemisphere confirms that the Little Ice Age was a global phenomenon. From the late 19th century to the present time, virtually

Figure 1. Oblique aerial photograph of the ice front in Okuma Bay, eastern edge of the Ross Ice Shelf, Antarctica, on 22 October 1961. A tabular iceberg is visible in the bottom left-center foreground.

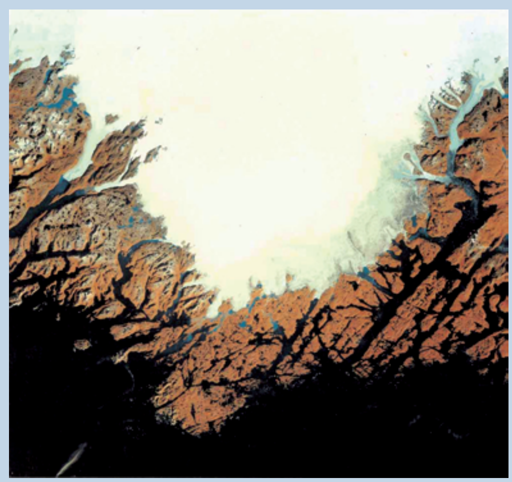

Figure 2. Landsat 1 MSS digitally enhanced false-color composite image of the south slope of the Greenland ice sheet northwest of Julianehåb (Qaqortoq), South Greenland on 13 September 1980. The image shows the well-defined edge of the Inland Ice, which spreads over the lowlands of South Greenland toward the outer coast. In some areas, the snowline is clearly visible. The marginal areas of the Greenland ice sheet have undergone severe thinning during the late 20th century and early 21st century.

Figure 3. Landsat 1 MSS image of the Vatnajökull ice cap, Iceland, on 22 September 1973. Digitally enhanced false-color composite Landsat image (1426-12070) from the U.S. Geological Survey EROS Data Center, Sioux Falls, SD 57198.

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all of the Earth's non-ice-sheet glaciers have been retreating in response to climate warming, interrupted only by brief periods of cooling. For example, since the late 19th century, all of Iceland's glaciers have decreased in area and thickness. Although Iceland's glaciers decreased 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. Glaciers 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 (for example, increased concentrations of carbon dioxide and other greenhouse gases) in the atmosphere.

The focus on glaciers as the dominant subelement of the cryosphere is scientifically important for four reasons.

- First, the mass balance of a glacier, which is determined by its climatic regime, conveys information about climate;
- Second, glaciers are the second largest reservoir of water on Earth, and they are the largest reservoir of fresh water: oceans hold 97 percent of the Earth's water; glaciers, about 2 percent;
- Third, change in the mass balance of glaciers is the primary contributor to changes in eustatic (global) sea level (about 75 meters (m) of maximum sea-level rise remains stored in glacier ice on land); the secondary contributor is steric increase (in volume) of the oceans as its upper layers are warmed; and
- Fourth, satellite remote sensing instruments enable scientists to monitor and measure fluctuations in the areal extent of glaciers. The tandem GRACE satellite gravity sensors can measure changes in volume (mass) of ice sheets and large ice caps. Global Positioning System (GPS) surveys on the ground, combined with geodetic airborne laser altimeters, and satellite remote sensing instruments, can measure and monitor variations in the surface elevation of glaciers. The first Geoscience Laser Altimeter-System (GLAS), a part of the Ice, Cloud, and land Elevation (ICESat) Program, has been acquiring measurements of ice sheets and other landforms that are vertically accurate to within ± 1 m.

Glaciologists from many nations have been using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images on NASA's Earth Observing System (EOS) Terra satellite and data from Landsat 7 and other satellites to support an international project, Global Land Ice Measurements from Space (GLIMS). The goal of GLIMS is to survey all of the world's glaciers with the accuracy and precision needed to assess recent changes and to predict future trends in ice cover, regional water resources, hydropower generation (fig. 4), and global sea level. The 11-chapter ("volume") USGS Satellite Image Atlas of Glaciers of the World (USGS Professional Paper 1386-A–K) (http://pubs.usgs.gov/factsheet/fs/2005/3056) provides a global baseline for the entire extent of glacier area on Earth during the period 1972 to 1981, based primarily on analysis of Landsat images.

Figure 4. View of dam on Oberaarsee (Lake Oberaar) and Oberaargletscher (Oberaar Glacier) in the background, Bernese Alps, Bern Canton, Switzerland, in September 1978. Photograph by Richard S. Williams, Jr., U.S. Geological Survey.

URL Addresses:

http://nsidc.org/glaciers/

http://www.glaciers.er.usgs.gov/

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