Glaciers of Europe—

GLACIERS OF JAN MAYEN, NORWAY

By OLAV ORHEIM

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

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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

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By **OLAV ORHEIM**[1]

Abstract

Jan Mayen, Norway, the northernmost island on the Mid-Atlantic Ridge, has 113 square kilometers covered by glaciers, about 30 percent of its total area. The northern part of the island is the active Beerenberg stratovolcano (2,277 meters high), which is surmounted by an ice cap from which 20 outlet glaciers emanate. Sørbreen is the largest (15 square kilometers) and the best studied of these outlet glaciers. The maximum postglacial expansion of the outlet glaciers occurred at the end of the "Little Ice Age" (around the year 1850), and an oscillating retreat has taken place since that time. A marked advance around 1910 and again in 1960 was separated by a recession that ended about 1950. The 1960 advance was caused by reduced summer temperatures and ablation. The earliest recorded observations of Søbreen were in 1632, but the first modern topographic map was not published until 1959. This map was compiled photogrammetrically from aerial photographs taken in 1949 and 1955. The glaciers on Jan Mayen are especially sensitive to change in climate. Satellite monitoring of the variations of glacier positions on this isolated island has the potential to be a valuable tool but has been limited because the cloud cover is persistent.

Introduction

Jan Mayen, Norway, is the most northerly island on the Mid-Atlantic Ridge. It extends from 70°50' to 71°10' N. lat and from 7°55' to 9°05' W. long (fig. 1). The island covers an area of 373 km^2 and has very different landscapes on the north (Nord-Jan) and south (Syd-Jan): Nord-Jan is dominated by the volcano Beerenberg, 2,277 m in elevation; narrow Syd-Jan, stretching southwest, has a maximum elevation of 769 m on Rudolftoppen (figs. 1 and 2). Jan Mayen lies in the boundary between the cold East Greenland Current and the warmer north flowing Atlantic currents in the Norwegian Sea. The island is surrounded by pack ice during winter and spring, although the ice retreats west of the island during the summer (Vinje, 1976). Meteorological observations, begun in 1922, show that the island has a cool oceanic climate, is generally cloud covered, has a mean (1951–80) annual temperature near sea level of −1.2 °C and a mean (1963–80) yearly precipitation at the present meteorological station on Syd-Jan southwest of Sarlaguna of 685 mm (Steffensen, 1982). Barr (1991) recently reviewed its history.

The island consists of basaltic rocks of relatively young age (Fitch and others, 1965; Imsland, 1978, 1980). Glacial geologic studies by Hisdal (oral commun., 1985) show that the island has been covered by glaciers during several phases of the Weichselian (Wisconsinan). The most recent episode probably terminated before 9,000 yr ago. Considerable volcanic activity has taken place subsequently, and nearly 20 percent of the area is covered by postglacial lavas (Noe-Nygaard, 1974; Imsland, 1978; Hisdal, oral commun., 1985). The most recent effusive eruptions

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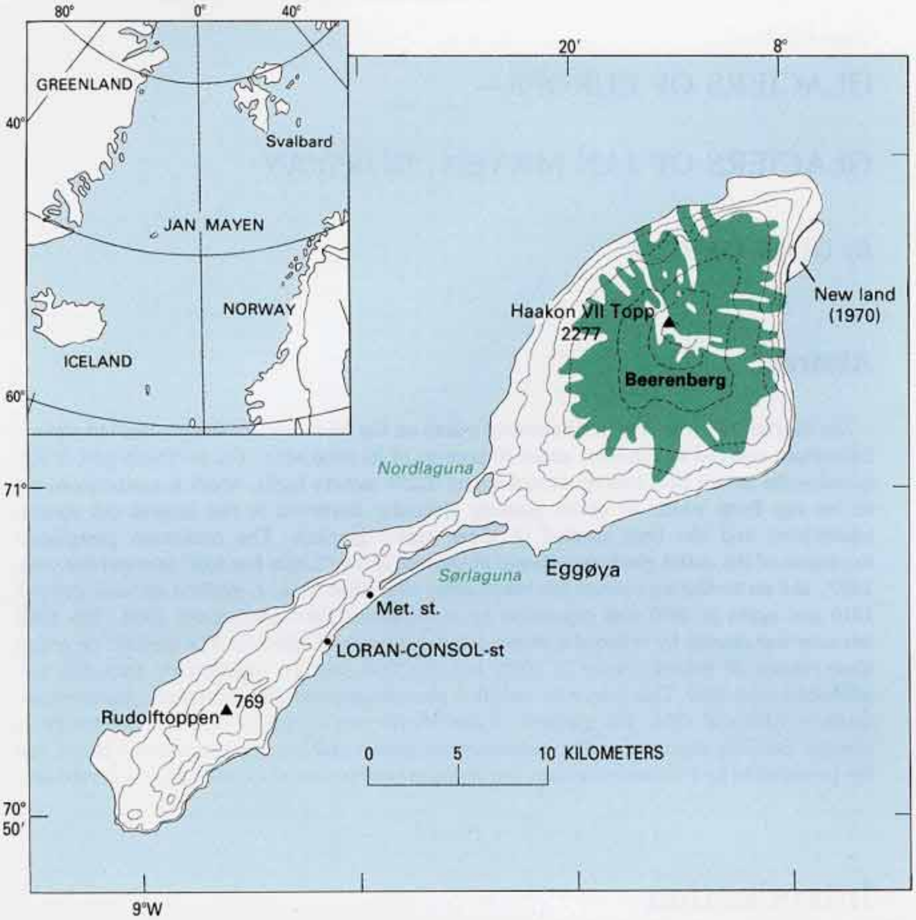

