Satellite Glaciology of Iceland

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ABSTRACT

The glaciers of Iceland have been studied by scientists for nearly 200 years, and variations have been monitored for about 50 years. Although maps of the principal glaciers appeared in 1792 (Pálsson), 1844 (Gunnlaugsson), and 1901 (Thoroddsen), modern maps were not available until the Danish Geodetic Survey conducted plane-table surveys from 1904 until just before World War II. Several series of modern maps prepared by using aerial photogrammetric techniques, by the Defense Mapping Agency (U.S.) and/or the Icelandic Geodetic Survey, have been published since World War II. Aerial photographs of Iceland's glaciers were first acquired in the 1930's. Aerial photographs of most of Iceland have been acquired twice by the United States in 1944-45 and in 1956 and 1969-61. During this same period the Icelandic Geodetic Survey has also acquired aerial photographs of selected areas of Iceland.

Periodic monitoring of Iceland's glaciers, usually on an annual basis, was begun by Eythórsson in the 1930's. After his death, the annual measurement of glacier variation has been carried out by Rist. At the present time about 40 positions are measured annually, including the 34 International Hydrological Decade (IHD) index-numbered glacier margins. This represents about 12 percent of the total number of named and unnamed glaciers and outlet glaciers that could be monitored annually (total about 330).

For the past 10 years (1972-82) the Landsat series of satellites has been imaging Iceland's glaciers. Successive Landsat images acquired by U.S., Canadian, and Swedish receiving stations have provided new information about the glaciers of Iceland and have also provided a new way of monitoring changes in glacier area and changes in positions of glacier termini and margins of ice caps. Although satellite glaciology of Iceland is only in its infancy, the following studies have been completed by different scientists: glacier advance and recession (including surging glaciers), effect on the glacier surface of subglacial volcanic and geothermal activity, effect of jökulhlaups, glacier flow, ablation phenomena, and geomorphic, structural, and tectonic studies of the subglacial terrain. Landsat images have also been used to produce special image maps of Iceland's glaciers.

INTRODUCTION

Iceland abounds in dynamic geological phenomena which, for over 200 years, has attracted the attention of geologists. Special scientific emphasis have been directed at: (1) its geothermal areas (especially the occurence of hot springs and geysers), (2) its frequent volcanic activity and great diversity of volcanic landforms, and (3) its glaciers and the landforms produced by glacier action. It is Iceland's glaciers that are the subject of this paper, including a discussion of how the rapidly developing technology of satellite remote sensing is being used to provide a periodic and permanent record, in image form, of changes in the following physical characteristics of its glaciers: surface area, ice cap margins and glacier termini, and surface features caused by glacier flow or subglacial volcanic and geothermal acitivity.

OCCURRENCE OF GLACIERS

Glaciers in Iceland occur principally as ice caps or outlet glaciers from ice caps. Figure 1 is a sketch map showing the 13 principal ice caps of Iceland. According to published maps, books, and journal articles there are 33 separate glaciers (geographic place names of ice caps (not including outlet glaciers) and cirque glaciers where the suffix jökull occur) in Iceland. Most of these glacier names were listed by *Thorarinsson* (1943) in his discussion of the areas of Iceland's glaciers. From published maps, books, and journal articles, however, there are actually a total of 85 separately named outlet glaciers of the 13 individual ice caps out of a potential total of about 330 separate named and unnamed ice caps, outlet glaciers, and other types of glaciers (mostly cirque-type) which can be identified on maps of Iceland at a scale of 1:100,000 or smaller. The 13 major ice caps, all of whose areas exceed 20 km^2, are listed in Table 1.

