GLACIERS OF NORTH AMERICA*–

*Excluding Alaska. The Glaciers of Alaska is a separate chapter, 1386–K, in this U.S. Geological Survey Professional Paper series

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–J

Landsat images, together with aerial photographs, selected maps, and other data, have been used to provide a baseline of mid-1970's glacierization in Canada, the conterminous United States, and México

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 2002

U.S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

Technical editing by Susan Tufts-Moore

Technical editing by John M. Watson

Design, layout, and illustrations by Kirsten E. Healey

Text review and typesetting by Janice G. Goodell

Layout review by Carolyn H. McQuaig

Library of Congress Cataloging in Publication Data

(Revised for vol. J)
Satellite image atlas of glaciers of the world.
(U.S. Geological Survey professional paper; 1386)
Includes bibliography.
Contents: — Ch. B. Antarctica, by Charles Swithinbank; with sections on The "dry valleys" of Victoria Land, by Trevor J. Chinn, [and] Landsat images of Antarctica, by Richard S. Williams, Jr., and Jane G. Ferrigno — Ch. C. Greenland, by Anker Weidick — Ch. E. Glaciers of Europe — Ch. G. Glaciers of the Middle East and Africa — Ch. H. Glaciers of Irian Jaya, Indonesia, and New Zealand — Ch. I. Glaciers of South America — Ch. J. Glaciers of North America
Supt. of Docs. no.: I 19.16:1386–J
1. Glaciers—Remote sensing. I. Williams, Richard S., Jr. II. Ferrigno, Jane G. III. Series.
GB2401.72.R42S28 1988 551.3'12 87-600497
ISBN 0–607–98290–X

For sale by the U.S. Geological Survey, Information Services
Box 25286, Federal Center,
Denver, CO 80225

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 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 satellite 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.

Charles G. Groat,
Director,
U.S. Geological Survey

Preface

This chapter is the seventh chapter 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 to 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 regions or to discuss glaciological topics. In each geographic region, the present areal distribution of glaciers is compared, wherever 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 chapter is divided into three parts: Glaciers of Canada (J–1), Glaciers of the Conterminous United States (J–2), and Glaciers of México (J–3). The Glaciers of Alaska is a separate chapter, Chapter 1386–K, of this series.

Glaciers in Canada are located in three principal geographic settings: on several Arctic islands in Nunavut and the Northwest Territories of northern Canada, in the Rocky Mountains and *Interior Ranges* of Alberta, British Columbia, Yukon Territory, and the Northwest Territories, and along the Pacific Coast, where they are sometimes contiguous with glaciers of Alaska. Glaciers are also situated in the Ungava Peninsula of northern Labrador, Newfoundland, and on Vancouver Island, British Columbia. The area covered by glaciers is estimated to be 151,000 km^2 on the Arctic Islands and 50,000 km^2 on the mainland, a total of 201,000 km^2 The types of glaciers in Canada include ice caps and ice fields and associated outlet glaciers, valley glaciers, mountain glaciers, glacierets, and rock glaciers. Landsat images are most useful in the study of large glaciers, ice caps and ice fields and associated outlet glaciers in Arctic Canada, and of ice fields, outlet glaciers, and valley glaciers in western Canada.

Glaciers in the conterminous United States are located in the States of Washington, Oregon, California, Montana, Wyoming, Colorado, Idaho, Utah, and Nevada. They have a total area of about 580 km^2. Only the first five states have glaciers large enough in area to be discernable on Landsat MSS images. Many of the volcanoes in the Cascade Range of the western United States are capped by glaciers, posing a significant hazard in the form of lahars and jökulhlaups in the river basins that originate on the flanks of these volcanoes. In Glacier National Park, Montana, the larger cirque glaciers have been reduced in area and volume during the past 150 years, a reduction rate that accelerated during the 20th century.

Glaciers in México are located on two active stratovolcanoes, Volcán Citlaltépetl (nine named glaciers) and Popocatépetl (three named glaciers), and one dormant stratovolcano, Iztaccíhuatl (12 named glaciers). The total glacier area in the middle 1960's was 11.44 km^2; all glaciers have been receding during the 20th century. Since 1993, intermittent volcanic activity of Popocatépetl has produced changes in its glaciers. The small area of México's glaciers limits the usefulness of Landsat MSS data; Landsat 3 RBV data, however, has sufficient spatial resolution to delineate glacier margins.

Richard S. Williams, Jr.
Jane G. Ferrigno
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 on the Earth's cryosphere, including a discussion of the physical characteristics, classification, and global distribution of glaciers. The next 10 chapters, B through K, 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 (excluding Alaska); and Chapter K, Alaska.

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 or baseline 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 in order 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 write 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
Editors