Figure 1.—*Index map of Jan Mayen. The wide, northeastern end of the island is called Nord-Jan; the narrow southeastern end is called Syd-Jan. "New land" refers to the land created by effusive volcanic activity from Beerenberg in 1970. Elevations are shown in meters (from Siggerud, 1972).*

Figure 2.—*Jan Mayen viewed from the southwest on 23 August 1949. The southernmost part (foreground) is obscured by clouds. The Beerenberg Volcano can be seen in the background. Oblique aerial photograph No. JM49 0865 from Norsk Polarinstitutt, Oslo.*

occurred in September 1970 (Siggerud, 1972; Sylvester and others, 1974; Sylvester, 1976), and on 6–9 January 1985 (Smithsonian Institution, 1984, 1985) on the northeastern side of Beerenberg (Imsland, 1985). According to Sylvester (1976), the September 1970 lava flows created about 4 km^2 of new land on the northeastern part of the island (figs. 1 and 3). Lava flows also entered the sea during the January 1985 activity (fig. 3), and a steam vent formed on the northern edge of the summit crater and produced a collapse cauldron in the upper part of Weyprechtbreen (figs. 4 and 5) (Smithsonian Institution, 1985).

Nord-Jan's glaciers, some extending to sea level, have a combined area of 113 km^2, about 30 percent of the island's area. Several of the glaciers have a very uneven surface topography. The marginal regions are often covered by supraglacial material; large parts of the ablation area are covered on some of the glaciers. There are no glaciers on Syd-Jan. Here the highest mountain (Rudolftoppen) reaches 769 m elevation, or 1,508 m less than the summit of Beerenberg (Haakon VII Topp).

There have been two postglacial periods of glacier expansion at Jan Mayen (Anda and others, 1985). The first period may have taken place around 2,500 yr ago. The glaciers had their maximum extent during the second period, around the year 1850, toward the end of the so-called "Little Ice Age." They have subsequently shown an oscillating retreat, with marked expansion around 1910, and with a minimum extent around 1950. Many glaciers advanced again about 1960, and the advance of Sørbreen probably culminated about 1965.

Anda and others (1985) concluded that the advances of the glaciers around 1960 were caused by reduced summer temperatures and ablation and *not* by increased precipitation, as reported by Lamb and others (1962), Fitch and others (1962), and Sheard (1965).