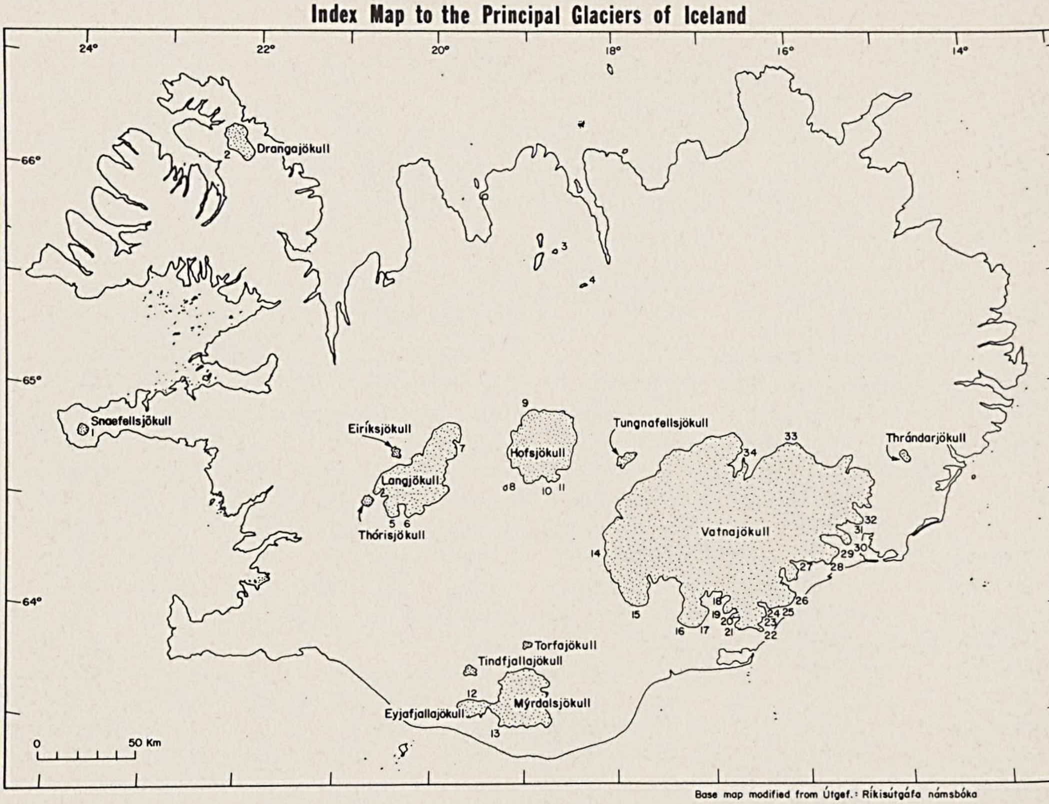

Fig. 1. Index map showing the 13 principal ice caps of Iceland and the 34 International Hydrological Decade (IHD) index numbers assigned by *Rist* (1967 and 1977) to the individual outlet glaciers (of 6 different ice caps) and cirque glaciers (3 different ones) monitored annually (see also Table 1).
Mynd 1. Þrettán helstu jöklar á Íslandi og 34 jökulsporðar þar sem hop og framskrið er mælt.

OBSERVATION OF GLACIERS

The glaciers of Iceland have been observed by Icelanders since the time of settlement about 874 A.D. *Thorarinsson* (1960) noted that *Sveinn Pálsson*, the Icelandic physician-naturalist and pioneer glaciologist, made many astute observations of the principal glaciers in Iceland in the late 18th century. *Pálsson's* original handwritten manuscript, including four sketch maps and 8 perspective drawings (1795), was translated *in toto* from Danish to Icelandic and published by *Eythórsson* in 1945.* *Thorvaldur Thoroddsen* was the next Icelander to extensively study and publish scientific reports on Iceland's glaciers (1892 and 1906). His 1892 paper was the first systematic attempt to determine areas and provide other scientific information about the glaciers of Iceland. *Thorarinsson* (1943) compiled a table of the areas of Iceland glaciers which was based on 1:50,000- and 1:100,000-scale, pre-World War II maps of the Danish Geodetic Institute and *Thoroddsen's* work. The systematic measurement of the annual variation of the position of outlet glaciers and ice cap margins was begun by the Icelandic

* An English translation of *Pálsson's* original work has recently been completed and is presently being edited by the author (*Williams*).

TABLE 1. Areas of the Principal Glaciers of Iceland (km²)
TAFLA 1. Flatarmál helstu jökla á Íslandi í km²

		A	B	C	D	E	F	G	H
IHD Index[1] Number	Glacier Name *Jökull*	*Bödvarsson*[2] (From *Gunnlaugsson* 1844) (unpub.)	*Bödvarsson*[3] (From *Thoroddsen* 1901) (unpub.)	*Thoroddsen*[4] 1906	*Thorarinsson*[5] 1943	*Thorarinsson*[6] 1958	*Williams*[7] (From Landsat images, unpub. and *Björnsson* 1980b)	*Björnsson*[8] (From Landsat images or aerial photos*) 1980b	Percentage[9] Decrease (E-ForG/E) in Area *Flatarmálsrýrnun* (G/E)×100
14–34 (outlet glaciers)	Vatnajökull	8940	8500	8500	8410	8538	8300	8300	−3.0%
5–7 (outlet glaciers)	Langjökull	1384	1400	1300	1021	1022	953	953	−7.0%
9–11 (outlet glaciers)	Hofsjökull	1570	1400	1350	987	996	925	925	−7.0%
12&13 (outlet glaciers)	Mýrdalsjökull	1100	1000	1000	685	701	596	596	−15.0%
	Eyjafjallajökull				101	107	77.5	77.5	−28.0%
2 (outlet glacier)	Drangajökull	708	340	350	204	199	–	160*	−19.6%
None	Tungnafellsjökull	115	170	100	50	50	–	48	−4.0%
None	Thórisjökull	Included in Langjökull			34.5	33	–	32	−3.0%
None	Thrándarjökull	84	112	100	27	27	–	22	−18.5%
None	Tindfjallajökull	38	35	25	26	27	–	19	−29.6%
None	Eiríksjökull	96	113	100	23.5	23	–	22	−4.3%
1 (outlet glacier)	Snæfellsjökull	43	28	20	22	22	–	11*	−50.0%
None	Torfajökull	140	112	100	27.5	21	–	15	−28.6%

1 – In Iceland, IHD (International Hydrological Decade) Index Numbers are assigned only to 34 individual outlet glaciers from 6 ice caps and to 3 cirque glaciers. Annual measurements are made of the variation in the position of the termini (or at points along the termini) of these outlet and cirque glaciers not areal measurements of the entire ice cap. Within the resolution limits of the satellite images used, satellite imagery can permit a frequent areal measurement of each ice cap to be made, thereby providing a measurement of dynamic changes within and at the margins of an entire ice cap, including its outlet glaciers (from *Rist* 1967 and 1977, and *Williams* 1979a).

