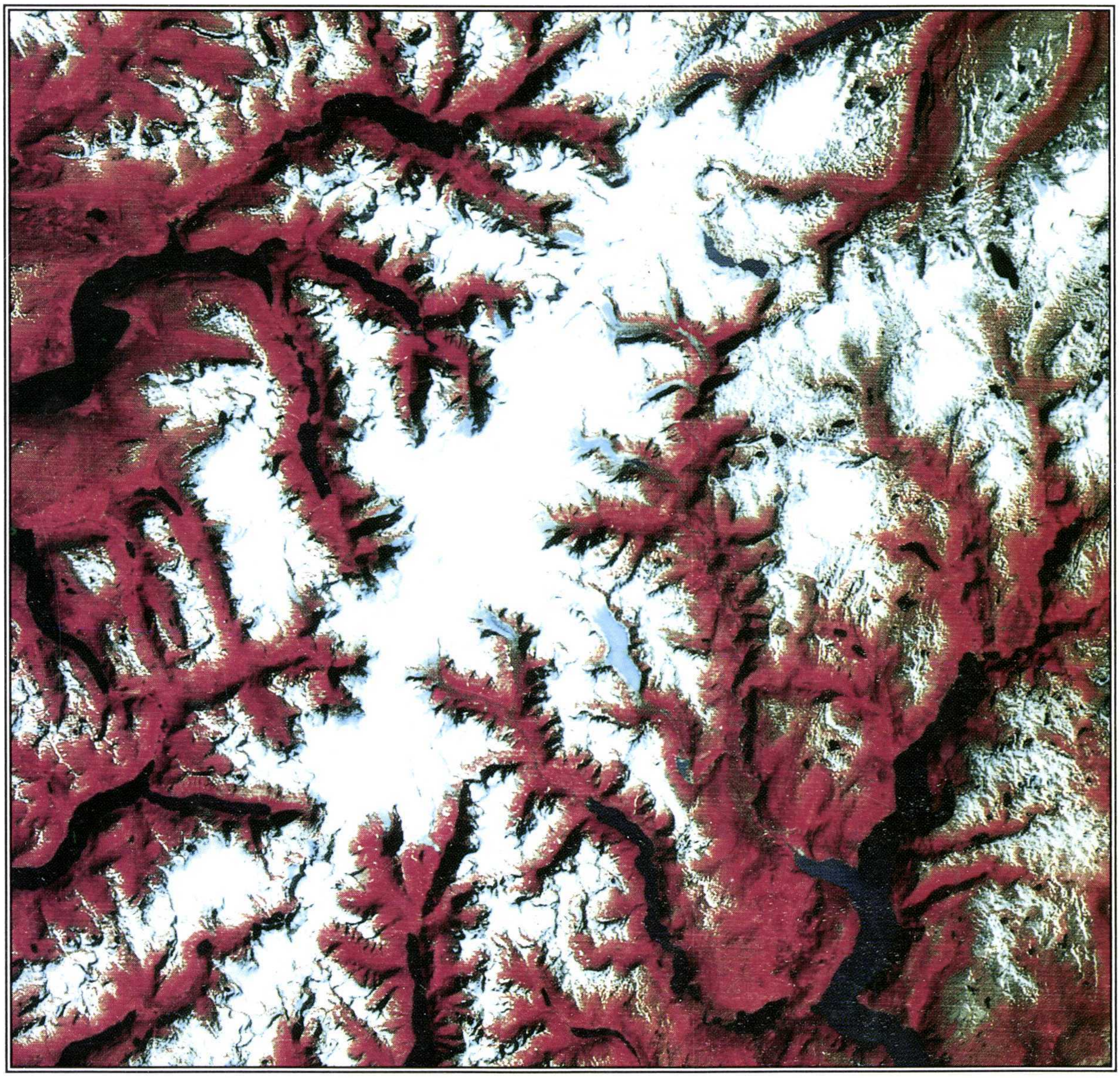
GLACIERS

OF

NORWAY



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Glaciers of Europe—

GLACIERS OF NORWAY

By GUNNAR ØSTREM *and* NILS HAAKENSEN

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–3

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

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By GUNNAR ØSTREM[1] *and* NILS HAAKENSEN[1]

Abstract

Detailed glacier inventories made in 1969, 1973, and, finally, in 1988 for a modern glacier atlas of Scandinavia list 1,627 glaciers in Norway that have a total area of 2,595 square kilometers. Glaciers occur principally as ice caps, outlet glaciers, cirque glaciers, and small valley glaciers. The largest ice cap, Jostedalsbreen, covers 487 square kilometers and is the largest continuous ice mass in continental Europe. Since the "Little Ice Age" (culminating in about 1750 in Norway), when glaciers reached their greatest extent in historic time, the glaciers have retreated almost continuously, and advances have been relatively small. Minor glacier advances occurred during the first part of this century, but a major glacier recession started about 1930. Systematic measurements of glaciers in Norway began in the late 19th century, although the earliest recorded observation of termini fluctuation was made in 1742. The longest series of mass-balance observations are those of Storbreen, begun in 1949. Mass-balance measurements are carried out for other selected glaciers for hydropower purposes. High quality aerial photographs are available for almost all glacierized areas in Norway, and 31 modern glacier maps have been published at 1:10,000 to 1:50,000 scales. Landsat images have limited value in Norway for most glaciological studies, but the satellite data have been used to qualitatively evaluate suspended sediment in lakes and fjords and to monitor the transient snowline as an indication of the approximate net mass balance.

Introduction

Norway is a relatively small country, 323,000 km^2, but the total area covered by glaciers is proportionally higher than for most other countries in Europe. According to glacier inventories made during 1969 and 1988 in southern Norway and during 1973 in northern Norway, about 2,595 km^2 of the land is covered by glaciers (Østrem and Ziegler, 1969; Østrem and others, 1973, 1988). In the compilation of these inventories, which were made in accordance with criteria recommended by UNESCO (1970), all glacier masses were divided according to a system based on hydrological factors. This system was chosen because the information obtained would be used mainly for hydrological purposes. It was also decided that glaciers that drain into different rivers should be subdivided into separate "glacier units," each unit draining into one river. The total number of such glacier units amounts to 2,113, whereas the number of "glaciers," continuous masses of ice regarded as one glacier body, amounts to 1,627.

The largest ice cap in Norway, the Jostedalsbreen, covers 487 km^2 and is the largest continuous ice mass in continental Europe. Only Iceland and Spitzbergen (Svalbard) have larger glaciers. For the hydrological reasons discussed above, Jostedalsbreen was divided into 61 individual glacier units. On the other hand, the smaller Norwegian glaciers are, in general, not subdivided, because most valley glaciers and cirque glaciers drain into only one river. Table 1 lists the size and location of the 34 largest glaciers of Norway.

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TABLE 1.—*The size and location of the 34 largest glaciers in Norway (from Østrem and others, 1988)*

Glacier name	Area (km^2)	Height in meters		Location	
		maximum	minimum	East long	North lat
1. Jostedalsbreen	487	2,000	350	7°00′	61°40′
2. Vestre Svartisen	221	1,580	20	14°00′	66°40′
3. Søndre Folgefonni	168	1,660	490	6°20′	60°00′
4. Østre Svartisen	148	1,550	208	14°10′	66°40′
5. Blåmannsisen	87	1,560	810	16°00′	67°20′
6. Hardangerjøkulen	73	1,850	1,050	7°20′	60°30′
7. Myklebustbreen (Snønipbreen)	50	1,830	890	6°40′	61°40′
8. Okstindbreen	46	1,740	750	14°10′	66°00′
9. Øksfjordjøkulen	41	1,170	330	22°00′	70°10′
10. Harbardsbreen	36	1,950	1,250	7°40′	61°40′
11. Salajekna	33	1,680	830	16°20′	67°10′
12. Spørteggbreen	28	1,750	1,270	7°30′	61°40′
13. Nordre Folgefonni	26	1,640	990	6°30′	60°10′
14. Giččečåkka	25	1,500	870	16°50′	68°00′
15. Frostisen	25	1,710	840	17°10′	68°10′
16. Sekke/Sikilbreen	24	1,930	1,330	7°40′	61°50′
17. Tindefjellbreen	22	1,850	940	7°10′	61°50′
18. Simlebreen	21	1,320	780	14°30′	66°50′
19. Tystigbreen	21	1,900	1,220	7°20′	62°00′
20. Holåbreen	20	2,020	1,320	7°50′	61°50′
21. Grovabreen	20	1,640	1,090	6°30′	61°30′
22. Ålfotbreen	17	1,380	890	5°40′	61°40′
23. Fresvikbreen	15	1,660	1,270	6°50′	61°00′
24. Seilandsjøkulen	14	940	480	23°20′	70°20′
25. Strupbreen/Koppangsbreen	14	1,400	320	20°10′	69°40′
26. Smørstabbreen	14	2,070	1,390	8°05′	61°35′
27. Gjegnalundsbreen	13	1,590	900	5°50′	61°50′
28. Hellstugu/Vestre Memurubre	12	2,200	1,470	8°30′	61°30′
29. Unnamed glacier in Beiardalen	12	1,560	760	14°20′	66°40′
30. Storsteinsfjellbreen	12	1,850	930	18°00′	68°40′
31. Søndre Jostefonn	11	1,620	960	6°35′	61°25′
32. Midtre Folgefonni	11	1,570	1,100	6°30′	60°10′
33. Langfjordjøkulen	10	1,020	360	21°40′	70°10′
34. Veobreen	9	2,300	1,530	8°30′	61°35′

More detailed information about the length of glaciers, their orientation, the date of aerial photography, and similar information can be found in the two glacier atlases of Norway ((Østrem and Ziegler, 1969, revised edition by Østrem and others, 1988; Østrem and others, 1973). The glacier atlases also contain considerable geomorphological information, such as surface characteristics, morainal features, proglacial lakes, and other data related to each glacier unit listed.

The distribution of glaciers in Norway is shown on figures 1 and 2. These glacier index maps show that a concentration of glaciers exists in southwestern Norway and also in certain parts of northern Norway. Because glaciers seem to "attract more precipitation" than glacier-free areas in the mountainous parts of Norway, the glacierized areas have gained increased interest from waterpower engineers. During the last several decades, several hydroelectric powerplants have been considered for construction near the glacier-capped mountains because of the quantity of water available at high altitudes and the relatively short distances to sea level. In connection with this, mass-balance investigations have been undertaken at a number of selected glaciers, and special, highly detailed maps have been prepared for several glaciers in Norway during the last two decades (see table 3). Because glaciers have, in the past, been regarded as a remote and relatively uninteresting aspect of the landscape, very little information has been recorded on their behavior.

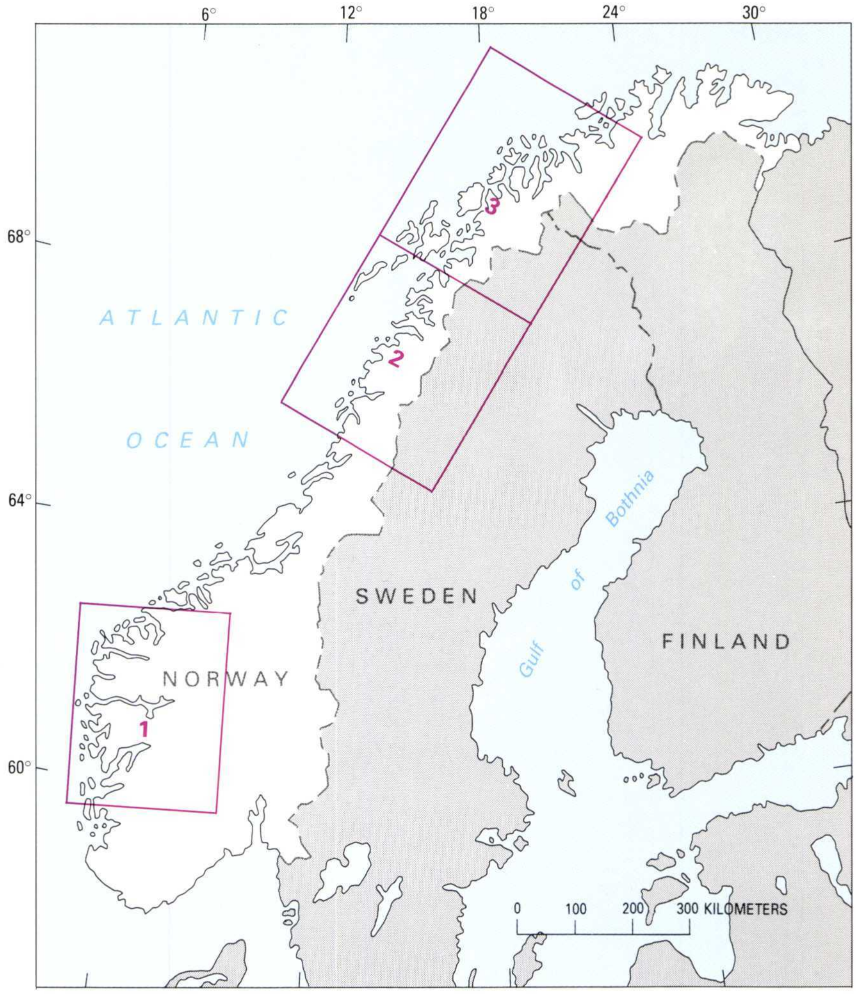
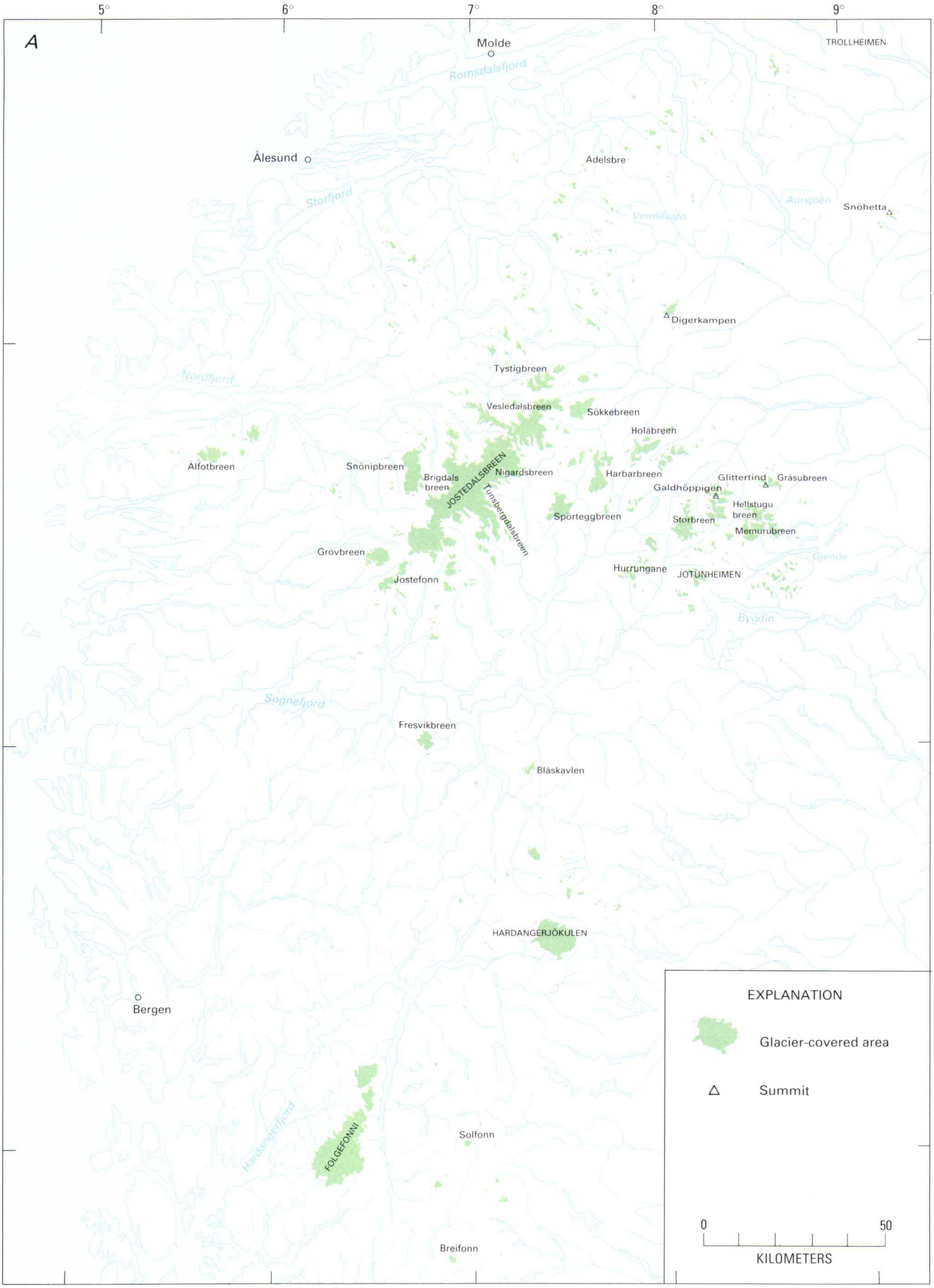


Figure 1.—*The areas covered by the three regional maps of Norwegian glaciers. Numbers correlate with the three maps in figure 2.*

Only in a few cases, for example, Nigardsbreen and Engabreen, have accurate measurements been made of their variations prior to the end of the last century (Øyen, 1898).