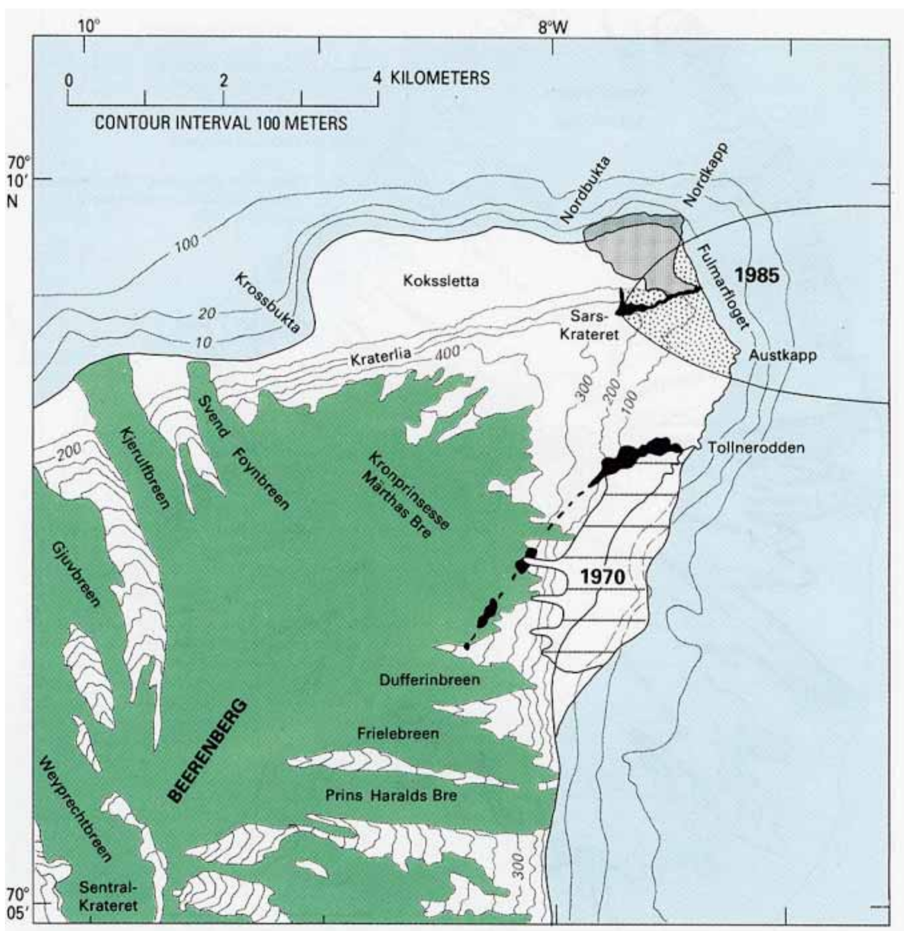

Figure 3.–Craters (solid black areas), effusive lava flows (lined, 1970; and shaded, 1985), tephra deposits (stippled, 1985), and tephra fallout pattern (parabola) associated with recent volcanic activity on Beerenberg. Note line of craters across eastern margin of Kronprinsesse Märthas Bre. Contours are in meters. Map modified from Imsland (1985).