2 – Unpublished area measurements by *Ágúst Bödvarsson,* former Director, Icelandic Geodetic Survey, from *Björn Gunnlaugsson's* 1844 map of Iceland (1:480,000)

3 – Unpublished area measurements by *Ágúst Bödvarsson,* former Director, Iceland Geodetic Survey, from *Thorvaldur Thoroddsen's* 1901 map (based on 1881–1898 field surveys)

4 – Thorvaldur Thoroddsen's area measurements of Iceland's glaciers were based on *Gunnlaugsson's* 1844 map and *Thoroddsen's* 1901 map (based on 1881–1898 field surveys)

5 – Based on Danish Geodetic Institute maps (surveyed in 1902–1938)

6 – Based on Danish Geodetic Institute maps, including post-World War II editions

7 – Area calculations made from 19 August 1973 (1392–12185; 1392–12191) and 22 September 1973 (1426–12070) Landsat images of Iceland (see also *Björnsson* 1980b)

8 – Area calculations made from 19 August 1973, 22 September 1973, 9 August 1978 (30157–11565–D) Landsat images, and 1960 arial photographs

9 – First five glaciers calculated by *Williams* (unpub.), remaining eight by *Björnsson* (1980b)

meteorologist-glaciologist, *Jón Eythórsson*, in the 1930's (*Eythórsson* 1949 and 1963). With the publication of *Jökull*, beginning in 1951, glacier variation data have been reported nearly every year since. After *Eythórsson's* death, *Sigurjón Rist*, the Icelandic hydrologist-glaciologist, assumed the responsibility for annual reports. In 1951, *Eythórsson* had reported on the position of 26 outlet glaciers or glacier margins of 8 different glaciers (*Eythórsson* 1951). In 1977, *Rist* reported on 40 of 61 monitored outlet glaciers or glacier margins of 11 different glaciers.

Although the annual monitoring of the position of 40 different glacier termini or ice cap margins represents a significant effort, it includes only about 12 percent of the 330 named individual glaciers and named and unnamed outlet glaciers of the various icecaps in Iceland which potentially could be monitored annually. It should also be noted that the current position measurements are "spot" measurements and represent only a "sample" of the overall state of Iceland's ice caps.

MAPS OF ICELAND'S GLACIERS

Pálsson's maps (1795) of Vatnajökull (Klofajökull) in 1794, Eyjafjallajökull (including Mýrdalsjökull) in 1795, Langjökull in 1792, and Hofsjökull (Arnarfellsjökull) in 1794 were the first attempt at the scientific mapping of Iceland's glaciers. *Thoroddsen's* "Geological Map of Iceland" (1901), which was based on field surveys (1881-98) and *Gunnlaugsson's* map (1844), portrayed nearly all of the glaciers of Iceland in their approximate geographic location. Both *Pálsson's* and *Thoroddsen's* maps of glaciers however, can really only be used in a qualitative sense (see Table 1). For example, *Pálsson* referred to present-day Ok (with a small glacier) as Okjökull, and *Thoroddsen* (1901 and 1906) mapped Glámujökull (230 km^2) on present-day Gláma (no present glacier).

The modern mapping of Iceland's glaciers was begun by the Danish Geodetic Survey in 1904, and the plane-table surveys continued until just before World War II, resulting in complete 1:250,000- and 1:100,000-scale maps and some 1:50,000-scale maps of Iceland. The U.S. Army Map service completed new 1:250,000- (Series C562) and 1:50,000-scale (Series C762) maps of Iceland after World War II, using aerial photogrammetric surveying techniques. The U.S. Defense Mapping Agency and the Icelandic Geodetic Survey are currently preparing a new series (C761) of 1:50,000-scale maps of Iceland. The Icelandic Geodetic Survey is currently preparing a 1:10,000-scale orthophotomap series. The Icelandic Geodetic Survey also publishes special-purpose maps at various scales, in addition to periodic revisions of the 1:100,000- and 1:250,000-scale Danish Geodetic Survey maps.

IMAGING OF ICELAND'S GLACIERS

Although aerial photographs of the glaciers of Iceland had been used by some scientists, such as *Iwan* (1935), who published oblique aerial photographs of glaciers taken from a Zeppelin, the Danish Geodetic Institute acquired the first aerial photographs of Iceland's glaciers in 1937 specifically for topographic mapping (*Norlund* 1938). Six oblique aerial photographs of Vatnajökull, taken by the Danish Geodetic Institute in June and August 1937 from 3600 m, were published by *Ahlmann* (1937).

In 1944 and 1945, the U.S. Army Air Force acquired vertical aerial photographs of most of Iceland. After World War II, the Icelandic Geodetic Survey assumed responsibility for acquisition of the vertical aerial photography of Iceland to support map revision needs and to support special map projects for other agencies (for example geothermal research, site planning for hydroelectric power projects, road construction, etc.). In 1956 and from 1959 to 1961 (Project 55-AM-3), the U.S. Air Force rephotographed most of Iceland to support a new 1:50,000-scale map series (Series C761).

There have been a number of miscellaneous aerial surveys of Iceland since 1960, mostly in support of special research projects. The U.S. Air Force, the U.S. Navy, and the National Aeronautics and Space Administration (NASA) all conducted limited aerial surveys in Iceland during the 1960's and 1970's.