Aerial photographs have been available during the last few decades, and detailed measurements of glacier mass balance were begun in 1948 when Dr. Olav Liestøl initiated systematic glaciologic investigations at Storbreen in Jotunheimen, southern Norway. His series of observations on Storbreen is the second longest of its kind in the world. Observations of variations in the position of termini of glaciers in Norway have been made on various occasions dating from about 1740 (see the section entitled "Historical Review").

Satellite images represent a new tool for glaciologists. In Norway, however, where good maps and aerial photographs exist and where glaciers are relatively small and accessible for detailed observations, Landsat images are of limited value for most types of glaciological studies. Due to the fact, however, that the elevation of the transient snowline (TSL) can be determined easily from Landsat images when compared with topographic maps of an area, and because there is a relation between this elevation at the end of the summer and the mass balance of the glacier, it seems possible that satellite images in the future may become a valuable tool for glacier-hydrologic studies. A high TSL indicates a negative mass balance, whereas the TSL will be situated at a lower altitude in years of positive mass balance. Thus, it is hoped that the high costs associated with fieldwork for the determination of selected glaciers' mass balance can be reduced, provided that optimum satellite



A
5°
6°
7°
8°
9°
62°
61°
60°
Molde
Romsdalsfjord
TROLLHEIMEN
Ålesund
Adelsbre
Storfjord
Aursjöen
Snöhetta
Vermevatn
Digerkampen
Nordfjord
Tystigbreen
Vesledalsbreen
Sökkebreen
Holåbreen
Ålfotbreen
Snönipbreen
Brigdals breen
JOSTEDALSBREEN
Nigardsbreen
Harbarbreen
Glittertind
Gråsubreen
Galdhöppigen
Tunsbergdalsbreen
Hellstugu breen
Sporteggbreen
Storbreen
Memurubreen
Grovbreen
Gjende
Hurrungane
JOTUNHEIMEN
Jostefonn
Bygdin
Sognefjord
Fresvikbreen
Blåskavlen
HARDANGERJÖKULEN
EXPLANATION
Bergen
Glacier-covered area
Summit
Hardangerfjord
FOLGEFONNI
Solfonn
0
50
KILOMETERS
Breifonn

◀ *Figure 2A.—The glaciers in southern Norway (from Østrem and Ziegler, 1969). Map location shown by number 1 on figure 1. Base from Norges Vassdrags- og Elektrisitetsvesen, 1:500,000, Glacier Map of Southern Norway, 1969.*

images can be acquired at the end of the summer ablation season. However, cloud cover presents a serious problem that may be solved in the future, if cloud-penetrating sensors (such as radar images) can produce images that have sufficient detail.

In the text that follows, the occurrence, observational history, modern investigations, mapping, photographing and imaging, glaciological phenomena, and Landsat images of Norway's glaciers will be discussed. In Norway, glaciers occur principally as ice caps, outlet glaciers from these ice caps, cirque glaciers, and small valley glaciers. In the Norwegian language, several words are used to describe the term "glacier." Perhaps the oldest word still in use is "jøkul" (ice cap). The most common word used for glacier in modern Norwegian is "bre." "Fonn" and "is" are also used, although more commonly on the island of Svalbard (see "Modern Glaciological Investigations") than in Norway. "Botn" is used in reference to a cirque glacier, and "skåkje" is used locally in the Hardanger area in reference to three outlet glaciers of Hardangerjøkulen. In a few places "skavl" (snow drift) is used for small glaciers. Most geographic names of Norway's glaciers are compounds, as in Jostedalsbreen. Jostedals-bre-en is composed of a descriptive location name, followed by the word for glacier and the definite article in Norwegian, or literally, Joste Valley–glacier–the. Another example is Storbreen or, literally, large–glacier–the. In northern Norway, several ice caps carry Lappish names, such as Salajekna and Giččečåkka (see table 1). The Lappish word for glacier is variously spelled as jekna, jiek'ki, jietna, and so on.

Occurrence of Glaciers

The glaciers in Norway are concentrated in two areas: (1) the high-mountain area in the central and western part of southern Norway that has the dominating ice caps Jostedalsbreen, Hardangerjøkulen, and Folgefonni, and the numerous valley and cirque glaciers in the Jotunheimen mountain area and (2) northern Norway, where most of the glaciers are concentrated in Nordland County—the narrowest part of Norway— approximately between 66° N. and 68° N. latitude. However, a number of valley glaciers and small ice caps are also distributed farther north, particularly on the Lyngen peninsula, east of Tromsø. The northernmost glacier in continental Europe is found on the island Seiland, 70°25′ N. latitude (see the Landsat image and the aerial photograph of Seilandsjøkulen in figures 23 and 24, respectively).

The largest glaciers in Norway are ice caps. Valley glaciers are of reasonable length—normally not longer than a few times their width. The smallest are cirque glaciers, with an almost circular outline.

Very early descriptions of permanent ice and snow do exist (for example, the work by P.C. Friis in 1632), but no area measurements were made. The oldest known Norwegian glacier map, published in 1853 of the Jotunheimen area, is discussed in the section "Mapping of Glaciers."

Inventories of the glaciers in Norway have been made at various intervals. The first really complete inventory was made by Olav Liestøl in 1958, however. His inventory was first printed as a small booklet but was later included in the comprehensive publication "Glaciers and Snow-fields in Norway" (Liestøl, 1962a). According to Liestøl's inventory, the total number of glaciers and snow fields in Norway amounted to approximately 1,750 and covered a total area of about 3,900 km^2. This figure is considerably higher than the figure given in the modern glacier atlases (1,627 glaciers covering 2,595 km^2), but this discrepancy is mainly due to the fact that Liestøl's inventory included both glaciers and snow-

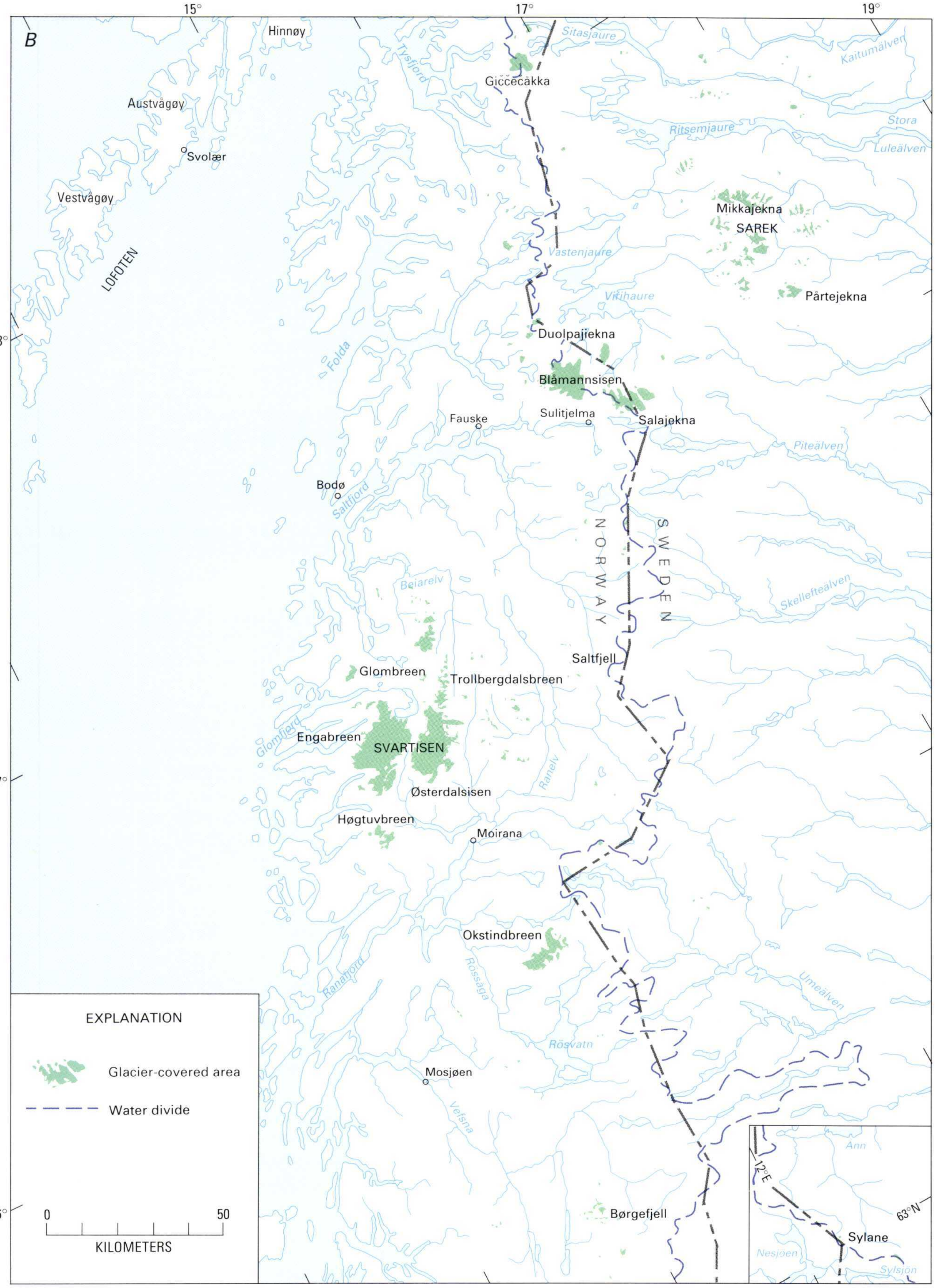


Figure 2B.—*The glaciers in the southern section of northern Scandinavia (Norway and Sweden) (from Østrem and others, 1973). Map location shown by number 2 on figure 1. Base from Norges Vassdrags- og Elektrisitetsvesen og Stockholms Universitet, 1:500,000, Glacier Map of Northern Scandinavia, Southern Sheet, 1972.*

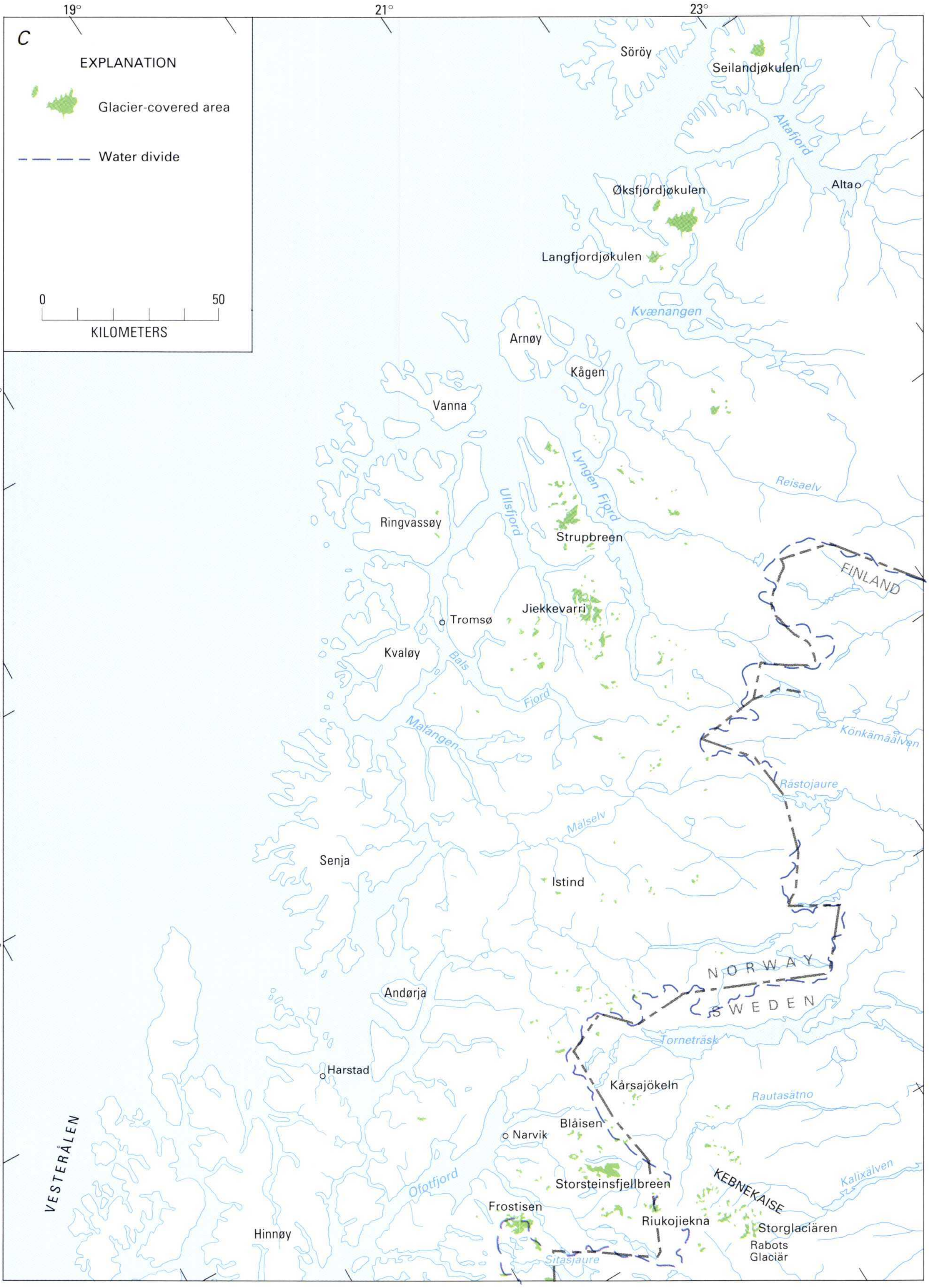


***Figure 2C.**—The glaciers in the northern section of northern Scandinavia (Norway and Sweden) (from Østrem and others, 1973). Map location shown by number 3 on figure 1. Base from Norges Vassdrags- og Elektrisitetsvesen og Stockholms Universitet, 1:500,000, Glacier Map of Northern Scandinavia, Northern Sheet, 1972.*

fields. The topographic maps that Liestøl used as source materials did not distinguish cartographically between true glaciers and snow fields.

Another inventory, which was less detailed, was made by Østrem (1963). He prepared an index map at a scale of 1:1,800,000 showing all glaciers in Scandinavia. An improved version of the southern part of this map was made in 1963, when a glacier map of southern Norway was issued at a scale of 1:500,000 and printed in three colors (Liestøl and Østrem, 1963). Detailed glacier inventories were prepared of southern Norway in the late 1960's (Østrem and Ziegler, 1969) and of northern Norway and Sweden in the early 1970's (Østrem and others, 1973). A second glacier inventory for southern Norway was completed in the late 1980's (Østrem and others, 1988).

A concept related to the existence of glaciers is the so-called *glaciation level*. This term is defined as the critical mountain height above which glaciers can form. A mountain that is higher than the glaciation level will normally carry one or more glaciers, provided the topography is suitable for glacier formation. Mountains lower than the critical level will not collect sufficient snow to form a glacier, or complete disappearance of the snow during the summer makes glacier formation impossible.

On the western coast of southern Norway, this critical level is about 1,200 m, so that mountains higher than this level normally carry glaciers. In the eastern part of Jotunheimen, the glaciation level is about 2,200 m; consequently, all glaciers there are situated at much higher elevations than those near the coast. Similar conditions prevail in northern Norway, where glaciers form at considerably lower elevations in the coastal districts than in the more continental inland part of the Scandinavian peninsula. For further details please refer to Østrem (1964, p. 333–335; 1966, p. 128).