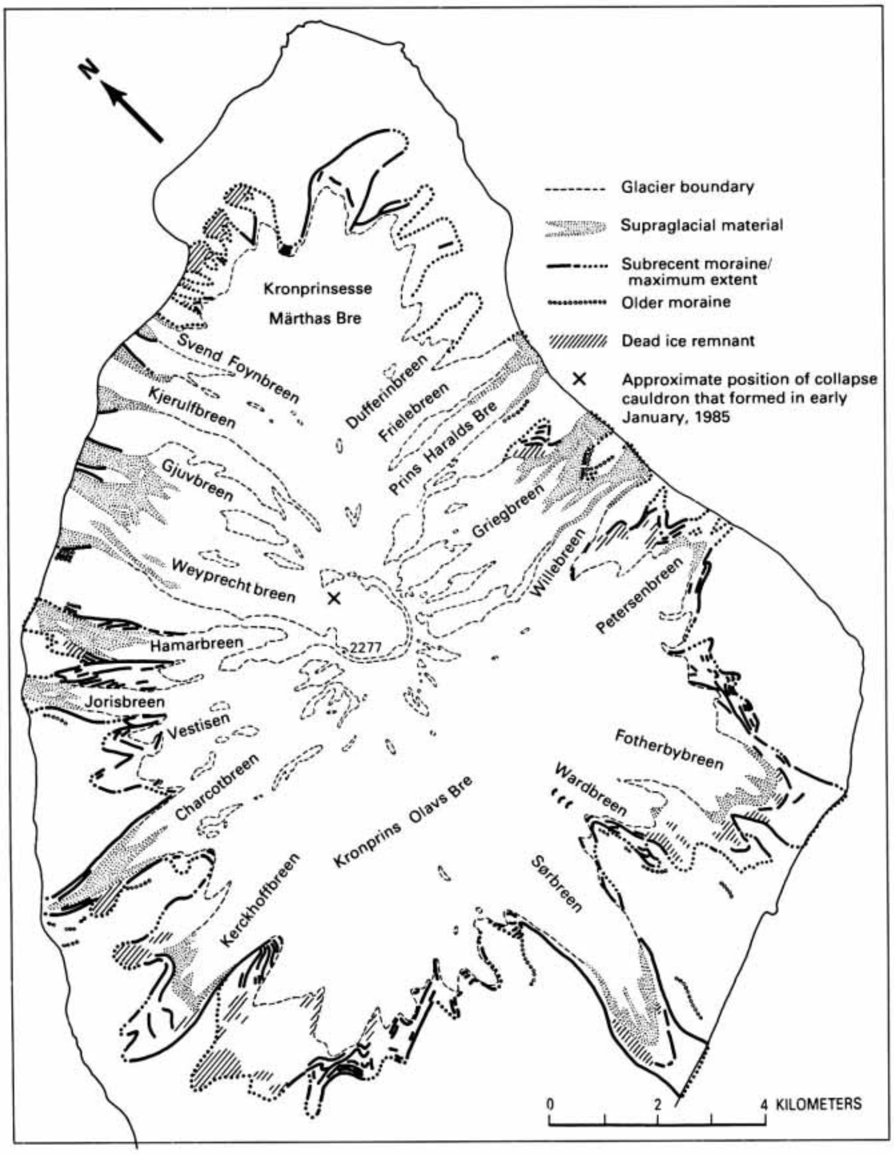

Figure 4.– *Steam billowing from the new vent (collapse cauldron) that formed on the upper part of Weyprechtbreen on the northern part of the summit crater of Beerenberg Volcano on 7 April 1985. Photograph from Norsk Polarinstitutt, courtesy of Lindsay McClelland (Smithsonian Institution, 1985).*

◀ ***Figure 5.***–*The glaciers on Nord-Jan showing locations of moraine stages, dead (stagnant)-ice remnants, and supraglacial material.*

Glacier Distribution and Mass-balance Conditions

The ice cap on Beerenberg Volcano can be divided into 20 individual outlet glaciers. These are shown in figure 5, and their individual areas, lengths, and elevations are listed in table 1. The glaciers are steep, typically covering elevation intervals of about 2,000 m over lengths of 5 to 7 km. Table 1 also shows that the elevation of the equilibrium line varies from 600 to 950 m, from the northwest-facing to the south-facing glaciers, probably caused mainly by variations in winter accumulation (Anda and others, 1985). This precipitation comes mostly from the orographic influence of north-northwesterly winds (Steffensen, 1982), giving the heaviest accumulation on the windward side of Jan Mayen.

Sørbreen (fig. 61, the largest glacier, has an area of 15 km^2 and is by far the best studied glacier on the island. Mass-balance measurements are available for the lower half of Sørbreen, up to 1,100 m (Orheim, 1976; Anda, 1984). It seems likely that the upper part of the glacier has no true summer season and that practically all precipitation here is in solid form. Over the lower part of the glacier, however, the temperature fluctuations may cause large variations in the percentage of precipitation that falls in frozen form. The studies at Sørbreen show that the winter balance is around 1 to 2 m water equivalent but that there are large local variations caused by wind drift and uneven surface topography (fig. 7). Convection and condensation account for most of the heat transfer to the surface in the ablation season, and there appears to be a good correlation between summer temperature at sea level and the ablation of the glacier. This correlation is, however, complicated by the temperature distribution over the glaciers of Jan Mayen, with frequent temperature inversions in the lower altitudes. Dibben (1965) showed that surface ablation is highest

TABLE 1. –*Size, elevation, and orientation of the glaciers on Jan Mayen, Norway*

[Eql, equilibrium line, defined as the boundary between the accumulation area (positive net mass balance) and the ablation area (negative net mass balance)]

Glacier name	Area (km^2)	Length (km)	Elevation (m)				Orientation
			Maximum	Median	Minimum	Eql	
Sørbreen	15.00	8.7	2,200	940	80	950	S.
Southwest part of Kronprins Olavs Bre	11.40	7.4	2,240	860	440	900	SW.
Kerckhoffbreen	9.00	7.3	2,200	860	280	850	W.
Charcotbreen	5.55	6.9	2,240	880	40	800	W.
Vestisen	2.30	3.4	1,500	860	540	800	W.
Jorisbreen	3.30	6.0	2,260	980	20	750	NW.
Hamarbreen	2.25	4.7	1,580	720	10	700	NW.
Weyprechtbreen	8.90	6.8	2,080	800	0	650	NW.
Gjuvbreen	2.80	5.3	2,100	660	0	600	NW.
Kjerulfbreen	5.80	6.4	2,140	900	0	650	N.
Svend Foynbreen	2.60	4.6	1,400	800	0	700	N.
Kronprinsesse Märthas Bre	9.40	4.7	1,320	710	420	750	NE.
Dufferinbreen	1.55	3.7	1,500	920	400	800	E.
Frielebreen	2.80	5.0	1,660	780	0	750	E.
Prins Haralds Bre	3.50	5.3	2,200	980	0	750	E.
Griegbreen	4.95	5.1	2,160	830	10	800	E.
Willebreen	5.50	5.9	2,160	900	0	850	E.
Petersenbreen	5.35	5.5	1,620	820	230	900	SE.
Fotherbybreen	9.00	7.2	2,140	820	300	900	SE.
Wardbreen	3.25	5.7	2,200	1,010	550	950	S.

