Satellite Image Atlas of Glaciers of the World

E U R O P E

United States Geological Survey
Professional Paper 1386–E

Cover: Landsat false-color image mosaic of Svalbard, Norway, a heavily glacierized archipelago situated about 900 kilometers north of the Norwegian mainland. Mosaic compiled by Fjellanger Widerøe A-S. *See page E142.*

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SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

Edited by RICHARD S. WILLIAMS, Jr., *and* JANE G. FERRIGNO

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1386–E

Landsat images, in conjunction with other data, have been used to map the extent of glaciers, update glacier inventories, determine changes in mass balance, and produce runoff estimates for hydroelectric power production

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Foreword

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 now become an essential means for monitoring global change.

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 images. Such images provide a permanent historical record of the surface of our planet; they also make possible comparative two-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 current distribution of glaciers on our 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 image record of the 1970's.

Although many geological processes take centuries or even millenia to produce obvious changes on the Earth's surface, other geological phenomena, such as glaciers and volcanoes, cause noticeable changes over short'er periods. Some of these phenomena can have a worldwide impact and often are interrelated. Explosive volcanic eruptions 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, thereby causing 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 more wisely manage the use of our finite land and water resources. This Professional Paper 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.

Dallas L. Peck
Director,
U.S. Geological Survey

Preface

This chapter, consisting of six independently authored subchapters, including one subchapter, Glaciers of the Alps, that has four independently authored sections, is the fourth to be released in U.S. Geological Survey Professional Paper 1386, Satellite Image Atlas of Glaciers of the World, a series of 11 chapters. In each chapter, remotely sensed images, primarily from the Landsat 1, 2, and 3 series of spacecraft, are used to study the glacierized regions of our planet and monitor glacier changes. Landsat images, acquired primarily during the middle to late 1970's, were used by an international team of glaciologists and other scientists to study various geographic areas or discuss glaciological topics. In each geographic area the present areal distribution of glaciers was compared, where possible, with historical information about their past extent. The atlas provides an accurate regional inventory of the areal extent of glacier ice on our planet during the 1970's as part of a growing international scientific effort to measure global environmental change on the Earth's surface.

The Alps of Austria, Switzerland, France, and Italy have a total area covered by glaciers of 542, 1,342, 350, and 608 square kilometers, respectively. Landsat multispectral scanner (MSS) images have been used in this area to map the extent of snow and ice areas, update glacier inventories, correlate changes in snowline elevation to glacier mass balance, and with digital processing to monitor individual glaciers to calibrate snowmelt models used to produce runoff estimates for hydroelectric power production.

The 41 glaciers in the Pyrenees (Spain and France), covering a total area of 8.10 square kilometers, have all receded since the mid-19th century, although some minor advances took place in the late 1950's. The small-size of Pyrenean glaciers precludes the use of Landsat MSS images for monitoring glacier variations.

Norway has 1,627 glaciers that total 2,595 square kilometers in area; these glaciers, most commonly ice caps, outlet, cirque, and valley glaciers, have been receding since about 1750. Landsat images are used to evaluate suspended sediment in lakes and fjords and to monitor the transient snowline as a measure of approximate net mass balance.

Sweden has a total area of 314 square kilometers covered by glaciers, one of which (Storglaciären, in Swedish Lapland) is the subject of the longest continuous series of mass-balance measurements in the world, initiated in 1945-46. Landsat MSS images have only limited application because of spatial resolution considerations and the small size of Sweden's glaciers.

Svalbard, Norway, an archipelago in the North Atlantic Ocean, has more than 2,100 glaciers that cover 36,591 square kilometers, or 59 percent of the total area of the islands; Landsat images have been used to monitor fluctuations in the equilibrium line and glacier termini and to revise maps.

Jan Mayen, Norway, has 113 square kilometers, or 30 percent of its area, covered by an ice cap and the 20 named outlet glaciers that surmount the active Beerenberg stratovolcano. Satellite monitoring of fluctuations of outlet glaciers would be useful, but persistent cloud cover has limited the acquisition of cloud-free Landsat images.

Richard S. Williams, Jr.

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Editors

About this Volume

U.S. Geological Survey Professional Paper 1386, Satellite Image Atlas of Glaciers of the World, contains 11 chapters designated by the letters A through K. Chapter A is a general chapter containing introductory material and a discussion of the physical characteristics, classification, and global distribution of glaciers. The next nine chapters, B through J, are arranged geographically and present glaciological information from Landsat and other sources of data on each of the geographic areas. Chapter B covers Antarctica; Chapter C, Greenland; Chapter D, Iceland; Chapter E, Continental Europe (except for the European part of the former Soviet Union), including the Alps, the Pyrenees, Norway, Sweden, Svalbard (Norway), and Jan Mayen (Norway); Chapter F, Asia, including the European part of the former Soviet Union, China (P.R.C.), India, Nepal, Afghanistan, and Pakistan; Chapter G, Turkey, Iran, and Africa; Chapter H, Irian Jaya (Indonesia) and New Zealand; Chapter I, South America; and Chapter J, North America. The final chapter, K, is a topically oriented chapter that presents related glaciological topics.

The realization that one element of the Earth's cryosphere, its glaciers, was amenable to global inventorying and monitoring with Landsat images led to the decision, in late 1979, to prepare this Professional Paper, in which Landsat 1, 2, and 3 multispectral scanner (MSS) and Landsat 2 and 3 return beam vidicon (RBV) images would be used to inventory the areal occurrence of glacier ice on our planet within the boundaries of the spacecraft's coverage (between about 81° north and south latitudes). Through identification and analysis of optimum Landsat images of the glacierized areas of the Earth during the first decade of the Landsat era, a global benchmark could be established for determining the areal extent of glaciers during a relatively narrow time interval (1972 to 1982). This global "snapshot" of glacier extent could then be used for comparative analysis with previously published maps and aerial photographs and with new maps, satellite images, and aerial photographs to determine the areal fluctuation of glaciers in response to natural or culturally induced changes in the Earth's climate.

To accomplish this objective, the editors selected optimum Landsat images of each of the glacierized regions of our planet from the Landsat image data base at the EROS Data Center in Sioux Falls, S. Dak., although some images were also obtained from the Landsat image archives maintained by the Canada Centre for Remote Sensing, Ottawa, Ontario, Canada, and by the European Space Agency in Kiruna, Sweden, and Fucino, Italy. Between 1979 and 1981, these optimum images were distributed to an international team of more than 50 scientists who agreed to author a section of the Professional Paper concerning either a geographic area or a glaciological topic. In addition to analyzing images of a specific geographic area, each author was also asked to summarize up-to-date information about the glaciers within the area and to compare their present areal distribution with historical information (for example, from published maps, reports, and photographs) about their past extent. Completion of this atlas will provide an accurate regional inventory of the areal extent of glaciers on our planet during the 1970's.

Richard S. Williams, Jr.
Jane G. Ferrigno
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