Another concept, the *equilibrium line*, is directly related to the mass balance of glaciers. It divides the glaciers in two parts: the accumulation area and the ablation area. Strictly speaking this is a theoretical and invisible line across the glacier, the exact determination of which is a complicated procedure. It is situated higher up on the glaciers during years of negative mass balance and lower during years of positive mass balance. For most temperate glaciers, however, the equilibrium line coincides quite well with the TSL at the end of the melt season, and this line is fully visible on the glacier because it forms the transition between remaining snow and uncovered (bare) glacier ice. Its position can be determined on satellite images, and certain conclusions can be drawn about the "health" of the glacier (see the section entitled "Glaciological Phenomena").

Historical Review

During historic time there have been several periods of glacier advance and retreat. However, very little has been written about these events in Norway, mainly because glaciers were relatively far from populated areas and generally of little interest to people. However, some documentation exists concerning the last large glacier advance, called "The Little Ice Age," which culminated about 1750 in Norway. As a result of several years of climatic deterioration, most glaciers advanced considerably, and, in many cases, the outermost moraine at any glacier today was deposited during this large advance. The first known direct measurement of a glacier terminus in relation to a fixed point was made in 1742 at Tverråbreen in the Jostedalen area (Hoel and Norvik, 1962, p. 9).

The first written documentation of glacier measurements made in Norway was of the outlet glacier Nigardsbreen, which drains southeastward from the Jostedalsbreen ice cap. This glacier advanced so far that it reached cultivated land and even destroyed houses. Farmers who lost their fertile land wrote to the king, Fredrik V, and asked for tax exemption because they had lost their grazing fields. The local judge and the minister were sent to the area to inspect the damage. The minister, Matthias Foss, wrote a "Short description from Justedalen 1750," which was published somewhat later (Foss, 1803). He wrote:

> In the year 1742, in the middle of August, his Majesty's representative and the judge went to observe the areas which had been destroyed by the glacier. A measurement was made from the glacier to the nearest house, and this distance was then 200 feet. On the same day next year, 1743, the glacier had not only moved forward these 200 feet, but it also increased in width and had pushed away the houses and tumbled them around. The ice had also plowed up large amounts of soil and gravel and large rocks and crushed these rocks into small pieces which are still visible. The owner of the farm had to leave his house in a great hurry to try to find another place to stay. His farm, named Nigard, was destroyed together with all its fertile land, and the glacier had also approached other areas during the following years. The farm Bjerkehougen lost cultivated land so that only the houses were left, and it is not possible to live there any more. However, we have noted that the ice has retreated since 1748 but only very slowly. In addition to the destroyed arable land the glacier is also harmful because it produces cold winds so that rime on the ground is not unusual during the summer.

Since this disastrous advance, the glacier has retreated almost continuously, interrupted only by relatively small advances. From 1748 until the present time, the retreat amounts to about 5 km (table 2). The effect from the small advances can be seen easily on the photograph (fig. 3). The series of small morainal ridges has been dated and described in detail by Faegri (1933) and by Andersen and Sollid (1971). A map showing the various moraines and the time of their formation has been constructed on the basis of all available information.

As a curiosity, it should be mentioned that glacier ice has been a commercial product in Norway for some time. From the beginning of the

Figure 3.—*Oblique aerial photograph of Nigardsbreen and its valley, named Mjølverdalen, taken in 1951 by Olav Liestøl. The terminal moraines from the 1750 advance are in the lower left of the picture. The distance between the 1750 moraine and the present position of the glacier terminus is about 5 km.*

TABLE 2.—*Variation of the terminus of Nigardsbreen outlet glacier during the period 1710–1991 (based upon data in Østrem and others, 1976, and additional information)*

Year	Variation (in meters)	Year	Variation (in meters)
1710–35	+2,800[1]	1940–41	−41
1735–42	0	1941–42	−19
1742–43	+100[1]	1942–43	−38
1743–48	+50[1]	1943–44	−10
1748–1818	−540	1944–45	−43
1818–23	−70[1]	1945–46	−35
1823–45	−80[1]	1946–47	−113
1845–73	−710	1947–48	−145
1873–99	−595	1948–49	−92
1899–1903	−73	1949–50	−47
1903–07	+8	1950–51	−56
1907–08	−10	1951–52	−87
1908–09	+18	1952–53	−60
1909–10	−31	1953–54	−41
1910–11	+5	1954–55	−72
1911–12	−40	1955–56	−53
1912–13	−11	1956–57	−34
1913–14	−13	1957–58	−49
1914–15	−25	1958–59	−66
1915–16	−20	1959–60	−87
1916–17	−19	1960–61	−55
1917–18	−16	1961–62	−30
1918–19	−21	1962–63	−65
1919–20	−14	1963–64	−65
1920–21	−16	1964–72	−515
1921–22	+7	1972–73	−65
1922–23	−23	1973–74	−46
1923–24	−13	1974–75	−16
1924–25	+10	1975–76	−1
1925–26	+16	1976–78	−14
1926–27	−16	1978–79	+3
1927–28	+12	1979–80	+1
1928–29	+20	1980–81	−11
1929–30	+6	1981–82	+4
1930–31	−9	1982–83	−6
1931–32	−15	1983–84	−2
1932–33	−15	1984–85	−4
1933–34	−45	1985–86	−7
1934–35	−25	1986–87	+11
1935–36	+5	1987–88	−18
1936–37	−17	1988–89	+1
1937–38	−21	1989–90	+7
1938–39	−50	1990–91	+10
1939–40	−28		

[1] Approximative values only.

last century it is reported that quantities of ice were carried from the Bondhusbreen outlet glacier (from the Folgefonni ice cap) down to the small community of Sunndal for sale to fishermen who used it for preservation of their fish. The first known ice export dates from 1822, when a ship carried glacier ice to Scotland. Later, in 1863, a small road was built up the valley to facilitate ice transport. Similarly, ice was taken for the same reason from a small regenerated glacier in Jøkulfjord, near the Øksfjordjøkulen ice cap in northern Norway. Here, during recent years, ice was blasted off the cone-shaped glacier that reaches sea level. However, this activity ceased in 1949 when a refrigeration plant was built in the area.

Modern Glaciological Investigations

More systematic measurements of glaciers in Norway started about 100 years ago, when some scientists began to establish survey points in front of selected glaciers for annual position measurements of each terminus. This kind of systematic measurement was first made by the geologist P.A. Øyen, who published his figures in annual reports (Øyen, 1898, 1907, 1915), and by J.B. Rekstad (1905), who also photographed many glaciers. His historic glass negatives contain a wealth of information from 1890 to about 1910. C. de Seue, a Norwegian Army officer and meteorologist, took several photographs of the Jostedalsbreen and Svartisen ice caps in 1868 (de Seue, 1870). The famous French geographer Charles Rabot took many photographs in Scandinavia during the 1880's. Several of his photographs provide considerable information about the position of selected glacier termini at that time. Later, Professor Werner Werenskiold began a long series of glacier-termini measurements in the Jotunheimen mountains. Many of his research students did their fieldwork in glaciology under his guidance. His interest in glaciology is recorded in several scientific papers, and he also reviewed the history of glaciological research in Norway (Hoel and Werenskiold, 1962, p. 14–18) in a work that contains a listing of many old sources. An extensive bibliography is also given in Hoel and Norvik (1962).

We know that minor glacier advances have occurred during the first part of this century (Liestøl, 1962b), but a period of major glacier retreat started about 1930 (fig. 4). One of the best studied glaciers in modern time is the Nigardsbreen outlet glacier, where several scientists, both

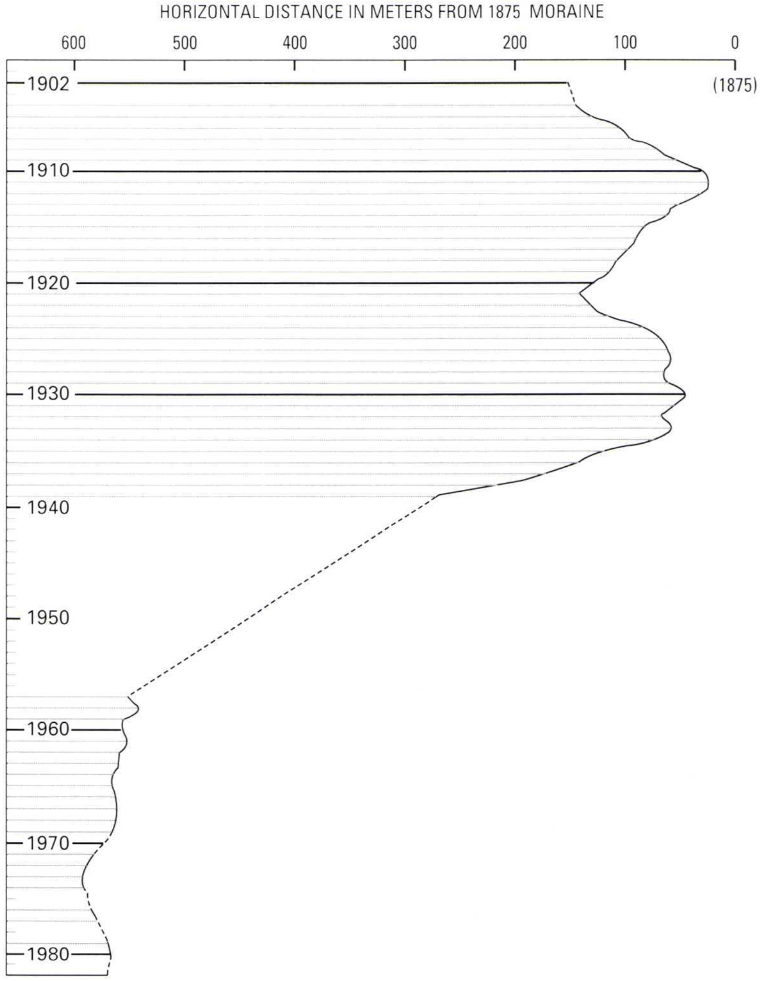


Figure 4.—Glacier terminus observations at Bondhusbreen. Distances given are in meters, measured horizontally from the 1875 terminal moraine (modified from the text accompanying the 1979 map of Bondhusbreen noted on table 3).

Norwegian and foreign, have carried out various types of glaciological studies. Detailed mass-balance investigations were started there in 1962. A map showing the retreat of Nigardsbreen since the 1750's is shown on figure 5, and the results of termini measurements are plotted in table 2. The longest mass-balance-observation series made in Norway concerns Storbreen, a valley glacier in the Jotunheimen mountain massif where measurements have been made since 1949 (fig. 6). For five other glaciers in Norway there are observations covering a time span of almost 30 years or longer (Haakensen, 1982, p. 49). At least some of these observations will continue in the future because of the need to gather hydrological data for various waterpower developments in Norway.

Continuous mass-balance investigations have also been carried out at intervals of 5 to 6 years for other selected glaciers in Norway (Roland and Haakensen, 1985; Østrem and others, 1991; Haakensen and Elvehøy, 1992). These studies have also been done mainly for hydrologic purposes.

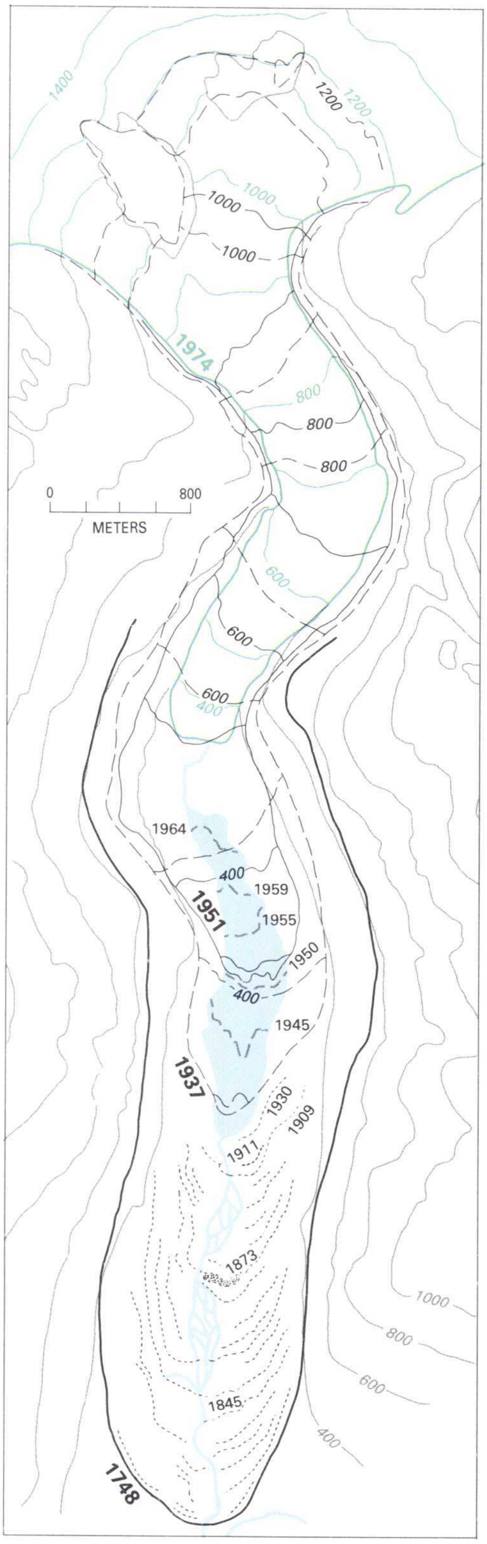
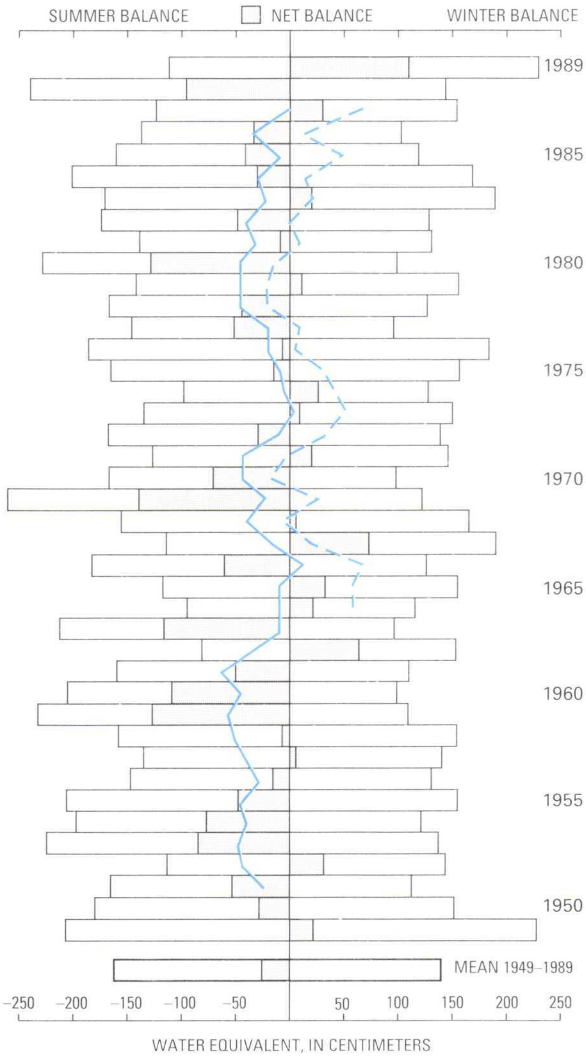


Figure 5.—Map of the retreat of Nigardsbreen. The information is based upon various datings of existing moraine ridges (oldest stages) and direct observations made in recent years. The dotted lines represent location of moraine ridges. The dashed lines represent 1937 glacier terminus and contours. The solid black lines represent 1951 glacier terminus and contours. The green lines represent 1974 glacier terminus and contours. The contours on the surrounding landscape are shown in gray (from Østrem and others, 1976). Since 1974, the retreat of the terminus of Nigardsbreen has been only 42 m. For more details, see Andersen and Sollid (1971). (See also table 2.)



◀ ***Figure 6.**—Mass-balance diagram for the glacier Storbreen in Jotunheimen during the period 1949–89, combined with a line for the 5-year running mean. The total mass loss in 41 years amounts to 10.5 m of water equivalent. For comparison, the 5-year running mean for Nigardsbreen is also indicated (dashed line). The average net balance for Nigardsbreen is about 0.6 m higher than that for Storbreen.*

Mapping of Glaciers

Figure 7.*—The oldest existing glacier map in Norway, published by J.D. Forbes in 1853, showing the glaciers in central Jotunheimen, southern Norway.*

No real glacier maps were made in Norway until the British Professor J.D. Forbes produced a map (fig. 7) of some of the most important glaciers in Jotunheimen during his visit to Norway in 1851 (Forbes, 1853). Another early glacier map was produced by Professor S.A. Sexe at

the University of Oslo. He studied the ice cap Folgefonni and produced a color map (fig. 8) (Sexe, 1864). In the 1920's, the famous Swedish Professor H.W:son Ahlmann started a glaciological research program on Styggedalsbreen in western Jotunheimen. Professor Ahlmann produced two glacier maps (Ahlmann, 1922) that were printed in color at a scale of 1:20,000. The Norwegian professors Adolf Hoel and Werner Werenskiold produced a glacier map (1:10,000) of Tverråbreen in Jotunheimen by terrestrial photogrammetry in 1927 (Hoel and Werenskiold, 1962). Some German scientific expeditions were also active in the production of glacier maps during the 1930's. An example is Wolfgang Pillewizer's map (Pillewizer, 1950) of the lower part of Nigardsbreen from 1937 (fig. 9).