Beginning in September 1972, the first in the Landsat series of satellites (three more were launched in 1975, 1978 and 1982, respectively), began to acquire Landsat images of Iceland, providing a new source of information about Iceland's glaciers. During 1973 the best images of the ice caps of Iceland were acquired, although a few excellent images have been acquired in recent years by Landsat receiving stations in Canada and Sweden. Landsats 1, 2 and 3 multispectral scanner (MSS) images have a maximum picture element (pixel) resolution of about 80 m; Landsats 1 and 2 return

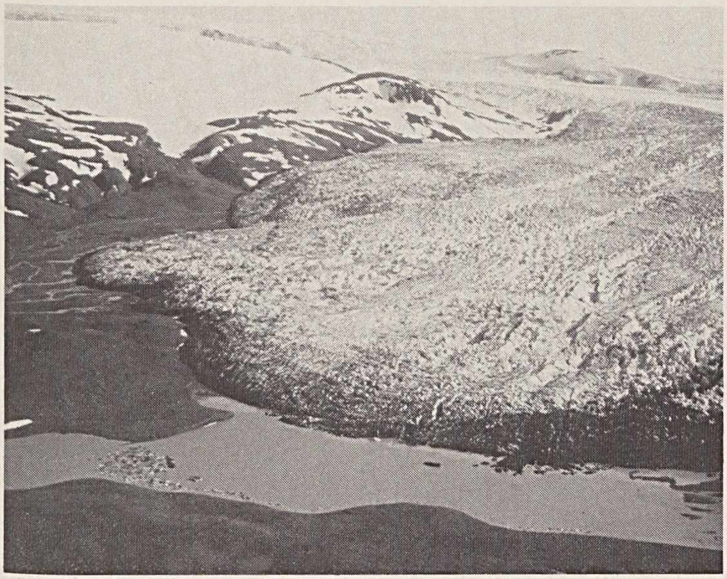

Fig. 2. Oblique aerial photograph looking south across the terminus of the surging glacier, Eyjabakkajökull, as it appeared on July 25, 1973, after it had completed a 2.8-km surge. Photograph by Richard S. Williams, Jr.
Mynd 2. Eyjabakkajökull í lok hlaups, 25. júlí 1973. Ljósm. R. S. Williams.

beam vidicon (RBV) images have a similar pixel resolution, but the Landsat 3 RBV image has a pixel resolution of about 30 m.

Aerial photographs and satellite images of glaciers are considerably more useful than conventional maps to glaciologists because: (1) they represent original source material; (2) they are acquired on a specific date at a specific time, important in studies of dynamics of glaciers; and (3) they portray considerable detail of areas peripheral to glaciers. Most maps lack those attributes needed for glaciological studies. In addition, aerial photographs of Icelandic glaciers, unlike Landsat images, can be used for stereoscopic analysis of glaciological features. Although aerial photographs provide considerable detail for most of the glaciers of Iceland, they are generally only available for 1944-45 and for 1959-60, the two times of comprehensive aerial surveys. Supplementary coverage is available of parts of some glaciers from subsequent aerial surveys by the Icelandic Geodetic Survey. Landsat images, however, are readily available to all scientists and provide a sequential (time-lapse) view of the glaciers of Iceland. The dynamic aspects of these glaciers can also be inferred from changes noted on successive Landsat images (within the resolution limitations of such images).

The limitation in using aerial photographs to produce a map of a large ice cap, such as Vatnajökull, is in the discontinuous nature of the source material. Nearly all existing maps of Vatnajökull are "composites" of a variety of source material and do not represent the entire ice cap as it was at a single time (except for the two U.S. Geological Survey Landsat image maps (1976 and 1977)). For an ice cap as dynamic as Vatnajökull, published line maps have serious deficiencies not only in the portrayal of the ice cap margins but in the depiction of proglacial lakes and surficial changes caused by subglacial volcanic and geothermal activity.

SATELLITE IMAGERY OF ICELAND

Three types of civilian satellite imagery currently exist of Iceland. The National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting weather satellites image Iceland daily with a maximum resolution of about 1 km, too coarse for most types of glaciological studies (*Williams et al.* 1974). During August 1978, The Seasat synthetic aperture radar (SAR) instrument imaged most of Iceland except for the south-west corner (*Ford et al.* 1980). It is the Landsat series of satellites, however, which has produced the most useful, albeit discontinuous, coverage of Iceland and its glaciers for the past 10 years, from 1972 to 1982.* (*Williams et al.* 1974; *Williams and Thorarinsson* 1974).

* *Gylfi Már Gudbergsson*, Department of Geosciences, University of Iceland, and the author (*Williams*) are presently compiling an „Index to Landsat Images of Iceland: 1972-82." The index will list images archived in the United States, Canada and Italy.

From analysis af Landsat images of Iceland the following types of glaciological phenomena have been observed on individual or successive paired images: (1) glacier advance and recession (including surging glaciers), (2) effect on the glacier surface of subglacial volcanic and geothermal activity, (3) variation in proglacial lakes, (4) effect of jökulhlaups, (5) glacier flow, and (6) ablation phenomena.