***Figure* 6.**–*Sørbreen on Nord-Jan viewed from the southeast on 23 August 1949. The summit of the Beerenberg Volcano (2,277 m) is visible on the right. Oblique aerial photograph No. JM49 0777 from Norsk Polarinstitutt, Oslo.*

◀ ***Figure 7.***–*Sørbreen viewed from above 600 m in elevation on 24 August 1973. Note the uneven topography. The summit of the Beerenberg Volcano is in the background. Oblique aerial photograph by Olav Orheim, Norsk Polarinstitutt, Oslo.*

during frontal activity (passage of warm fronts associated with low-pressure systems). Measurements by Orheim (1976) and Anda (1984) show that ablation increases with elevation over the lower parts of Sørbreen, because long-lasting advection fog reduces both incoming radiation and temperatures over the lowest section. This phenomenon is probably less important on the northwest glaciers. Calving is an important ablation mechanism for some of the glaciers around the northern sector of Nord-Jan (fig. 8).

Figure 8.—*Beerenberg viewed from the northwest on 23 August 1949. Weyprecht-breen, the outlet glacier that emanates from a breach in the summit crater, has the largest calving front of all the Jan Mayen glaciers. Oblique aerial photograph No. JM49 08 1 1 from Norsk Polarinstitutt, Oslo.*

Historical Variations in Positions of Glacier Termini

The variations of glaciers on Jan Mayen can best be established from Sørbreen, which has been visited frequently. Maps and descriptions from 1632 (Blaeu, 1662) and from 1817–18 (Scoresby, 1820) indicate that the glacier did not reach the sea during these periods. However, these descriptions cannot be considered wholly reliable.

Sørbreen was near its maximum "Little Ice Age" extent during 1861 (Vogt, 1863). A detailed sketch shows the glacier reaching the sea; the glacier surface is depicted as nearly level with high lateral moraines. A second sketch shows that Sigurdbreen and Smithbreen also were near their maximum subrecent extents. Sørbreen also terminated in the sea in 1878 (Mohn, 1878, 1882), but the elevation of the glacier surface cannot be estimated from this source.

A map of the island and a description of several glaciers were made by the Austrian expedition in 1882-83 (Bóbrik von Boldva, 1886). The front of Sørbreen had retreated from the sea, and 80 m from the sea the glacier surface disappeared under morainal material. The glacier surface was 30 m below the uppermost level (150 m) of the lateral moraines.

Flint (1948) described Sørbreen from a brief visit in 1937. The front was then about 600 m from the sea. The following year Jennings (1939, 1948) stated that the glacier front was 960 m from the sea. Comparison of the sketch maps made by Flint and Jennings suggests that the latter misinterpreted the boundary of moraine-covered ice as the glacier front. Norsk Polarinstitutt prepared a topographic map of Jan Mayen in 1959, based on aerial photographs taken during 1949 and 1955. The glaciers were mapped photogrammetrically from the 1949 aerial photographs. Sørbreen was, at this time, 1,200 m from the sea, which is the greatest recorded retreat of the glacier. Many other glaciers also had their greatest retreats at this time.

University of London expeditions made extensive studies of Sørbreen in 1959 and 1961 (Fitch and others, 1962; Kinsman and Sheard, 1963). The glacier advanced 100 m between 1949 and 1959, and the glacier advanced an additional 124 m during the following 2 years. They also observed that several other glaciers had advanced since 1949.

Aerial photographs acquired in 1975 by the Norsk Polarinstitutt showed that Sørbreen had advanced farther since 1961. The front part of the glacier now seemed to be stagnant, and the glacier front had probably been in the same position for several years. This situation persisted until 1978. The marked advance around 1960 probably culminated by 1965.

Anda and others (1985) constructed a lichenometric growth curve for Jan Mayen and used this to obtain additional ages for the moraines of Sørbreen and neighboring glaciers.

The results of these observations are shown in figures 9 and 10. It is clear that Sørbreen is sensitive to climatic change, and the observations suggest the variations of Sørbreen will be representative of the other south- and east-facing glaciers around Nord-Jan. However, more data are needed to give more confidence to this conclusion.