Topographic maps also contain some glacier information, but the oldest maps (called Amtskart and at a scale of 1:250,000) produced in the last

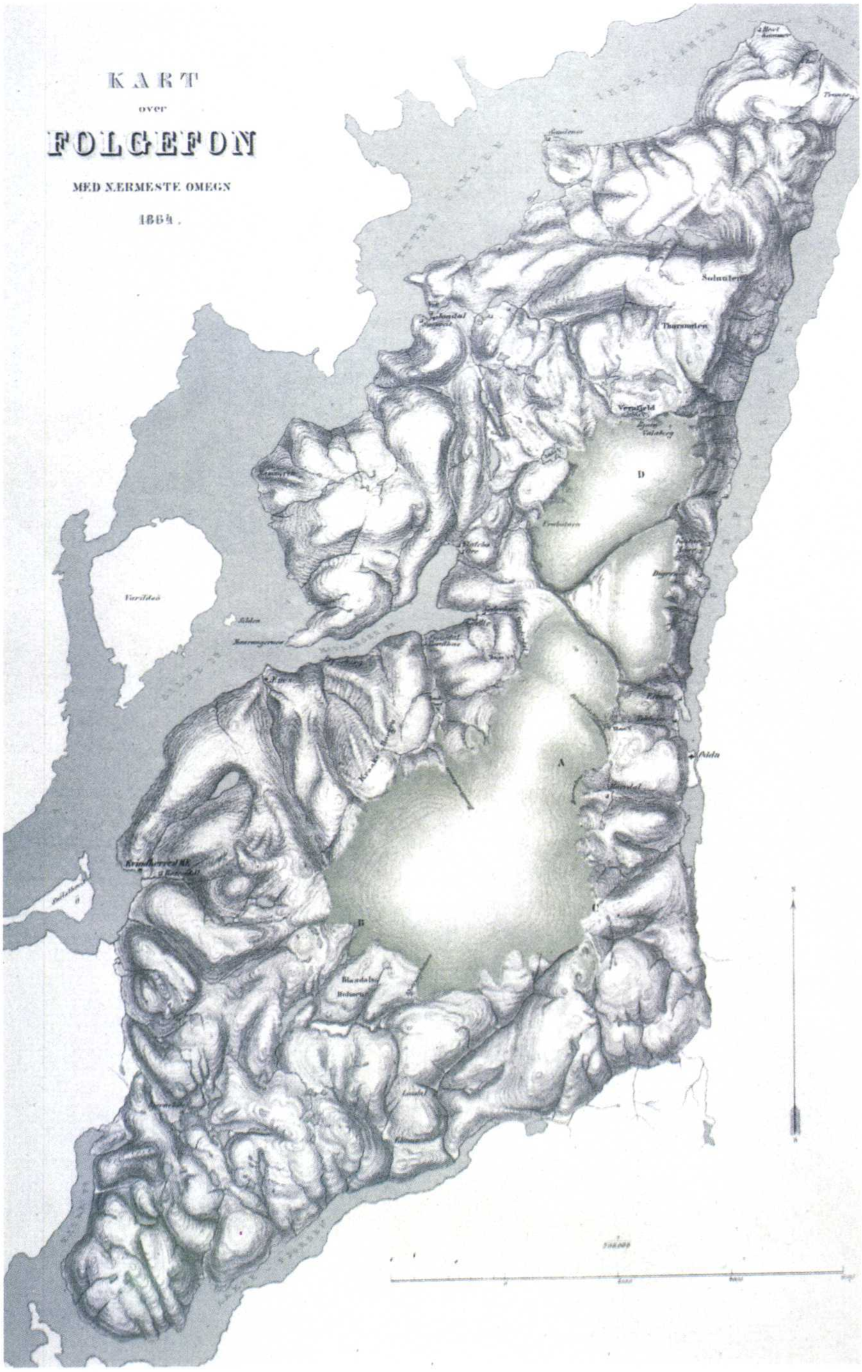


***Figure 8.**—The first glacier map of the Folgefonni ice cap and its surroundings, drawn by S.A. Sexe in 1864.*

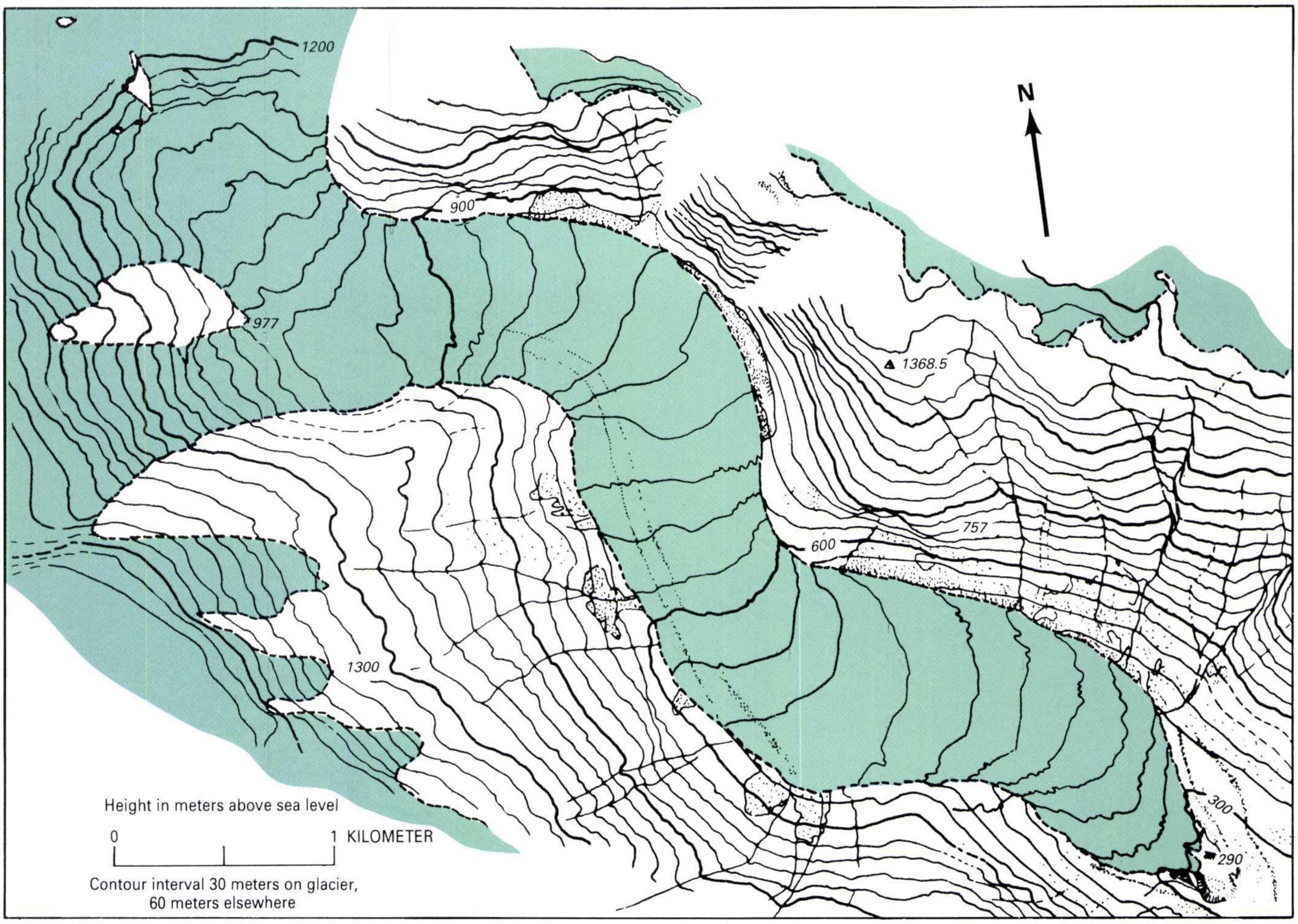


Figure 9.—Nigardsbreen, mapped in 1937 by terrestrial photogrammetry by the German professor W. Pillewizer (1950).

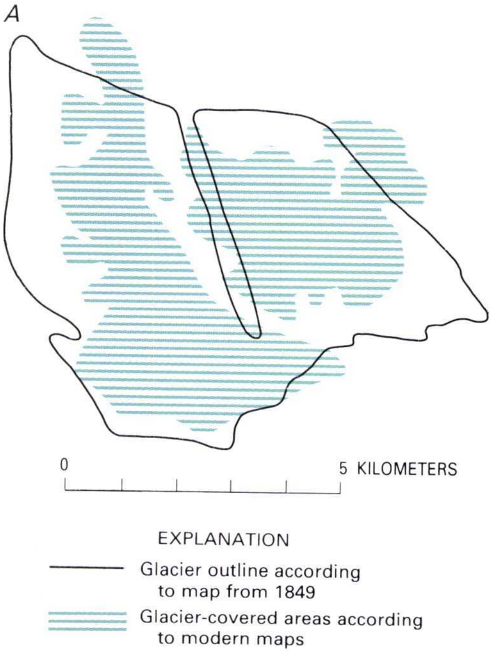


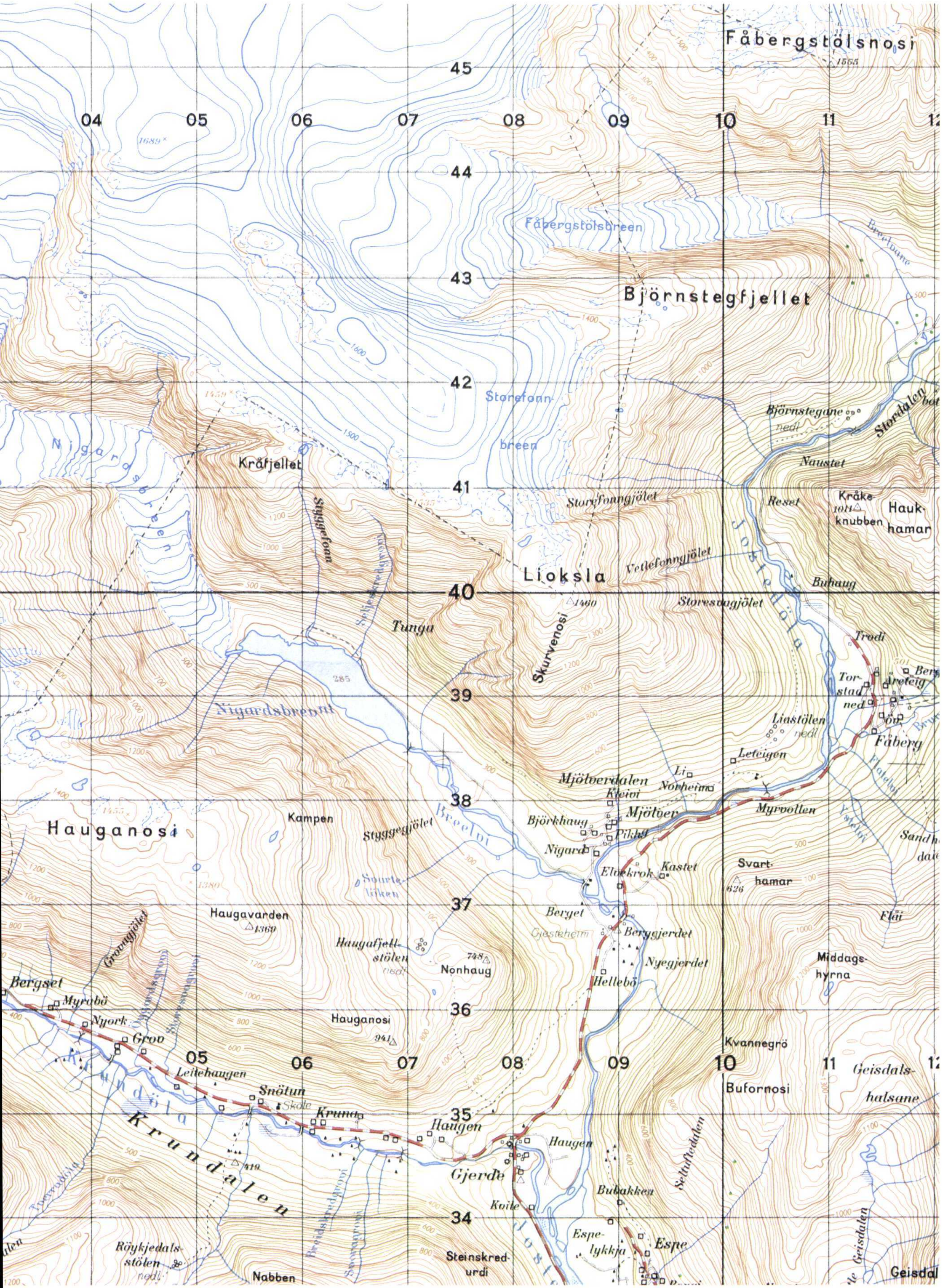
Figure 10A.—*The Memuru glaciers in Jotunheimen, showing differences in glacier area and outline as depicted on an old map surveyed in 1849 (Amtskart, scale 1:250,000) and on a modern topographic map surveyed in 1938 (scale 1:100,000; from Østrem, 1960). Compare with figure 7.*

century were not very reliable concerning the existence or size of glaciers (fig. 10*A*). Modern topographic maps are much better (fig. 10*B*), but the relatively small scale often limits the value of the information for glaciological studies. Furthermore, in some cases, permanent snow fields are interpreted as glaciers and marked as such on the maps.

Modern glacier maps are defined as maps produced according to standards established during the First International Symposium on Glacier Mapping held in Ottawa, Canada, in 1965. Such maps have been prepared for selected glaciers in connection with studies by the Norwegian Water Resources and Energy Administration (NVE) for planning of future hydroelectric power developments (fig. 11) and by the Norwegian Polar Research Institute for scientific purposes. Some glacier maps have also been produced for other reasons, such as special research projects. A list of all published glacier maps is given in table 3, and an index map showing the location of each map is shown in figure 12.