Glacier advance or recession has been noted on a number of sequential Landsat images during the past decade. Eyjabakkajökull, an outlet glacier in the northeastern part of Vatnajökull, began to surge in late August 1972, and had already surged about 1 km by the time of the acquisition of the first Landsat image of the area on October 14, 1972 (1083-12023) (*Williams et al* 1974). A September 22, 1973 image (1426-12070) showed additional movement of 1.8 km. Figure 2 is an oblique aerial photograph of Eyjabakkajökull as it appeared on July 25, 1973. Figure 3 is a Landsat 3 RBV image (30157-11565-D) of Eyjabakkajökull on August 9, 1978. The Landsat 3 RBV image has nearly three times better resolution than the MSS image and shows considerably more detail (*Williams* 1979, *Williams and Ferrigno* 1981). The advance, during the past several years of Hagafellsjökull eystri, an outlet glacier in southwestern Langjökull, can also be monitored on successive Landsat images. An image taken on September 27, 1981, (22440-12034), shows that the glacier has reentered Hagavatn and is now at approximately the same position as it was on aerial photographs taken on Project CJ20A by the U.S. Army Air Force on September 23, 1945 (Sortie 1234, Roll 1-1, frames 137 and 138). A comparison with the August 19, 1973 Landsat image (1392-12191) shows an advance of approximately 2 km across a 3-km-wide terminus during the past 8 years. *Crabtree* (1976) compared his field observations of Mýrdalsjökull with aerial photographs and

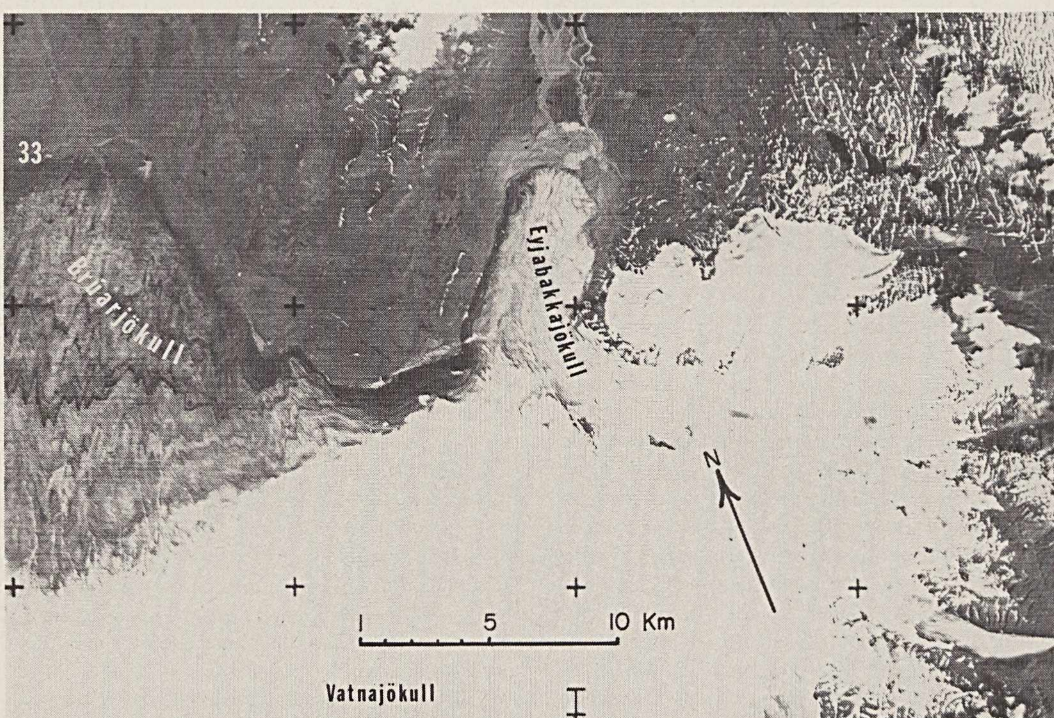

Fig. 3. Part of Landsat 3 RBV image 30157–11565–D, which was acquired on August 9, 1978. This Landsat 3 RBV image of the surging glacier Eyjabakkajökull indicates the amount of detail available on such images.
Mynd 3. Landsat-mynd frá 9. ágúst 1978.

three Landsat images (1392-12191; August 19, 1973; 1426-12070; September 22, 1973; and 1446-12180; October 12, 1973) to document advance and recession of the ice cap margin and termini of several outlet glaciers. He also used Landsat images to define the soaked zone from the percolation/dry snow zone of the accumulation zone facies and noted the ambiguity in determining exact position of the termini of outlet glaciers when covered with surface debris.

Subglacial volcanic and geothermal activity is manifested on Landsat images as collapse cauldrons of various diameters and related features. The January 31, 1973,image (1192-12084) and an enhanced September 22, 1973, image (1426-12064) of Vatnajökull have been analyzed for a number of investigations. An extension of geothermal activity south into Vatnajökull from Hveradalur in the Kverkfjöll area was discussed by *Thorarinsson et al.* (1974). Jökulhlaups on Skaftá are related to the two collapse cauldrons east of Hamarinn in western Vatnajökull (*Williams et al.*, 1974; *Thorarinsson et al.*, 1974; *Williams*, 1976). *Thorarinsson et al.* (1974) and *Björnsson* (1975) discussed a line of cauldrons north of Skeidarárjökull which are related to the March 1972 jökulhlaup from Grímsvötn. *Tómasson* (1975) published a map of the path of this jökulhlaup based on the Landsat image. *Rist* (1974), in his discussion of the August 1973 jökulhlaup from Graenalón, a glacier-dammed lake in southwestern Vatnajökull, used successive Landsat images to calculate a 175 Gl reduction in volume of Graenalón after the jökulhlaup.

