

Satellite Image Atlas of Glaciers of the World

Most mountain glaciers worldwide have been retreating since the late 1800's, and global sea level has risen about 12 centimeters since then. As glaciers vary in size, they respond to changes in global and regional climates (such as warmer summers). The U.S. Geological Survey (USGS) studies the complex links among glacier variation, climate change, and global sea level.

Sea-level changes, especially in densely populated, low-lying coastal areas and on islands, have significant effects on human activities and facilities. The present volume of the Earth's glacier ice, if totally melted, represents about 80 meters in potential sea-level rise. About 200 meters is the range of sea-level changes that can be caused by water being frozen in glaciers during an ice age or melted during an interglacial epoch. For example, during the last glacial maximum, about 21,000 years ago, sea level is estimated to have been 125 meters lower than it is today. During a warmer climatic interval in the last interglacial period, about 125,000 years ago, sea level was about 6

meters higher than it is today; during an even warmer interval about 2.2 million years ago, sea level is estimated to have been 25 to 50 meters higher.

A thorough global baseline study of the areal extent of existing glaciers (fig. 1) is required before scientists can assess the magnitude of glacier change that is forecast to occur worldwide during the 21st century. Satellite images (figs. 2–5) can be used to inventory glaciers and to monitor changes in their areal extent.

In 1978, the USGS began the preparation of the 11-chapter USGS Professional Paper 1386, "Satellite Image Atlas of Glaciers of the World." Between 1979 and 1981, optimum satellite images were distributed to a team of 70 scientists, representing 25 nations and 45 institutions, who agreed to author sections of the Professional Paper concerning either a geographic area (chapters B–K) or a glaciological topic (included in chapter A).

The scientists used Landsat 1, 2, and 3 multispectral scanner (MSS) images and Landsat 2 and 3 return beam vidicon (RBV) images to inventory the areal

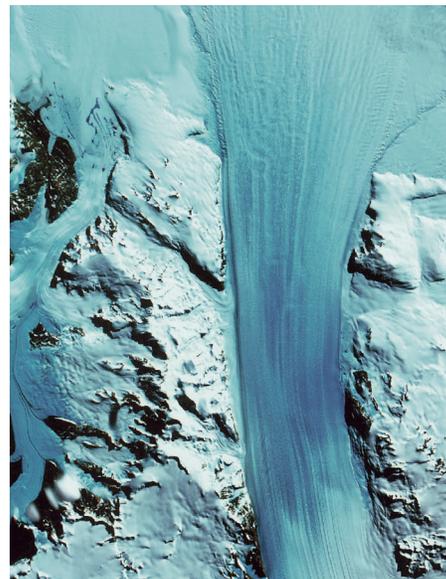


Figure 2. Landsat 1 MSS image of the Byrd Glacier where it joins the Ross Ice Shelf. From USGS Professional Paper 1386–B, Antarctica, fig. 23.

occurrence of glacier ice on our planet within the boundaries of the spacecraft's coverage (between about 82° north and south latitudes). Some later contributors also used Landsat 4 and 5 MSS and Thematic Mapper, Landsat 7 Enhanced Thematic Mapper-Plus (ETM+), and other satellite images.

In addition to analyzing images of a specific geographic area, each author was asked to summarize up-to-date information about the glaciers within each area and compare their present areal distribution with reliable historical information (from published maps, reports, and photographs) about their past extent. Because of the limitations of Landsat images for delineating or monitoring small glaciers in some geographic areas (the result of inadequate spatial resolution, lack of suitable seasonal coverage, or absence of coverage), some information on the areal distribution of small glaciers was necessarily derived from ancillary sources.

Completion of the atlas will provide an accurate regional inventory of the areal extent of glaciers on our planet during a relatively narrow time interval (1972–1981). This global "snapshot" of glacier extent is already being used for comparative analysis



Figure 1. White areas show ice sheets and other glaciers around the world. The white spots in the oceans are islands where glaciers are found. Reproduced from National Geographic World (February 1977, no. 18, p. 6) with permission.

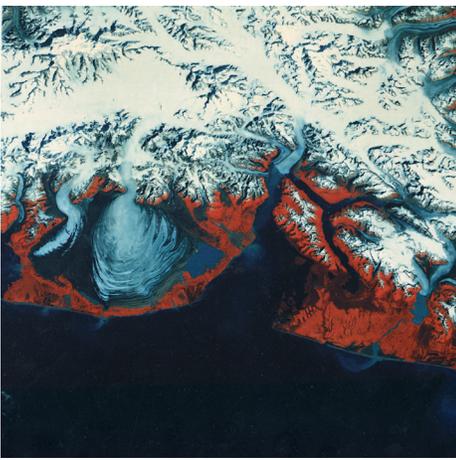


Figure 3. Landsat 2 MSS image of Malaspina Glacier, Alaska. From USGS Professional Paper 1386-K, *Glaciers of Alaska*.

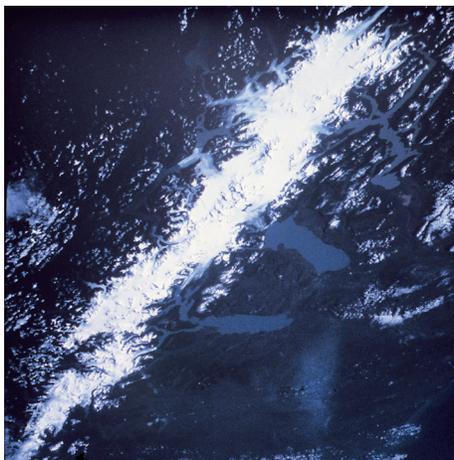


Figure 4. Salyut-6 photograph of the Southern Patagonian Ice Field, Chile and Argentina. From USGS Professional Paper 1386-I, *Glaciers of South America*, fig. 31.