Figure 10B.—*Part of the Norwegian Series M 711, 1:50,000-scale topographic map (Sheet 1418 III—Jostedalen) of Nigardsbreen outlet glacier from Jostedalsbreen prepared from 1966 aerial photographs. Map published in 1973 by the Norwegian Geographical Survey (NGO).* ▶

Kjenndalskruna
Kjenndalsbreen
JOSTEDALSBREEN
Högste Breakulen
Steinmannen
Tuftebreen
Kvitekulen
Kråfjellet
Bergset-
breen
Bakli
Vetlenibba
Grönskreda
Vetledalsbreen


Fåbergstölsnosi
1565
45
04
05
06
07
08
09
10
11
44
Fåbergstölsbreen
43
Björnstegfjellet
42
Storefonn-
breen
Björnstegane
Stordalen
Naustet
Kråfjellet
41
Storefonngjölet
Reset
Kråke-
knubben
Hauk-
hamar
Styggefonn
Lioksla
Vetlefonngjölet
Buhaug
40
1460
Storesvagjölet
Tunga
Skurvenosi
Trodi
Tor-
stad
Åreteig
39
285
Nigardsbreen
Liastölen
Fåberg
Leteigen
Mjölverdalen
Li
Norheim
Kleivi
38
Hauganosi
Kampen
Breelvi
Björkhaug
Mjölver
Myrvollen
Nigard
Kastet
Svart-
hamar
626
37
Haugavarden
1369
Beryet
Gjesteheim
Berggjerdet
Nyegjerdet
Flåi
Haugafjell-
stölen
748
Nonhaug
Middags-
hyrna
Bergset
Myrabö
Hellebö
Nyork
Grov
36
Hauganosi
941
Kvannegrö
Leitehaugen
Snötun
Skole
Kruna
Haugen
Bufornosi
Geisdals-
halsane
Krundalen
419
Gjerde
Bubakken
Kvile
34
Espe-
lykkja
Espe
Röykjedals-
stölen
Steinskred-
urdi
Nabben
Geisdal

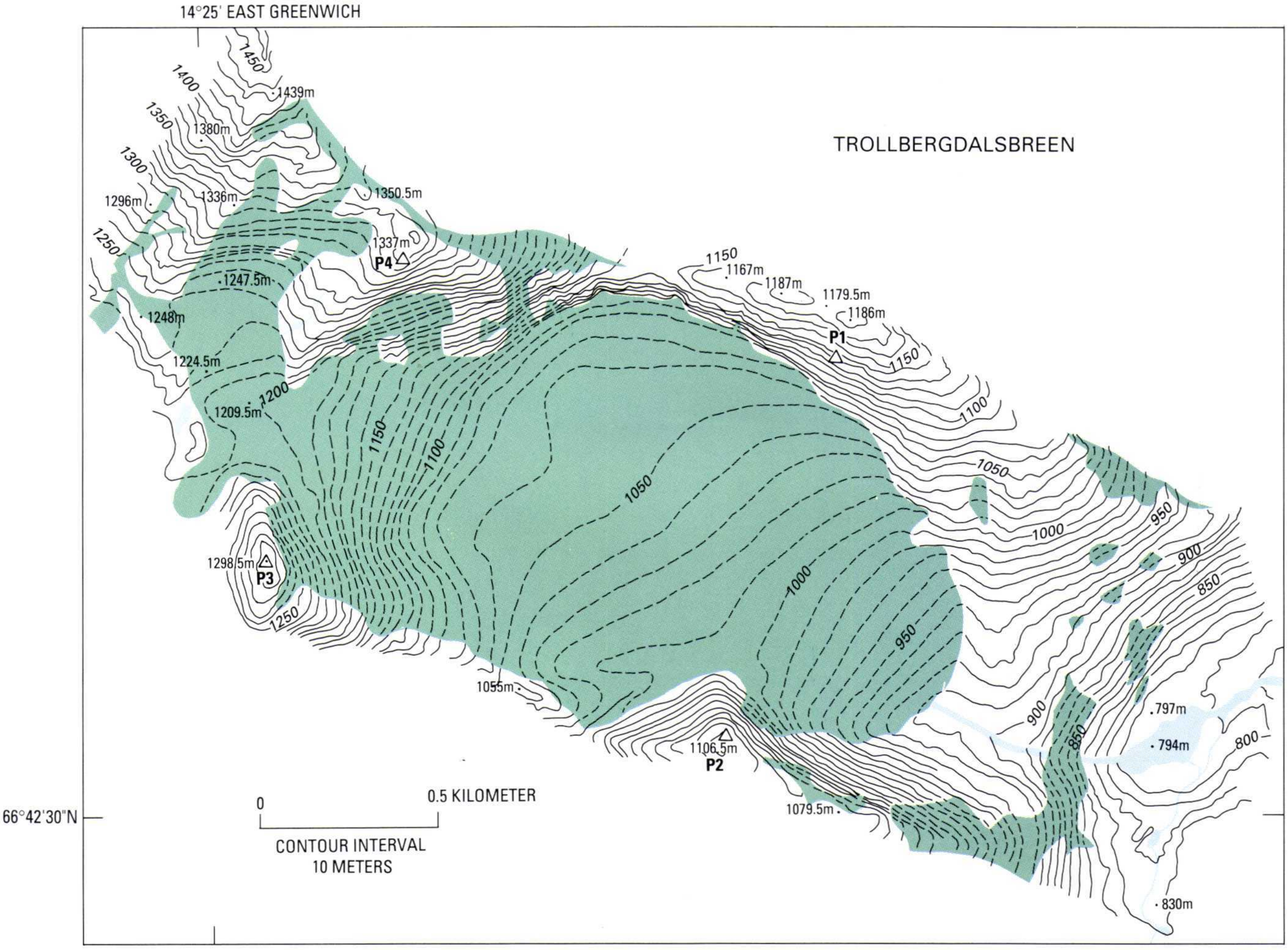


Figure 11.—*A modern glacier map of Trollbergdalsbreen, northern Norway, compiled from aerial photographs taken on 25 August 1968. The original map was printed in 1970 in four colors at a scale of 1:10,000 with 10-m contour intervals, in accordance with guidelines proposed by the First International Symposium on Glacier Mapping, which was held in Ottawa, 1965.*

TABLE 3.—*Glacier maps published in Norway during the period 1952–88 (see also fig. 12)*

[NPI, Norwegian Polar Research Institute; NVE, Norwegian Water Resources and Energy Administration; SU, University of Stockholm]

Map name	Scale	Year of aerial photography	Year of issue	Issued by	Colors	Remarks
Storbreen	1:10,000	1951	1952	NPI	Three	
Østerdalsisen	1:20,000	1954	1956	NPI	One	Manuscript; only lower part.
Tverråbreen	1:10,000	1927	1962	NPI	Three	
Hellstugubreen	1:10,000	1941	1962	NPI	Three	
Blåisen ved Sildvikvann	1:10,000	1960	1963	NVE	One	Manuscript.
Part of Folgefonni	1:10,000	1959	1964	NVE	Three	
Storsteinsfjell	1:10,000	1960	1964	NVE	Four	
Nigardsbreen	1:20,000	1955,1964	1965	NVE	Three	
Hellstugubreen	1:10,000	1962	1965	NVE	Three	
Tunsbergdalsbreen	1:20,000	1955,1964	1966	NVE	Four	
Cainhavarrebreen	1:10,000	1960	1967	NVE	Two	
Erdalsbreen–Vesledalsbreen	1,20,000	1966	1967	NVE	Four	
Gråsubreen	1:10,000	1968	1968	NVE	Four	
Austre Memurubre	1:10,000	1966	1968	NVE	Four	
Vestre Memurubre	1:10,000	1966	1968	NVE	Four	
Ålfotbreen	1:10,000	1968	1969	NVE	Four	

TABLE 3.—*Glacier maps published in Norway during the period 1952–88 (see also fig. 12)*—Continued

[NPI, Norwegian Polar Research Institute; NVE, Norwegian Water Resources and Energy Administration; SU, University of Stockholm]

Map name	Scale	Year of aerial photography	Year of issue	Issued by	Colors	Remarks
Hellstugubreen	1:10,000	1968	1969	NPI	One	Manuscript.
Engabreen	1:20,000	1968	1970	NVE	Four	
Trollbergdalsbreen	1:10,000	1968	1970	NVE	Four	
Storbreen	1:10,000	1968	1971	NPI	Four	
Høgtuvbreen	1:10,000	1972	1973	NVE	Four	
Nigardsbreen	1:20,000	1966,1974	1975	NVE	Four	
Bondhusbreen	1:10,000	1959,1979	1979	NVE	Five	
Hellstugubreen	1:10,000	1980	1980	NVE and NPI	Four	
Riukojietna[1]	1:10,000	1960,1978	1983	NVE and SU	Three	Two maps.
Salajekna (Sulitjelma)[1]	1:50,000 1:20,000	1950,1957–58 1971,1980–82	1983	NVE and SU	Four	Four maps.
Midtre Folgefonni	1:20,000 1:10,000	1959 1981	1984	NVE and SU	Four	Two maps.
Gråsubreen	1:10,000	1984	1985	NVE and SU	Four	
Strupbreen	1:20,000 1:10,000	1952,1978 1985	1985	NVE and SU	Four	Three maps.
Sylglaciären[2]	1:10,000	1958,1966, 1971,1975, 1982	1985	NVE and SU	Four	Five maps.
Nigardsbreen	1:20,000	1984	1988	NVE	Four	

[1] The glacier is partly located in Sweden.
[2] The glacier is located in Sweden.

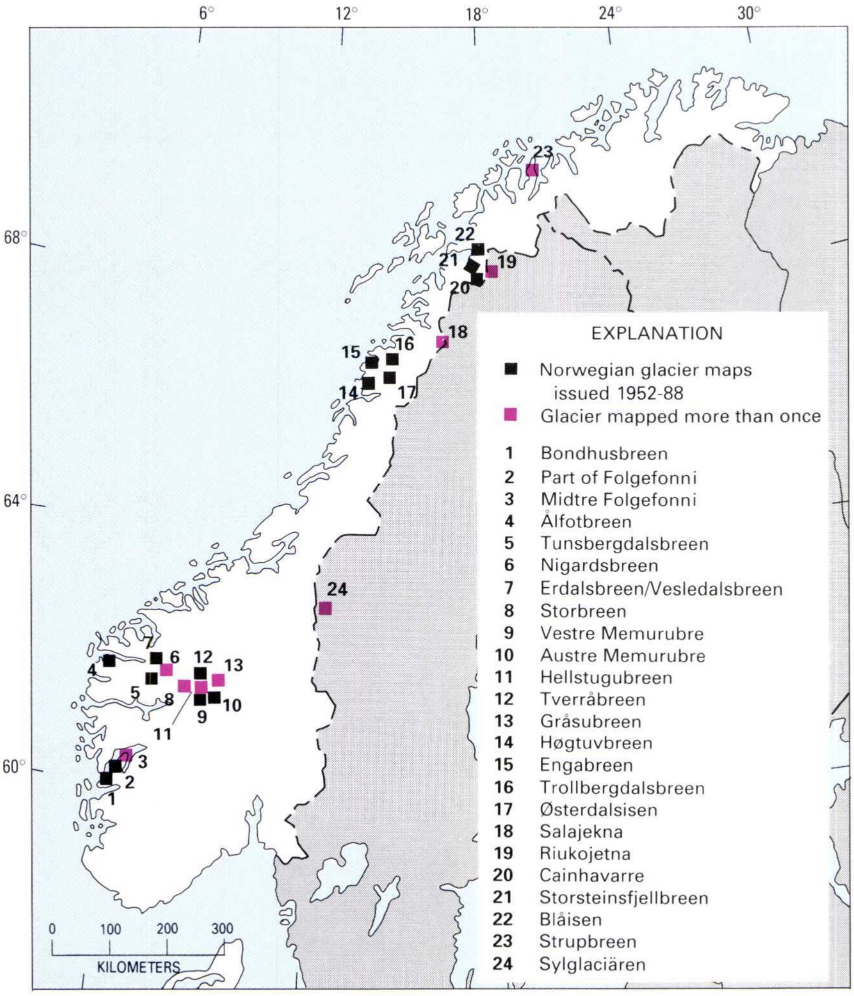


***Figure 12.**—Location of modern large-scale glacier maps of Norway published during the period 1952–88. Because some glaciers have been mapped more than once (red squares), one number may represent more than one glacier map.*

Historic and Modern Photographs and Satellite Images

Because of the distance from most glaciers to inhabited areas in Norway, there is a lack of historic pictures depicting glacier termini. However, some Norwegian paintings from the last century do exist, but they were not intended to show ice and snow; glaciers were included by chance only if the artist happened to have them within the field of view. In most cases the glaciers portrayed are so distant that the painting has very little value from a glaciological point of view.

The first "artistic" representation of glaciers in Norway was probably made by the Norwegian minister Niels Hertzberg, who portrayed the outlet glacier Bondhusbreen in August 1801 (fig. 13*A*). Another early glacier picture was made by the painter Johannes Flintoe; his product shows Nigardsbreen in 1822 in great detail—almost as good as that of a photograph (fig. 13*B*). Later, Professor J.D. Forbes from Edinburgh, who visited Norway in 1851, made a good drawing of Nigardsbreen that was printed in color (Forbes, 1853; fig. 14*A*). A photograph of

***Figure 13A.**—An artistic portrayal of Bondhusbreen, an outlet glacier from the Folgefonni ice cap, painted by Niels Hertzberg in 1801. This is the earliest known picture of a Norwegian glacier.*

Figure 13B.—*Nigardsbreen shown in great detail in an 1822 painting by the well-known Norwegian artist Johannes Flintoe.*

Figure 14A.—*Nigardsbreen in 1851 from an illustration by J.D. Forbes (1853).*

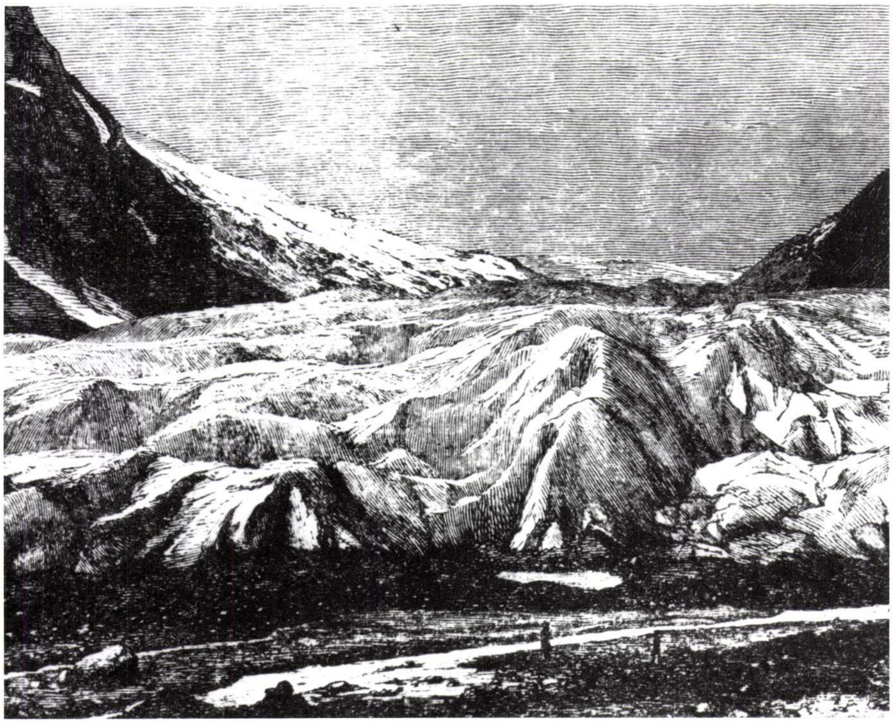


Figure 14B.—*Nigardsbreen in 1864 from a photograph by the pharmacist/photographer Selmer that was published in* Illustreret Nyhedsblad. *The original photograph was copied in a woodcut by H.P. Hansen in Leipzig so that it could be printed in the newspaper.*

Figure 15.—*One of the oldest known photographs of Nigardsbreen, taken by J.B. Rekstad in 1899. The glacier front had then retreated more than 1 km since J.D. Forbes made his drawing in 1851. (See fig. 14A.)*

Nigardsbreen by Selmer was made into a woodcut and published in *Illustreret Nyhedsblad* in 1864 (fig. 14*B*). Some of these artworks are so detailed that they can be used for calculations of the glacier volume at that time, but some are too "artistic" to be used in this context. The Norwegian scientist J.B. Rekstad, geologist and photographer, took numerous pictures of various glacier termini from the same viewpoint in different years (fig. 15). Also, the French geographer Charles Rabot took several photographs during the period 1880–90 of various geographical subjects, particularly in northern Norway, including some glaciers, and his pictures are of high quality (fig. 16). Engabreen has retreated 2 km between Rabot's photographs in 1883 and recent studies in 1974 (fig. 17).

Figure 16.—*Engabreen, an outlet glacier from the northwestern part of the Svartisen ice cap, photographed in 1883 by Charles Rabot. Compare with figure 17 (below), a photograph of the same area 91 years later that demonstrates about 2 km retreat.*

Figure 17.—*Engabreen in 1974. The glacier has retreated about 2 km since 1883 (compare with fig. 16), and most of the recession has occurred since 1930. Photograph by Nils Haakensen.*

A professional photographer, Mr. Knud Knudsen from Bergen, traveled extensively in Norway, particularly in western Norway during the years 1860–1900. He took numerous beautiful photographs, mainly to prepare postcards, but among them are a lot of good glacier photographs. Some of these can be dated. Most of his 20,000–25,000 glass negatives and some of his postcards were taken over by the University Library in Bergen and are now accessible to researchers.