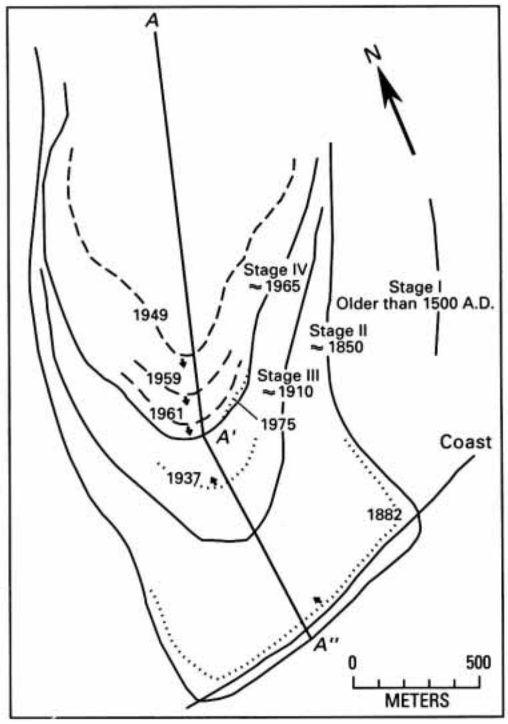

__Figure__ 9.-- The frontal position of Sørbreen on different dates. The solid lines indicate culmination of advances, dashed lines an intermediate position during an advance, and dotted lines an intermediate position during retreat. The arrows indicate whether the glacier is advancing or retreating. Section A–A'–A'' is shown in figure 10.

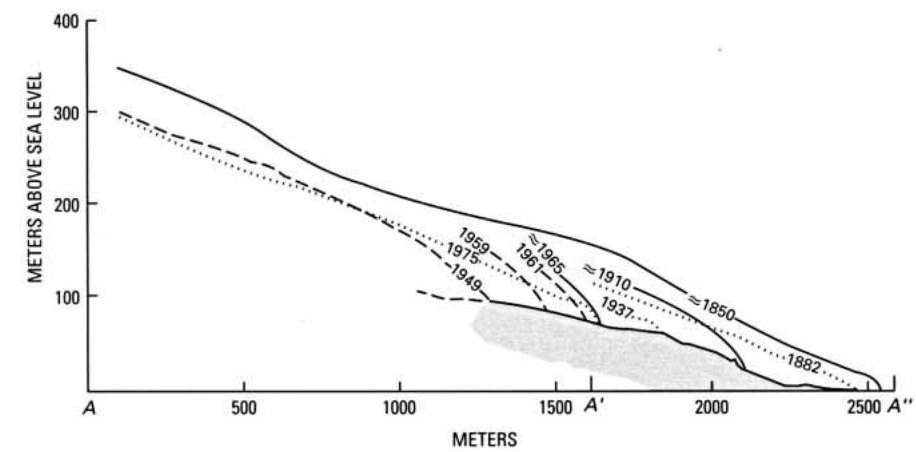

__Figure 10.__–Length profiles of Sørbreen along section A–A'–A''(see fig. 9) at various times. Vertical exaggeration 3 times. The shaded area represents the subglacial land surface.

Comparison of Glacier Fluctuations with Meteorological Data

A meteorological station has been operated continuously on Jan Mayen since 1922, with the exception of short periods during World War 11. The station has, however, been relocated several times. Parallel temperature measurements show that a continuous temperature curve can be constructed, whereas this cannot be done for the precipitation (Steffensen, 1982).

Lamb and others (1962), Fitch and others (1962), and Sheard (1965) claim that the glacier advances around 1960 were caused by increased precipitation from 1947 through the 1950's. Anda and others (1985) show that this period coincides with the period when the station was located on the western side of the island, where precipitation is highest. Thus, the recorded precipitation values during this period would not necessarily represent higher values on a continuous curve. Lamb and others (1962) also suggest that low temperatures in the 1940's may have contributed to the glacier expansion, and they refer to low mean annual temperatures. However, the records show that the summer temperatures, and thus the ablation, were not especially low at this time. Anda and others (1985) show that the summer temperatures were very high during the 1930's, which may have caused the glacier retreat from the period 1910–20 to about 1950. The marked reduction in summer temperatures from around 1940 to the mid-1960's is the most probable cause for the glacier expansion around 1960.

Use of Satellite Imagery in Glacier Monitoring

Jan Mayen is characterized by a very persistent cloud cover. On the average, only 4.4 days during the entire year are completely clear, and only 0.2 clear day occurs per month from June to September. More than 20 days are completely cloud covered during each of the summer months, and autumn shows the highest cloud-cover percentage during the year (Steffensen, 1982). Thus, it is difficult to obtain cloud-free satellite images of the island. When satellite images of the glaciers are most desired, at time of maximum ablation, the likelihood of obtaining them is the lowest.