Landsat images have also been used as substitutes for conventional line maps (*U.S. Geological Survey*, 1976 and 1977) and as illustrations for scientific articles: *Steinthórsson* (1978), in showing Bárdarbunga, an ice-core drilling site in northwestern Vatnajökull; and *Björnsson* (1980a), to illustrate his summary paper on the glaciers of Iceland. *Thorarinsson* (1974a) used a Landsat MSS color composite of Skeidarárjökull and environs as a dust-jacket cover and as an illustration in his historical review of Skeidarárhlaups and volcanic eruptions from Grímsvötn. He (*Thorarinsson* 1974b) also used the low sun angle image of Vatnajökull in his discussion of the morphology of Lakagígar and the móberg ridges southwest of Vatnajökull, *Sugden and John* (1976) in their textbook, *Glaciers and Landscape: A Geomorphological Approach* used a Landsat MSS color composite on the cover and two other black and white images of Iceland as illustrations in the text. The cover of *Science* (v. 207, no. 4434, February 29, 1980) showed a computer-enhanced image (1426-12070) of Vatnajökull. The cover of *Jökull* in 1978 (v. 28) carried a specially enhanced image (1392-12185) of Hofsjökull, showing the prominent subglacial volcanic landform in the southwestern quadrant of this ice cap. *Björnsson* (1978) used a Landsat image of Vatnajökull to show the traverse line of his radio-echosounding survey between Tungnárjökull and Grímsfjall and for comparison with the cross-section showing ice thickness and subglacier topography. *Hoppe* (1982) used the computer-enhanced image of Vatnajökull (1426-12070) in his discussion of studying the Earth from space.

Unenhanced and specially enhanced Landsat images have been used by various scientists for analysis of geomorphic, structural, and tectonic features concealed by Iceland's glaciers (*Williams et al.*, 1973; *Williams and Thorarinsson*, 1974; *Thorarinsson et al.*, 1974). *Williams et al.* (1977) discussed how the interpretability of the September 22, 1973, Landsat image of Vatnajökull could be markedly improved by computer-enhancement techniques with computer-compatible tapes (CCT's). *Soha et al.* (1976) had applied a similar technique to the same image of Vatnajökull to delineate reflectivity variations on the surface of Vatnajökull. These reflectivity variations were considered by *Williams et al.* (1979) to portray the accumulation zone – ablation zone facies (bare glacial ice, superposed ice, saturated snow or slush, and wet snow) on Vatnajökull. Delineation of the snowlines on Hofsjökull, Langjökull, Mýrdalsjökull, and Eyjafjallajökull was discussed by *Williams* (1976a). *Münzer* and *Bodechtel* (1980) used digital image processing techniques of CCT's to analyze the subglacial topography of and to map lineaments on Vatnajökull. *Bodechtel et al.* (1979) compared Landsat and Seasat synthetic aperture radar (SAR) images of Iceland, including its glaciers, in their analysis of morphologic and tectonic features. Hunting Surveys Ltd. constructed a 1:500,000 - scale Seasat-1 radar mosaic of most of Iceland which delineates the glaciers of Iceland (*Hunting Geology and Geophysics, Ltd.* n.d.).

Contorted medial moraines or tephra layers in Skeidarárjökull visible on successive Landsat images have been used to calculate the speed of flow of this outlet glacier east of Graenalón. During an 11-month interval, between October 14, 1972 (1083-12023) and September 22, 1973 (1426-

12070), about 600 m of displacement had occurred (*Williams et al.,* 1974 and 1975).

Area calculations from Landsat images for Iceland's glaciers have been carried out by *Williams et al.,* (1975), and *Björnsson* (1980b). *Björnsson* (1980b) included some unpublished data of *Williams*, added his own calculations, compared the results with *Thorarinsssson's* previous area calculations (1958), and showed the percentage decrease in area for each of the principal glaciers of Iceland. Table 1 summarizes excerpts from the work of many scientists who have calculated the area of Iceland's glaciers from published maps, aerial photographs, and Landsat images.

REFERENCES

Ahlmann, H.W., 1937: Vatnajökull in relation to other present day Iceland glaciers. Geografiska Annaler 19 (3-4): 212-231.

Björnsson, H., 1975: Explanation of jökulhlaups from Grímsvötn, Vatnajökull, Iceland. Jökull 24: 1-26.

Björnsson, H., 1978: Könnun á jöklum med rafsegulbylgjum. Náttúrufraedingurinn 47 (3-4): 184-194. (In Icelandic).

Björnsson, H., 1980a: Glaciers in Iceland. Jökull 29: 74-80.

Björnsson, H., 1980b: The surface area of glaciers in Iceland. Jökull 28: 31.

Bodechtel, J., K. *Hiller* and U. *Münzer,* 1979: Comparison of Seasat and Landsat data of Iceland for qualitative geologic applications. In Proceedings of the Seasat-SAR Processor Workshop, Frascati, Italy (10-14 December 1979). pp. 61-67.

Crabtree, R.D., 1976: Changes in the Mýrdalsjökull ice cap, south Iceland: Possible uses of satellite imagery. Polar Record, 18 (112): 73-76.

Eythórsson, J., 1945: Jöklaritid. J. Eythórsson (Ed.) Ferðabók Sveins Pálssonar. Prentsmiðjan Oddi, Reykjavík. pp. 423-552. (In Icelandic).

Eythórsson, J., 1949: Variations of glaciers of Iceland, 1930-1947. Journal of Glaciology, 1 (5): 250-252.