The first commercial aerial photographs showing a Norwegian glacier were taken in 1937 and show part of the Folgefonni ice cap (Widerøe's Contract No. 14), but the negatives have been lost. A German scientific expedition arranged for vertical aerial photographs of selected glaciers in southern Norway in the 1930's, and an example is shown in figure 18. Unfortunately, in this case also, the negatives have been lost. Since

Figure 18.—*One of the first known vertical aerial photographs of a Norwegian glacier, showing the snout of Nigardsbreen and its associated terminal moraine system. The photograph was taken in 1938 by the Norwegian Surveying Company Widerøe under contract from a German scientific expedition. The scale is approximately 1:37,000.*

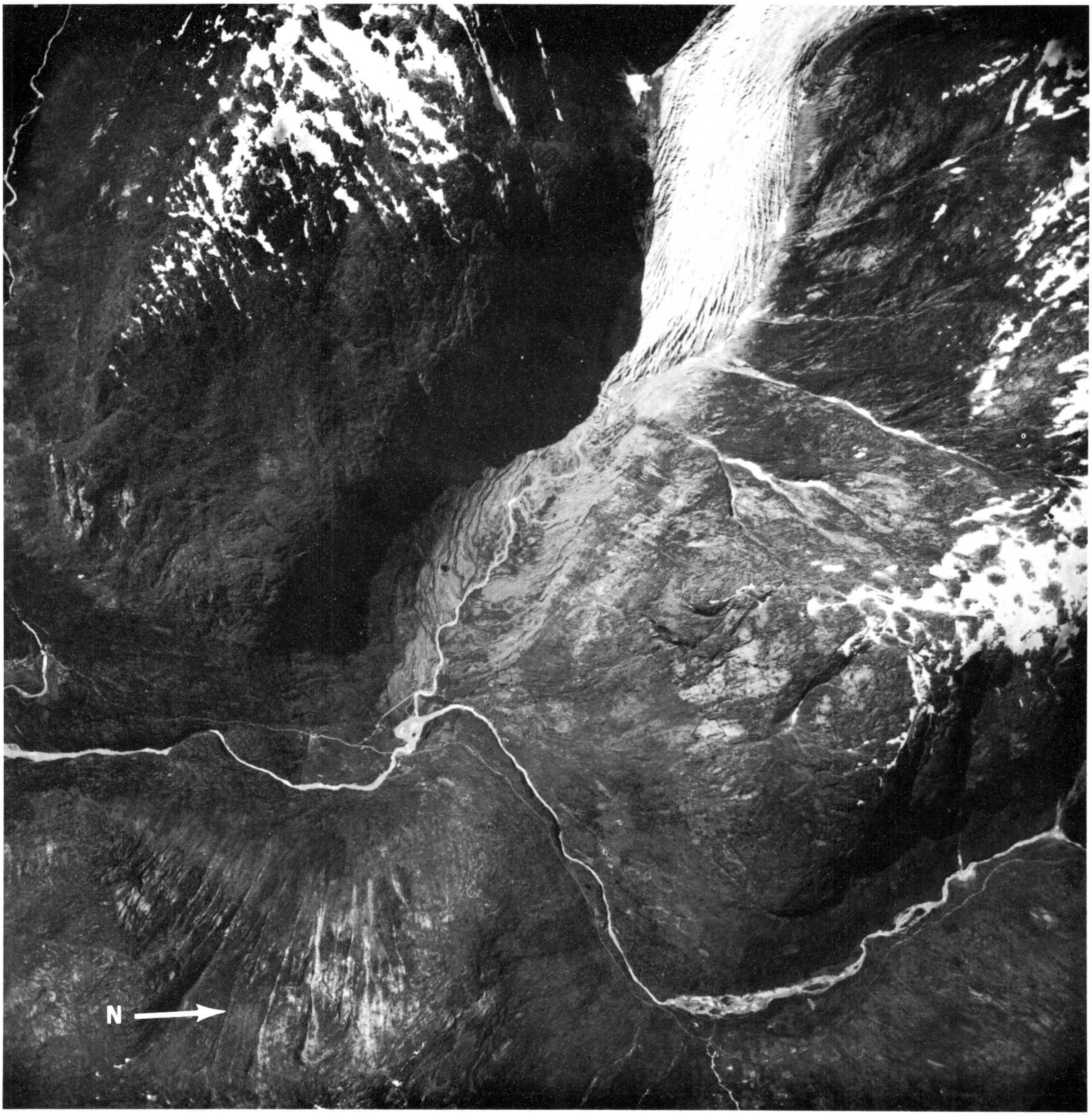
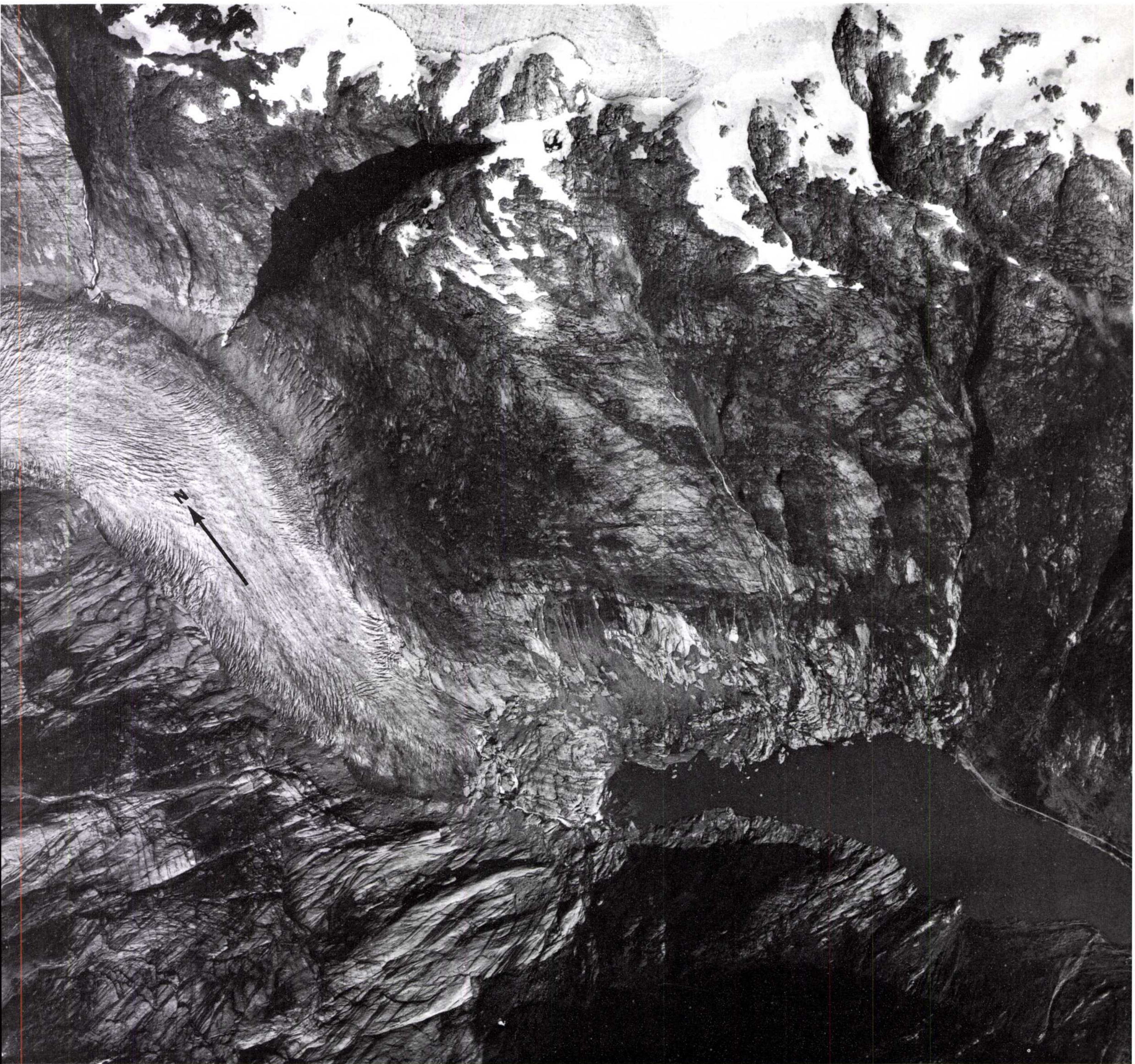


Figure 19.—Vertical aerial photograph of the terminus of Nigardsbreen taken in August 1974 (Fjellanger-Widerøe No. 4409–A3). The length of the lake is about 1.9 km, and the scale is approximately 1:18,000. In 1938 (see fig. 18), the snout was located just at the lower end of the lake.

World War II a great number of vertical aerial photographs have been taken, particularly for production of the new 1:50,000-scale topographic map series of Norway.

Aerial photographs, taken from various altitudes, are now available of almost every glacier in Norway. Repeated aerial photographic surveys make possible comparisons of volume changes of glaciers during intervals of several years. A modern vertical aerial photograph is shown in figure 19 and can be compared with the old German aerial photograph (fig. 18). Another interesting comparison can be made between terrestrial photographs of Nigaardsbreen that were taken in 1959 and 1981. They show



continuous retreat (figs. 20 and 21). Similarly, the outlet glacier Mjølkevoldsbreen, on the western side of the Jostedalsbreen ice cap, has receded most dramatically (fig. 22), in one of the most rapid retreats seen in Norway over such a short period of time.

It is quite obvious that similar comparisons will be possible through the use of satellite images taken at intervals of several years. Thus, an archive of images showing glaciers on a global scale will be most valuable in the future.

As a historical note, it should be mentioned that one of the very first images produced by Landsat 1 in 1972 (on the sixth day of its operation

Figure 20.—*Nigardsbreen, in July 1959, photographed from nearly the same position as that illustrated by Forbes (see fig. 14A) and photographed by Rekstad (see fig. 15). Photograph by Olav Liestøl, Norsk Polarinstitutt.*

Figure 21.—*Nigardsbreen, photographed in 1980 from nearly the same position as in figures 13B, 14, 15, and 20. Photograph by Nils Haakensen.*

Figure 22.—Two photographs showing the retreat of Mjølkevoldsbreen (western side of the Jostedalsbreen ice cap) between 1933 (top) and 1939 (bottom) (from Fægri, 1940).

since its launch on 22 July 1972) was of the northernmost glacier in continental Europe, Seilandsjøkulen. The transient snowline could be seen easily on the image. This almost "historical image" (fig. 23) is compared with a vertical aerial photograph taken 2 years earlier (fig. 24), where a similar, but not identical, snowline can be seen. From the Landsat digital (computer-compatible tape, or CCT) data a dotprint "map" of this glacier was also made (fig. 25).

Investigations have been made to evaluate usefulness for hydrological purposes of image data from meteorological satellites (Østrem and others, 1979). It is obvious that the resolution in images from the television and infrared observation satellite (TIROS) or the National Oceanic and Atmospheric Administration (NOAA) satellites, about 1.1 km, cannot give the same glaciological information as Landsat data, but the location of glaciers, their approximate size, and so on can be obtained from analysis of such images (figs. 26 and 27).

A much better tool in glaciological research is, of course, the Landsat image taken under cloud-free conditions. For many purposes the MSS

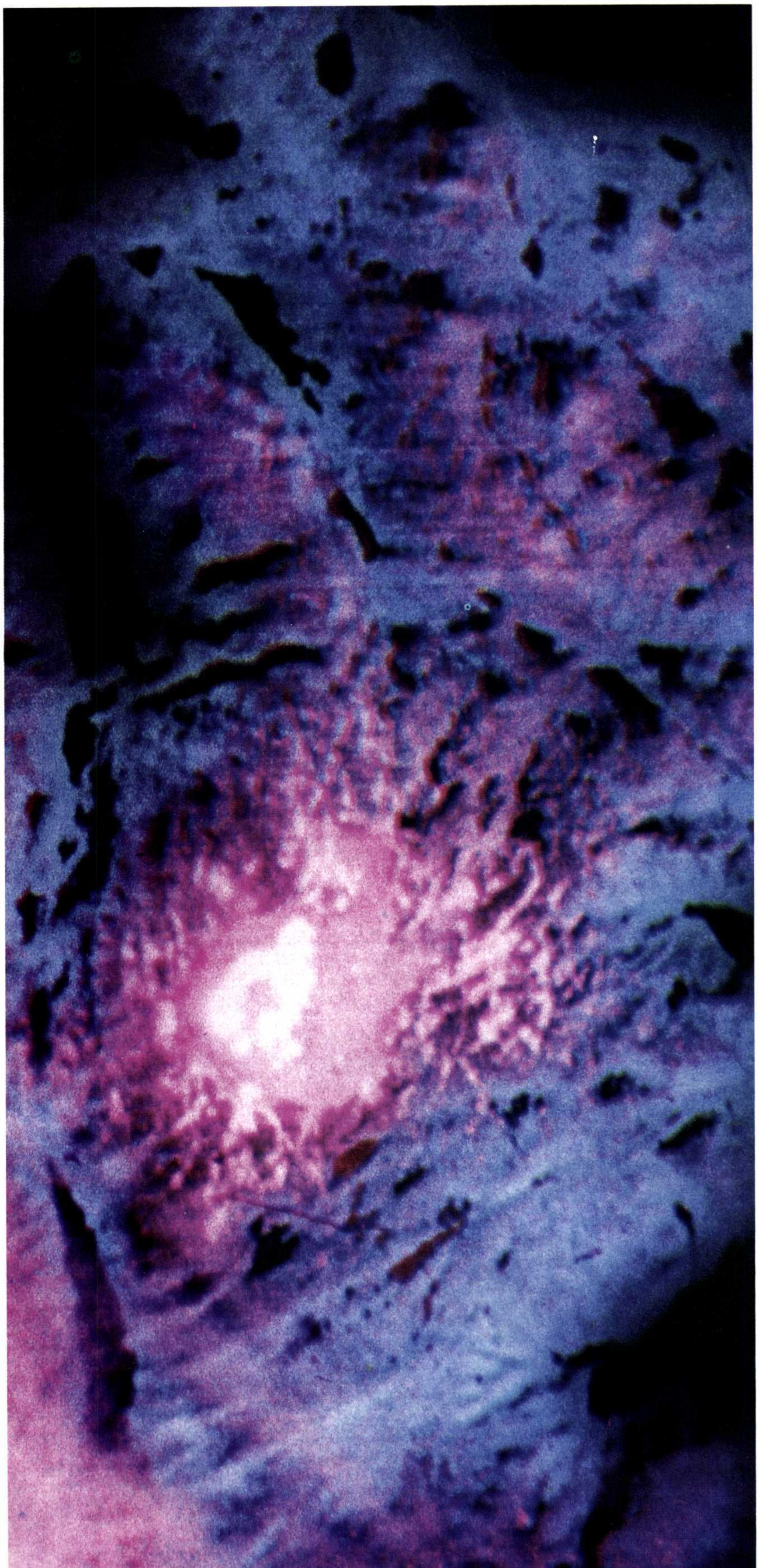


Figure 23.—*Landsat MSS false-color composite image of Seilandsjøkulen, the northernmost glacier in Norway, taken on 29 July 1972 (1006–09481, MSS band 5 with a red filter, MSS band 6 with a blue filter, and MSS band 7 with a green filter; Path 211, Row 10). Snow is white and bare ice is red. Sediment-laden water appears red, whereas clear water is black. The bedrock is blue. This is the first Landsat 1 image acquired over Norwegian territory. The image covers an area of approximately 25 km × 50 km.*