Indeed, few glaciologically usable Landsat images have yet been obtained of Jan Mayen (table 2). The best available in the U.S. archive, 1084–12061, was acquired on 15 October 1972, but even this shows clouds over most of the island (figs. 11 and 12). The lack of recent Landsat imagery is especially unfortunate, because the glaciers on Jan Mayen are especially sensitive to climatic change, as is demonstrated by the numerous frontal variations of Sørbreen. It would therefore be particularly valuable to monitor glacier frontal variations by satellite imagery. This technique would be exceptionally useful here on this isolated island. It is also the only practical way to clarify whether all the glaciers of different aspects respond in parallel, because it is difficult to gain access to several of the glaciers.

Even with the recognition of the difficulties posed by the high cloud cover, it is still recommended that efforts be made to obtain satellite

TABLE 2.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Jan Mayen, Norway*

[See figure 12 for explanation of symbols used in the "Code" column]

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
233–10	70°35′N. 06°13′W.	No usable data			◔		
234–10	70°35′N. 07°39′W.	22077–11483	29 Sep 80	16	◐	20	Archived by ESA.
235–09	71°50′N. 06°48′W.	22060–11535	12 Sep 80	21	◐	20	Covers north end of island; archived by ESA[1].
235–10	70°35′N. 09°05′W.	1084–12061	15 Oct 72	10	◐	60	Only image available from EDC[2].
236–09	71°50′N. 08°14′W.	No usable data			◔		
236–10	70°35′N. 10°31′W.	22403–11561	21 Aug 81	30	◐	10	Covers south end of island; archived by ESA.

[1] ESA archive located at Kiruna, Sweden.
[2] U.S. Geological Survey EROS Data Center (EDC) archive located at Sioux Falls, S. Dak.

imagery of Jan Mayen. Imagery with good resolution (25 m or better) obtained in late summer or autumn at regular intervals (every few years) would satisfy the monitoring requirements. Data of this kind would, with the field data now available, allow sophisticated studies of the relationship between glacier fluctuations and the observed climatic variations. It would be particularly interesting to investigate models showing how these glaciers respond to changes in mass balance. Short glaciers covering large elevation intervals likely will respond much more quickly to changes in summer temperatures and net ablation than to changes in precipitation (Anda and others, 1985). The reason is that the temperature variations influence mostly the lower reaches of the glaciers, whereas precipitation variations probably are most important around the central and upper half of the glaciers. Thus, such a model could be tested by monitoring glacier variations on Nord-Jan and combining this information with analysis of the regularly obtained meteorological data.

Acknowledgment

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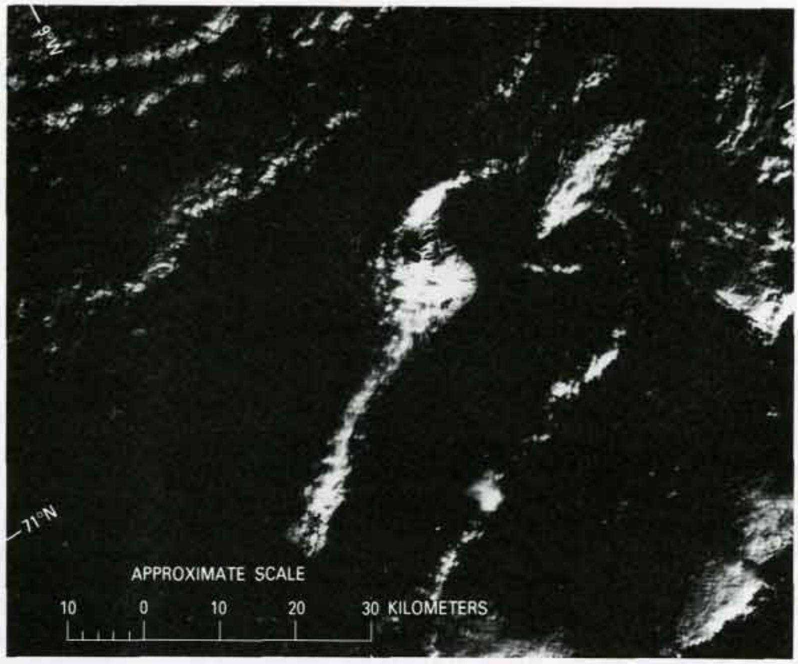
Figure *11.–Landsat 1 image (1084–12061; 15 October 1972) of Jan Mayen, Norway, the best Landsat image acquired (in the U.S. archive) of the island. Clouds obscure most of the coastline of both Nord-Jan and Syd-Jan, making the image unusable for determining positions of the termini of any of the 20 outlet glaciers emanating from the ice cap on Beerenberg Volcano, Nord-Jan.*