Eythórsson, J., 1951: Jöklamaelingar 1950 og 1951. Jökull 1: 16. (In Icelandic).

Eythórsson, J., 1963: Variations of Iceland glaciers 1931-1960. Jökull 13: 31-33.

Ford, J.P., R.G. *Blom,* M.L. *Bryan,* M.I. *Daily,* T.H. *Dixon,* C. *Elachi,* and E.C. *Xenos,* 1980: Seasat views North America, the Caribbean, and Western Europe with imaging radar. California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California, JPL Publication 80-67 (1 November 1980), 141 pp.

Gunnlaugsson, Björn, 1844: Uppdráttr Íslands, gjörðr að fyrirsögn Ólafs Nikolas Ólsens eptir landmælingum Bjarna Gunnlaugssonar, er styðjast við Þríhyrningamál og strandamælingar þær, sem hið Konúngliga Rentukammer hefir látið gjöra og reiknað hefur Hans Jakob Scheel. Gefinn út af enu Íslenska Bókmentafélagi, Reykjavík og Kaupmannahöfn. 1:480,000. (In Icelandic).

Hoppe, G., 1982: Jordan från rymden. In: R. *Edberg* (Ed.), Här är vi hemma. Bokförlaget Bra Böcker, Höganäs, pp. 186-201. (In Swedish).

Hunting Geology and Geophysics, Ltd. (undated): Seasat-1 radar mosaic (of) Iceland. 1:500,000-scale mosaic constructed by Hunting Surveys, Ltd., Borehamwood, Hertfordshire, England, for the Royal Aircraft Establishment (European Space Agency – Earthnet), from Seasat SAR data acquired by the Royal Aircraft Establishment receiving station, Oakhanger, England. Survey mode optical correlation of the SAR data by the Environmental Research Institute of Michigan.

Iwan, W., 1935: Island. Studien zu einer Landeskunde. Berlinger Geographische Arbeiten, Herausgegeben vom Geographischen Institut der Universitat Berlin, No. 7, Kommissionsverlag von J. Englehorns Nachf., Stuttgart, 155 pp. (In German).

Münzer, U. and J. *Bodechtel,* 1980: Digitale Verarbeitung von Landsat-Daten über Eis-und Schneegebieten des Vatnajökulls (Island). Bildmessung und Luftbildwesen 48: 21-28. (In German)

Norlund, N.E., 1938: Denmark. Photogrammetric Engineering 4(31): 119-120.

Pálsson, S., 1795 (unpub.): Forsög til en physisk, geographisk og historisk Beskrivelse over de islandske Isbjorge i Anledning af en Reise til de fornemste deraf i Aarene 1792-1794 med 4 Situations – og Prospect – Tegninger. „Om isbjerge 1792 – 1794". Landsbókasafn Íslands, JS 26 fol., Reykjavík, 133 pp. (In Danish).

Rist, S., 1967: Jöklabreytingar 1964/65, 1965/66 og 1966/67. Jökull 17: 321-325. (In Icelandic).

Rist, S., 1974: Jökulhlaupaannáll 1971, 1972 og 1973. Jökull 23: 55-60. (In Icelandic).

Rist, S., 1977: Jöklabreytingar 1964/65 – 1973/74 (10 ár), 1974/75 og 1975/76. Jökull 26: 69-74. (In Icelandic).

Soha, J.M., A.R. *Gillespie,* M.J. *Abrams* and D.P. *Madura,* 1976: Computer techniques for geological applications. Proceeding of the Caltech/ JPL Conference on Image Processing Technology, Data Sources and Software for Commercial and Scientific Applications, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California (3-5 November 1976), pp. 4-1 – 4-21.

Steinthórsson, S., 1978: Tephra layers in a drill core from the Vatnajökull ice cap. Jökull 27: 2-27.

Sugden, D.E., and B.S. *John,* 1976: Glaciers and landscape. A geomorphological approach. John Wiley and Sons, New York, 376 pp.

Thorarinsson, S., 1943: Oscillations of the Iceland glaciers in the last 250 years. Geografiska Annaler 25 (1-2): 1-54.

Thorarinsson, S., 1958: Flatarmál nokkurra íslenzkra jökla samkvaemt herforingjarádskortunum. Jökull 8:25. (In Icelandic).

Thorarinsson, S., 1960: Glaciological knowledge in Iceland before 1800. A historical outline. Jökull 10: 1-17.

Thorarinsson, S., 1974a: Vötnin stríð. Saga Skeiðarárhlaupa og Grímsvatnagosa. Bókaútgáfa Menningarsjóðs, Reykjavík, 254 pp. (In Icelandic).

Thorarinsson, S., 1974b: On the topography of the volcanic zones in Iceland. In: L. *Kristjánsson* (Ed.) Geodynamics of Iceland and the North Atlantic Area. D. Reidel Publishing Co., Dordrecht, pp. 203-205.

Thorarinsson, S., K. *Saemundsson,* and R.S. *Williams, Jr.,* 1974: ERTS-1 image of Vatnajökull: Analysis of glaciological, structural, and volcanic features. Jökull 23: 7-17.

Thoroddsen, Th. 1982: Islands Jøkler i Fortid og Nutid. Geografisk Tidsskrift 11 (5-6): 111-146.

Thoroddsen, Th., 1901: Geological map of Iceland. Surveyed in the years 1881 – 1898, Edited by the Carlsberg Fund: Scale 1:600,000, 2 sheets.