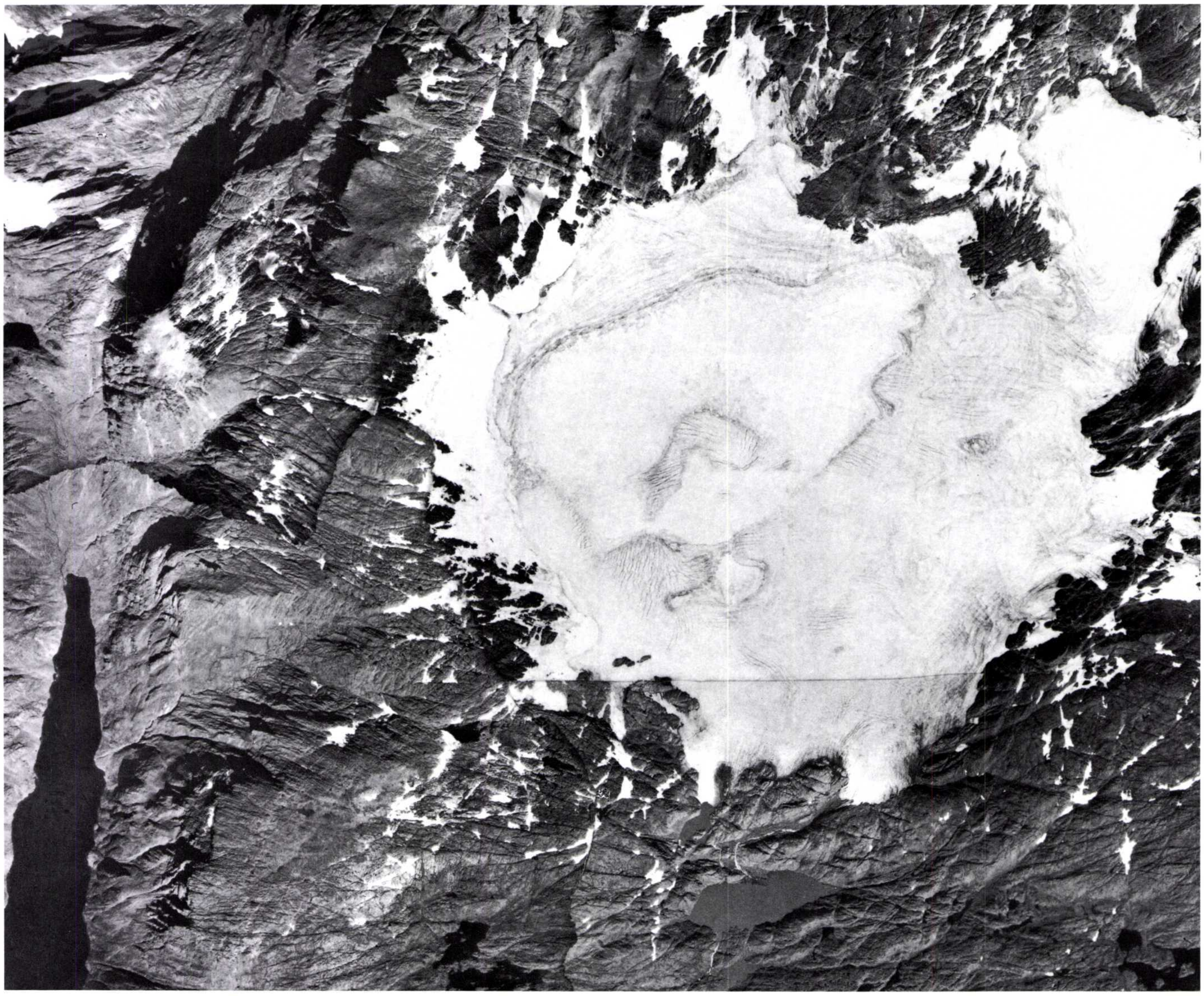


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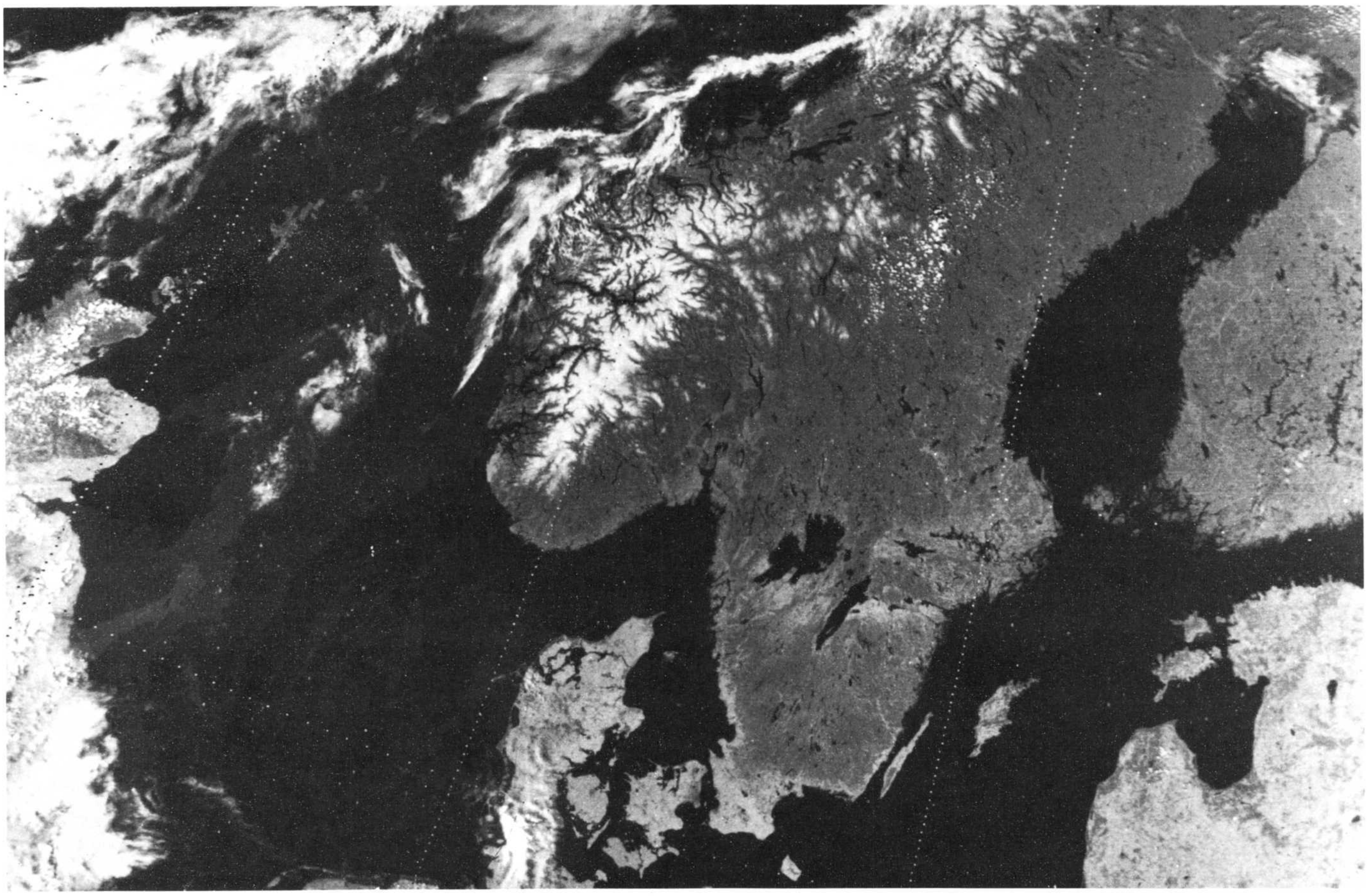
Figure 24.—*Vertical aerial photograph of the small Seilandsjøkulen ice cap, the northernmost glacier in Norway (Fjellanger-Widerøe No. 3615, August 1970). The scale is approximately 1:45,000.*

Figure 25.—*A "map" of Seilandsjøkulen ice cap produced as a computer-generated dot-print from Landsat MSS band 7 digital data (1006–09481; 29 July 1972; Path 211, Row 10). The white areas represent residual snow from the past winter; the gray areas (in general marked by –, 1, A, or Θ) represent bare glacier ice, whereas darker areas and overprinted characters indicate bedrock or water. Each character represents one pixel (about 60 × 80 m). The scale is approximately 1:50,000. From Østrem (1975); reproduced from the Journal of Glaciology, v. 15, no. 73, p. 403–415, by courtesy of the International Glaciological Society.*



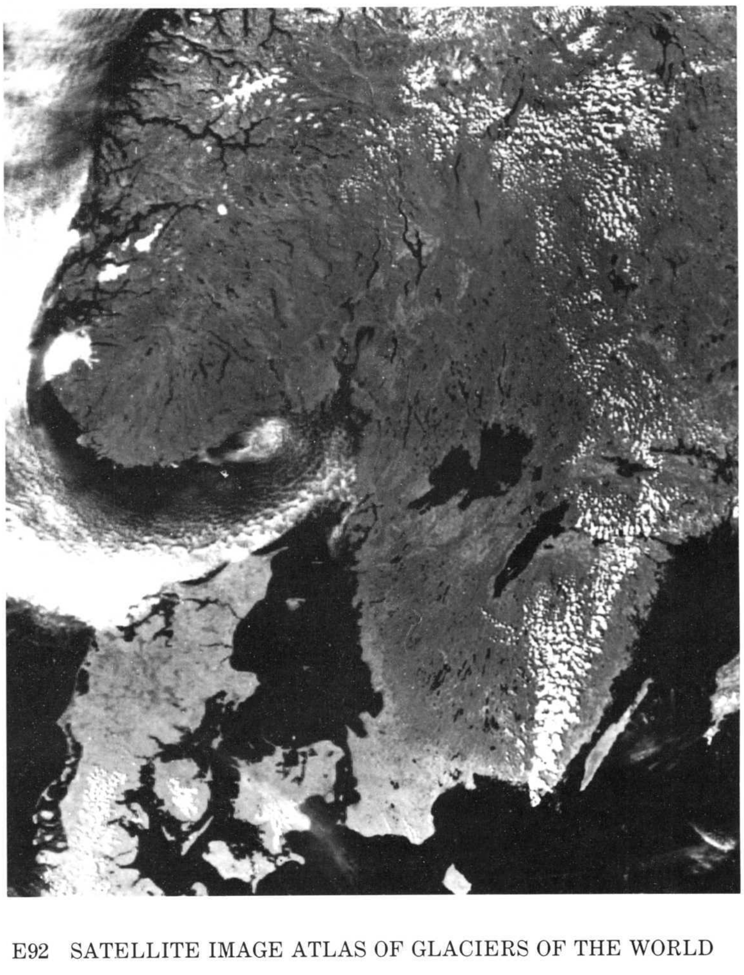


Figure 26.—*NOAA image of southern Norway taken on 1 June 1982. The high-altitude areas (about 1,000 m above mean sea level) are still snow covered. Scale approximately 1:10,000,000. NOAA image received and processed by the Norwegian Telemetry Station in Tromsø.*

Figure 27.—*NOAA image of southern Norway taken on 30 July 1982. The snow has disappeared, and the glaciers appear as white areas. The large white dot in the southwest is a cloud. In the northeast some cumulus clouds are visible. Scale approximately 1:8,000,000. NOAA image received and processed by the Norwegian Telemetry Station in Tromsø.*

false-color composite images may be even more useful. The EROS Data Center (EDC) standard MSS false-color composite (MSS band 4 through a blue filter, MSS band 5 through a green filter, and MSS band 7 through a red filter) distributed by EDC will normally show bare glacier ice in blue and the rest of the glacier in white (fig. 28). It is, however, possible to change the color filters or vary the intensity of the colors in order to emphasize glaciological features, such as sediment in glacier streams and lakes. A good example is the image of Hardangervidda shown in figure 29, where sediment in lakes can be seen easily. A decreasing amount of suspended sediment is apparent at increasing distance from the terminus of the glacier. It may be possible, in the future, to calibrate satellite images so that the sediment concentration in lakes could be calculated from satellite data. So far, this task has proven difficult; a qualitative determination is possible, but reliable *quantitative* calculations are still impossible.

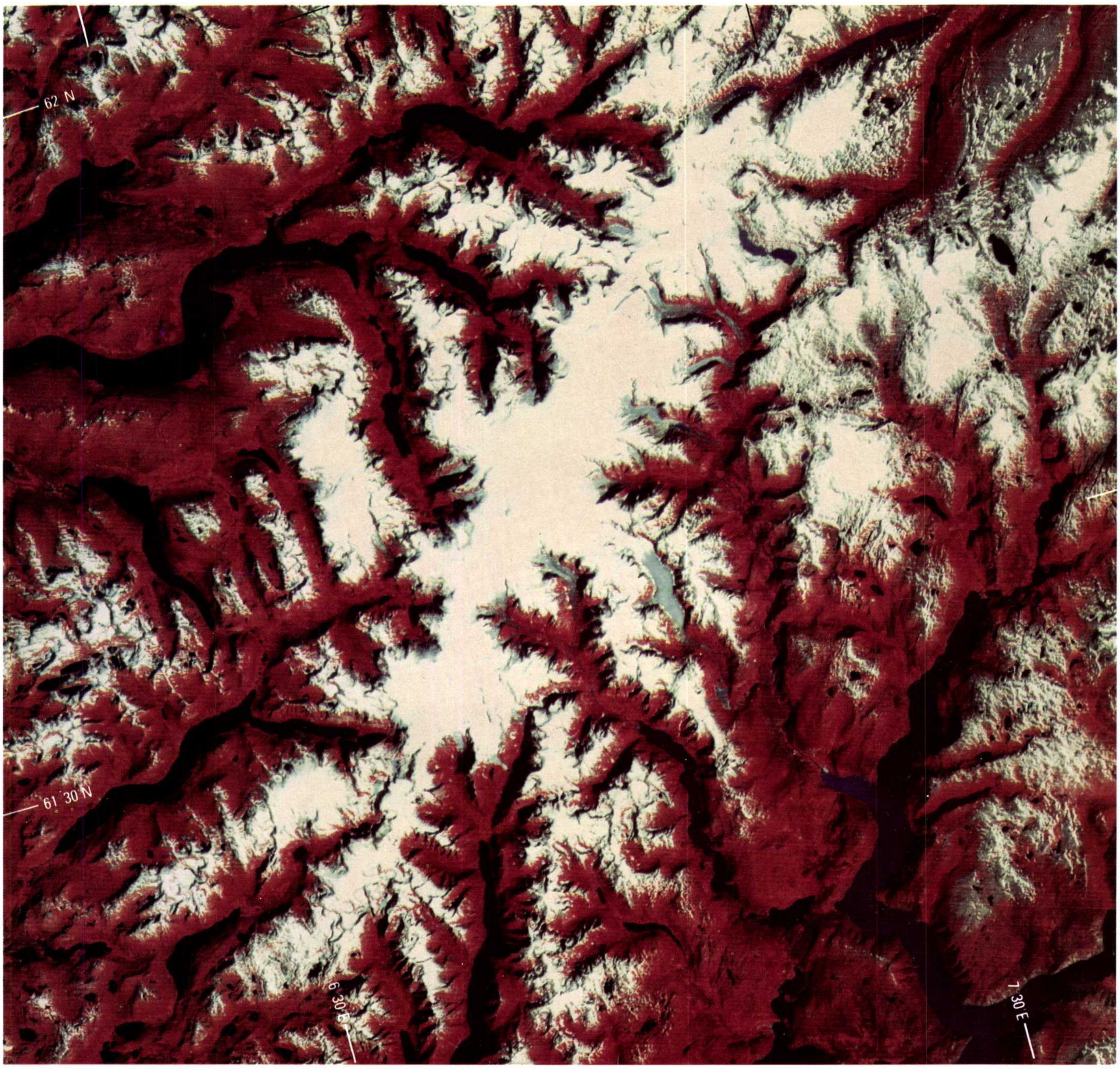


Figure 28.—*A section of a Landsat MSS false-color composite image (2565–10004; MSS band 4 with a blue filter, MSS band 5 with a green filter, and MSS band 7 with a red filter; 9 August 1976; Path 216, Row 17) showing the Jostedalsbreen ice cap, the largest continuous ice mass in continental Europe. The section covers approximately 90 × 85 km.*

Glaciological Phenomena

The transient snowline (TSL) on a glacier is defined as the transition line between exposed (bare) glacier ice and snow or firn. This line is situated somewhere on the lower part of the glacier at the beginning of the melt season when last winter's snow disappears and the bare glacier ice is gradually exposed. It moves to higher altitudes throughout the melt season and reaches its highest position at the end of the summer. If this highest position, given in meters above sea level, is plotted against the net mass balance, given in meters of water equivalent, this relation is expressed by a straight line (see Liestøl, 1967, p. 46; Østrem, 1975; and figure 30). Each single dot in this diagram is a result of 1 year's field and office work. For Nigardsbreen this means an annual cost in the order of several thousand dollars.

After this diagram has been established for a particular glacier, however, it becomes possible to determine the approximate net mass balance directly from the height of the TSL at the end of the summer, provided its position (and elevation) can be identified. By an appropriate, very simple color coding of Landsat images it may be easy to distinguish exposed glacier ice from the snow-covered areas on glaciers (fig. 31). If the Landsat image is compared with a topographic map, the height of the TSL can be determined, as has been done in figure 32 for Jostedalsbreen and environs. At Jostedalsbreen the height of the TSL was between 1,160 m and 1,360 m above sea level on 27 August 1976 (table 4). It increases eastward as can be seen on Spørteggbreen and Holåbreen. Within a limited area the height of the TSL does not vary very much. The steepest glaciers, however, show a tendency for a higher TSL level.

Similarly, for the cirque and valley glaciers in Jotunheimen (figs. 33 and 34) the TSL on 27 August 1976 could be determined for 15 glaciers (table 5). Also, the TSL in the Jotunheimen area shows a consistent increase in altitude toward the east, the more continental part of Norway.