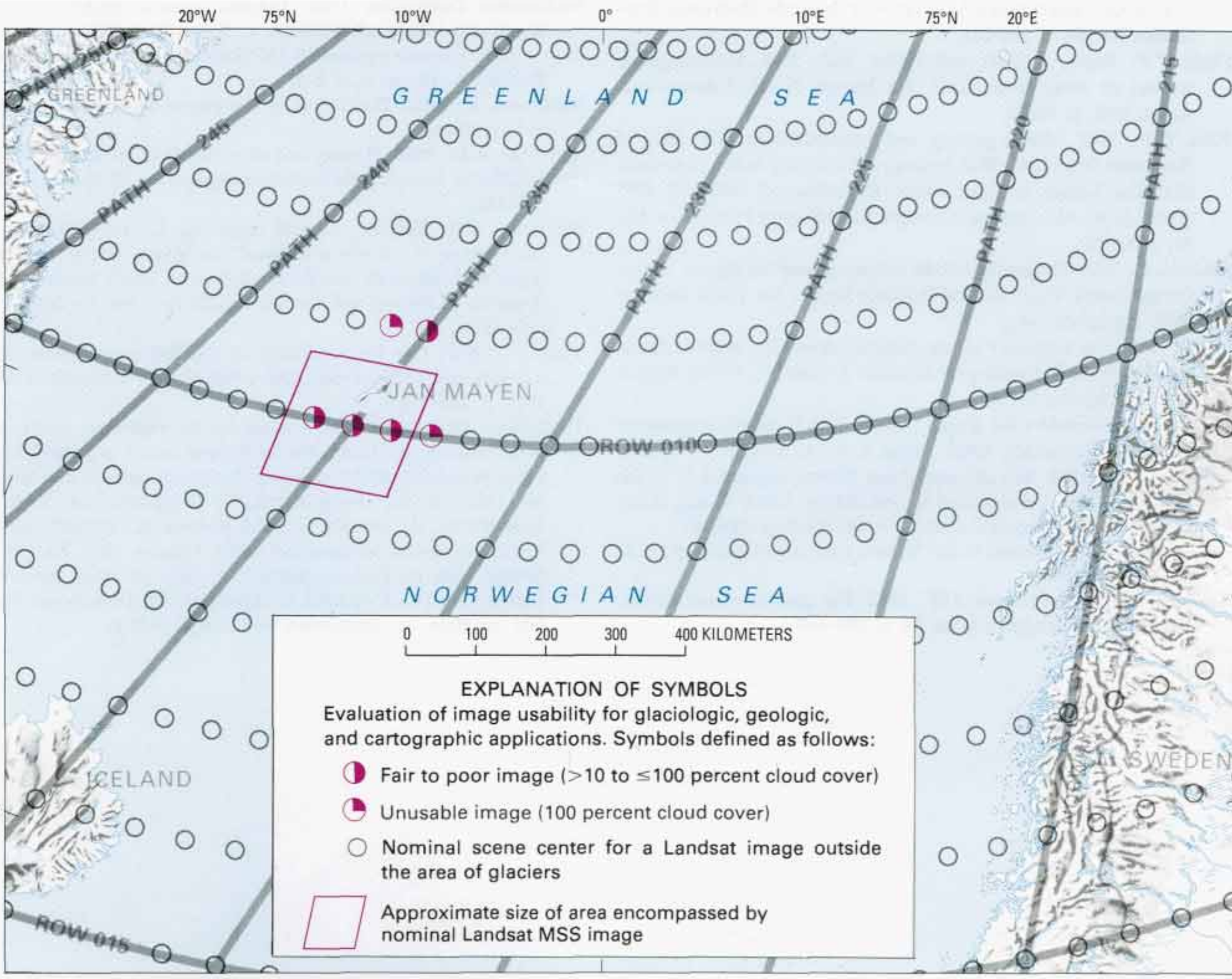


Figure 12.–*Optimum Landsat 1, 2, and 3 images of the glaciers of Jan Mayen, Norway. (See also table 2.) The vertical lines represent nominal paths. The rows (horizontal lines) have been established to indicate the latitude at which the imagery has been acquired.*

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