Thoroddsen, Th., 1906: Die Gletscher Islands. Island, Grundriss der Geographie und Geologie. Petermanns Geographische Mitteilungen. 152/ 153: 163-208.

Tómasson, H., 1975: Grímsvatnahlaup 1972, merchanism and sediment discharge. Jökull 24:27–39.

U.S. Geological Survey, 1976: Vatnajökull, Iceland, (Fall Scene). Landsat Image Format series, N6359WO1723, Experimental Printing, 1:500,000-scale, U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey, 1977: Vatnajökull, Iceland (Winter Scene). Landsat Image Format Series, N6359WO1723, Experimental Printing, 1:500,000-scale, U.S. Geological Survey, Reston, Virginia.

Williams, R.S., Jr., 1976a: Dynamic environmental phenomena in southwestern Iceland. U.S. Geological Survey Professional Paper 929: 109-112.

Williams, R.S., Jr., 1976b: Vatnajökull icecap, Iceland. U.S. Geological Survey Professional Paper 929: 188-193.

Williams,, R.S., Jr., 1979a: Iceland – satellite monitoring of changes of glaciers of Iceland. In: R. *Vivien* (Ed.). Glaciological Field Stations, pt. 1; *Glaciological Data,* Rpt. GD-4, World Data Center A for Glaciology (Snow and Ice), Boulder, Colorado, February, pp. 72-77.

Williams, R.S., Jr., 1979b: Regional geologic mapping using Landsat 3 return beam vidicon images: Examples from Iceland and Cape Cod, Massachusetts (abs.). Abstracts with Programs, 1979 Annual Meetings, Geological Society of America, Boulder, Colorado. 11 (7): 541.

Williams, R.S., Jr., and S. *Thorarinsson,* 1974: ERTS-1 image of Vatnajökull area: General comments. Jökull 23: 1-6.

Williams, R.S., Jr., and J.G. *Ferrigno,* 1981: Satellite image atlas of the Earth's glaciers. In: M. *Deutsch,* D.R. *Wiesnet,* and A. *Rango* (Eds.) Satellite Hydrology. Proceeding of the Fifth Annual Wm. T. Pecora Memorial Symposium of Remote sensing, Sioux Falls, South Dakota (10-15 June 1979), American Water Resources Association, Minneapolis, Minnesota, pp. 173-182.

Williams, R.S., Jr., S. *Thorarinsson,* and K. *Saemundsson,* 1973: Vatnajökull area, Iceland: New volcanic and structural features on ERTS-1 imagery (abs.). Abstracts with Programs, 1973 Annual Meetings, Geological Society of America, Boulder, Colorado. 5(7): 864-865.

Williams, R.S., Jr., Á. *Bödvarsson,* S. *Fridriksson,* G. *Pálmason,* S. *Rist,* H. *Sigtryggsson,* K. *Saemundsson,* S. *Thorarinsson,* and I. *Thorsteinsson,* 1974: Environmental studies of Iceland with ERTS-1 imagery. Proceedings of the Ninth Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan. 1: 31-81.

Williams, R.S., Jr., A. *Bödvarsson,* S. *Rist,* K. *Saemundsson* and S. *Thorarinsson,* 1975: Glaciological studies in Iceland with ERTS-1 imagery (abs.). Journal of Glaciology. 15 (73): 465-466.

Williams, R.S., Jr., T.N. *Mecklenburg*, M.J. *Abrams* and B. *Gudmundsson*, 1977: Conventional vs. computer-enhanced Landsat image maps of Vatnajökull, Iceland (abs.). Abstracts with Programs, 1977 Annual Meetings, Geological Society of America, Boulder, Colorado. 9(7): 1228-1229.

Williams, R.S., Jr., S. *Thorarinsson*, H. *Björnsson*, and B. *Gudmundsson*, 1979: Dynamics of Icelandic ice caps and glaciers. Journal of Glaciology 24 (90): 505-507.

JÖKLAR ÍSLANDS KANNAÐIR ÚR GERVITUNGLUM

R.S. WILLIAMS, JR.
Jarðfræðastofnun Bandaríkjanna

Á sl. 10 árum hafa hin svonefndu Landsat gervitungl (nr. 1, 2 og 3) náð allmörgum myndum af Íslandi, sem komið hafa að gagni við jöklarannsóknir. Með þessum myndum má á fljótvirkan hátt fá samtímis yfirsýn yfir stór svæði, sem áður tók mörg ár með venjulegri kortagerð og könnun á landi. Flatarmál jökla hefur nú verið mælt af gervitunglamyndum og í 1. töflu eru niðurstöður birtar og bornar saman við gamlar tölur af korti Björns Gunnlaugssonar frá 1844, Þorvalds Thoroddsens (1901—1906), dönsku herforingjaráðskortin og fleiri gögn. Af öðrum upplýsingum sem fengist hafa af gervitunglamyndum má nefna gögn um framskrið jökla, t.d. Eyjabakkajökuls 1972 (3. mynd) og Hagafellsjökla 1981, um sigkatlana norðvestan við Grímsvötn, sem veita vatni í Skaftá, og um hæð snælínu þegar mynd er tekin. Á myndunum má einnig sjá móta fyrir landslagi undir jöklunum og því koma þær að góðum notum við könnun á eldstöðvum og jarðhitasvæðum undir jökli, auk rannsókna á gerð jarðskorpu sem hulin er ís (struktur og tektonik).