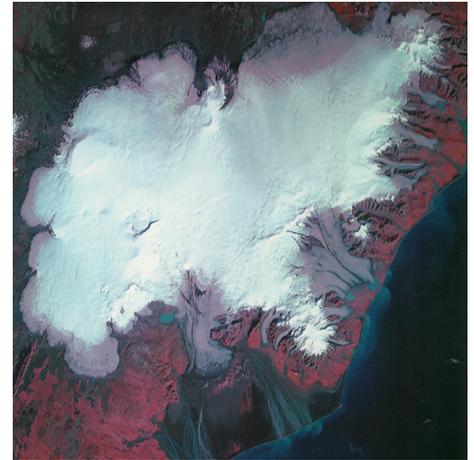


Figure 5. Digitally enhanced Landsat 1 MSS image of Iceland's largest (8,200 square kilometers) ice cap, Vatnajökull. From USGS Professional Paper 1386-D, *Glaciers of Iceland*.

with previously published maps and aerial photographs, as well as with new maps, satellite images (for example, ASTER, Landsat 7 ETM+, and RADARSAT), and aerial photographs, to determine the areal fluctuation of glaciers in response to natural or human-induced changes in the Earth's climate. For example, sequential Landsat 4, 5, and 7 and RADARSAT images have documented major changes in the coastal regions of Antarctica. See USGS Fact Sheets FS-050-98, "Coastal-Change and Glaciological Maps of Antarctica" (at <http://pubs.usgs.gov/fs/fs50-98>) and FS-017-02, "Coastal-Change and Glaciological Maps of the Antarctic Peninsula" (at <http://pubs.usgs.gov/fs/fs17-02>). See also the USGS Glacier Studies Project web site at <http://www.glaciers.er.usgs.gov>.

Table 1. Topics and publication dates of USGS Professional Paper 1386, chapters A-K.

[Chapters A-D include supplemental maps folded in a pocket, as indicated in column 2 by "w/map(s)." Chapters A, D, F, and K are not yet published]

| Chapter | Topic | Date published |
|---------|---|----------------|
| A | Introduction and synthesis w/map | ---- |
| B | Antarctica w/maps | 1988 |
| C | Greenland w/map | 1995 |
| D | Iceland w/map | ---- |
| E | Continental Europe ¹ | 1993 |
| F | Asia | ---- |
| G | Turkey, Iran, and Africa | 1991 |
| H | Irian Jaya (Indonesia) and New Zealand ² | 1989 |
| I | South America ³ | 1998 |
| J | North America ^{4 5} | 2002 |
| K | Alaska | ---- |

¹Excluding the European part of the former Soviet Union, which is included in chapter F (Asia).

²Web accessible: <http://pubs.usgs.gov/prof/p1386h/>

³Web accessible: <http://pubs.usgs.gov/prof/p1386i/>

⁴Web accessible: <http://pubs.usgs.gov/prof/p1386j/>

⁵Excluding Alaska, which is chapter K.

Chapter A of USGS Professional Paper 1386 will contain introductory material, a synthesis of chapters B-K, a 1:50,000,000-scale map titled "The Earth's Dynamic Cryosphere," and a discussion of the cryosphere (the frozen part of the Earth's surface), including past and present changes, physical characteristics, classification, and global distribution of glaciers. The next 10 chapters, B-K, are arranged geographically (table 1) and present glaciological information on each of the Earth's glacierized regions. The foreword of chapter J is reproduced here.

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Foreword to USGS Professional Paper 1386-J

On 23 July 1972, the first Earth Resources Technology Satellite (ERTS 1 or Landsat 1) was successfully placed in orbit. The success of Landsat inaugurated a new era in satisfying mankind's desire to better understand the dynamic world upon which we live. Space-based observations have become an essential means for monitoring global environmental changes.

The short- and long-term cumulative effects of processes that cause significant changes on the Earth's surface can be documented and studied by repetitive Landsat and other images. Such images provide a permanent historical record of the surface of the planet; they also make possible comparative two- and three-dimensional measurements of change over time. This Professional Paper demonstrates the importance of the application of Landsat images to global studies by using them to determine the 1970's distribution of glaciers on the planet. As images become available from future satellites, the new data will be used to document global changes in glacier extent by reference to the baseline Landsat image record of the 1970's.

Although many geological processes take centuries or even millennia to produce obvious changes on the Earth's surface, other geological phenomena, such as glaciers and volcanoes, cause noticeable changes over shorter periods. Some of these phenomena can have a worldwide impact and often are interrelated. Explosive volcanic eruptions, such as the 1991 Mount Pinatubo, Philippines, eruption, can produce dramatic effects on the global climate. Natural or culturally induced processes can cause global climatic cooling or warming. Glaciers respond to such warming or cooling periods by decreasing or increasing in size, which in turn causes sea level to rise or fall.

As our understanding of the interrelationship of global processes improves and our ability to assess changes caused by these processes develops further, we will learn how to use indicators of global change, such as glacier variation, to manage more wisely the use of our finite land and water resources. This USGS Professional Paper series is an excellent example of the way in which we can use technology to provide needed earth-science information about our planet. The international collaboration represented by this report is also an excellent model for the kind of cooperation that scientists will increasingly find necessary in the future in order to solve important earth-science problems on a global basis.

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