◀ ***Figure 29.****—A section of Landsat MSS image 22059–10083 (11 September 1980; Path 216, Row 18) showing the Hardangervidda mountain plateau in the central part of southern Norway. Note the ice caps of Folgefonni in the west and Hardangerjøkulen in the north. The northern part of the latter ice cap drains eastward, and the sediment is clearly visible (light bluish color) in the lakes in the upper right part of the image. The sediment content decreases with increasing distance from the glacier. Approximate scale 1:42,000. Special MSS false-color composite processing by Fjellanger-Widerøe, Oslo, with MSS band 4 in blue, MSS band 5 in green, and MSS band 7 in red.*

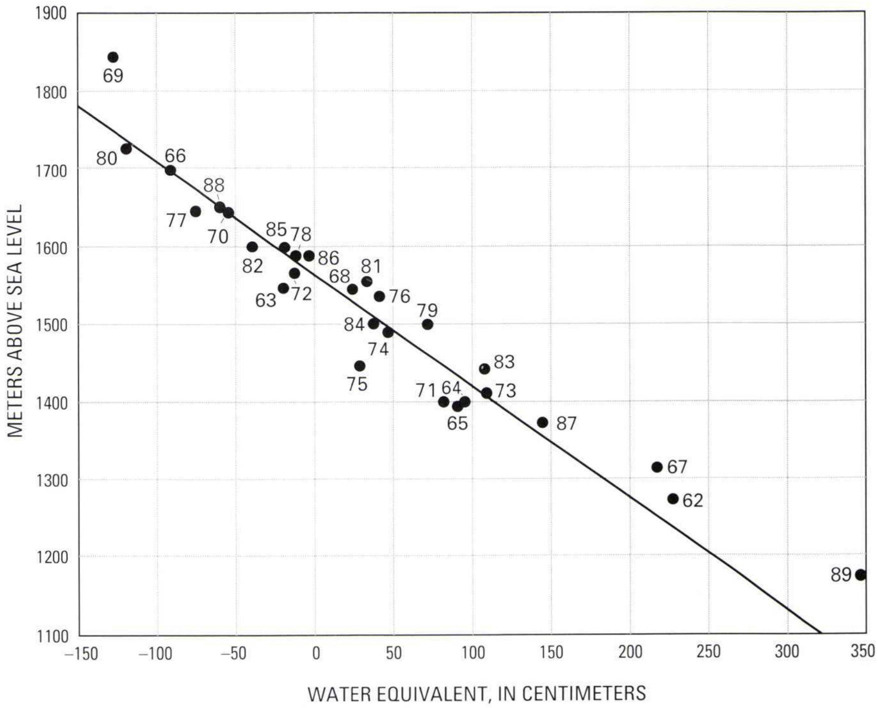


Figure 30.*—The clear linear relation between the elevation of the equilibrium line at the end of the ablation season and the specific net balance of a glacier. This example is from Nigardsbreen, where mass-balance studies have been performed continuously since 1962. The plotted points show the relations for each year from 1962 to 1989. Similar diagrams have been made for several other glaciers. From Østrem, 1975; reproduced from the Journal of Glaciology, v. 15, no. 73, p. 403–415, by courtesy of the International Glaciological Society.*

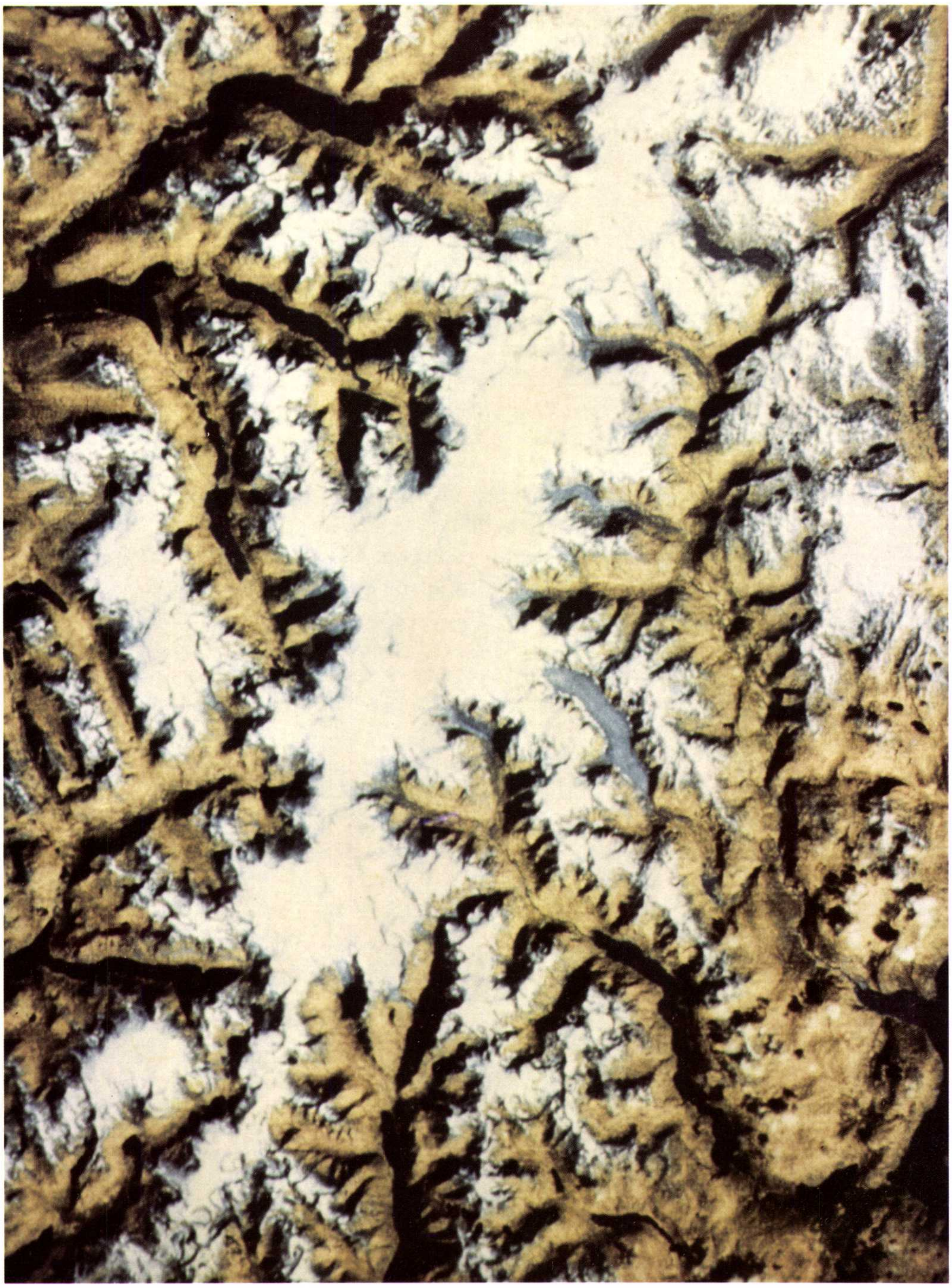


Figure 31.—*Landsat special MSS false-color composite image of the Jostedalsbreen ice cap (2583–10001; MSS band 4 in blue, MSS band 7 in yellow; 27 August 1976; Path 216, Row 17). The transient snowline is clearly visible on many outlet glaciers as the border between white snow-covered areas and bluish areas representing exposed or bare glacier ice. Black areas are lakes, fjords, or shadows in narrow valleys. (The image covers the same area as shown on the map in fig. 32, or approximately 60 × 75 km.)*

Figure 32.—Areas of exposed ice as of 27 August 1976 that were determined on 24 outlet glaciers in the Jostedalsbreen area from the Landsat MSS image (2583–10001; 27 August 1976; Path 216, Row 17). (Compare also with fig. 31.) The contour interval is 200 m, heights in 100's of meters. The altitude of the transient snowline, as determined from topographic maps, was between 1,160 and 1,360 m above sea level at Jostedalsbreen (average 1,242 m) but a little higher farther east. Abbreviations and individual transient snowline altitudes are shown in table 4.

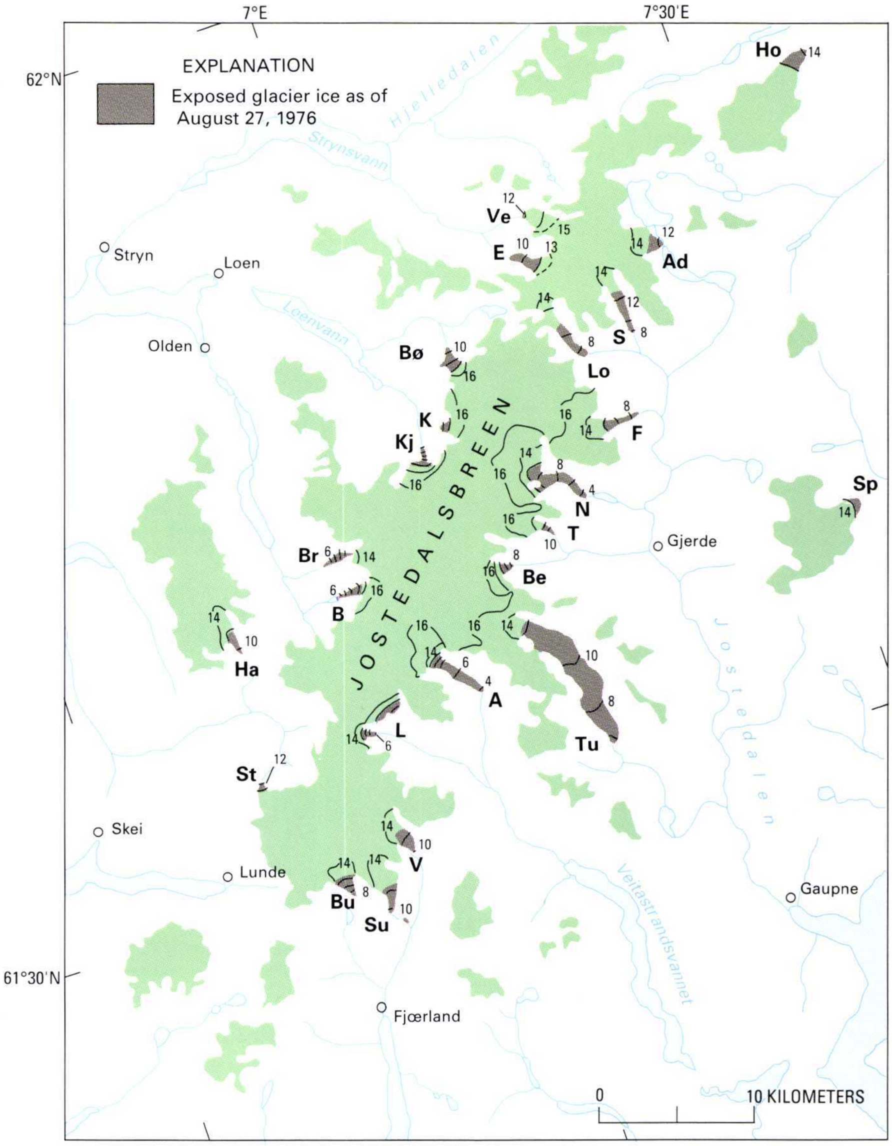


TABLE 4.—*Results of height determinations of the transient snowline (TSL) level on 27 August 1976 from a Landsat image of the area of the Jostedalsbreen ice cap (compare with figs. 31 and 32)*

Abbreviation	Glacier name	Height of TSL (meters)
A	Austerdalsbreen	1,200
Ad	Austdalsbreen	1,280
B	Briksdalsbreen	1,300
Be	Bergsetbreen	1,200
Br	Brenndalsbreen	1,250
Bu	Bøyumsbreen	1,300
Bø	Bødalsbreen	1,360
E	Erdalsbreen	1,220
F	Fåbergstølsbreen	1,200
Ha	Haugabreen	1,200
Ho	Holåbreen	1,580
K	Krunebreen	1,300
Kj	Kjenndalsbreen	1,240
L	Langedalsbreen	1,200
Lo	Lodalsbreen	1,160
N	Nigardsbreen	1,220
S	Stegholtbreen	1,240
Sp	Spørteggbreen	1,400
St.	Strupebreen	1,240
Su	Supphellebreen	1,220
T	Tuftebreen	1,300
Tu	Tunsbergdalsbreen	1,240
V	Veslebreen	1,250
Ve	Vesledalsbreen	1,200

Consequently, if good satellite images are available at the end of the melt season and the above-mentioned relation has already been established, it is obvious that great savings could be made in the cost of glacier mass-balance work. However, several constraints remain. Many glaciers are located in areas of frequent bad weather or heavy cloud cover, and it might be difficult to accurately define the end of the melt season. Furthermore, this method gives the *net* balance only; data on the two most important factors that determine it, the winter accumulation and the summer ablation, cannot be obtained so easily. For an operational use of this method it is necessary to obtain images that are not obscured by clouds and that give good temporal coverage during a period near the end of the melt season.

Glaciers, in the course of their movement, produce copious amounts of sediment (fine-grained, about 50 percent; coarse material, about 50 percent), that is carried away by melt water. Large rocks, gravel, and some finer material carried within the ice will be deposited in the front as terminal moraines. Suspended sediment, sometimes called glacier rock flour, gives the characteristic milky color to glacier rivers and lakes downstream. One example of this was shown in figure 29 in the previous section. Another example is shown in figure 35, where the suspended

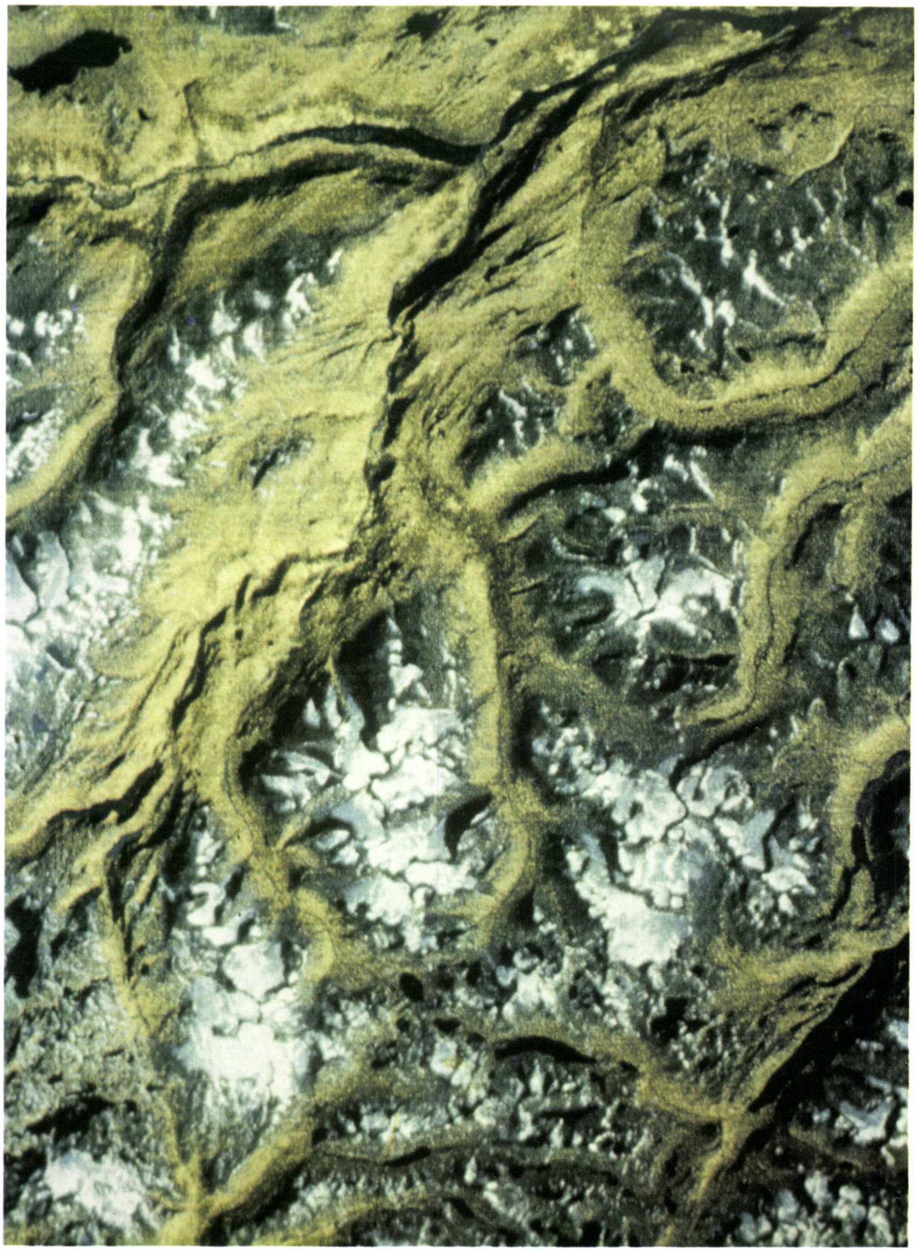
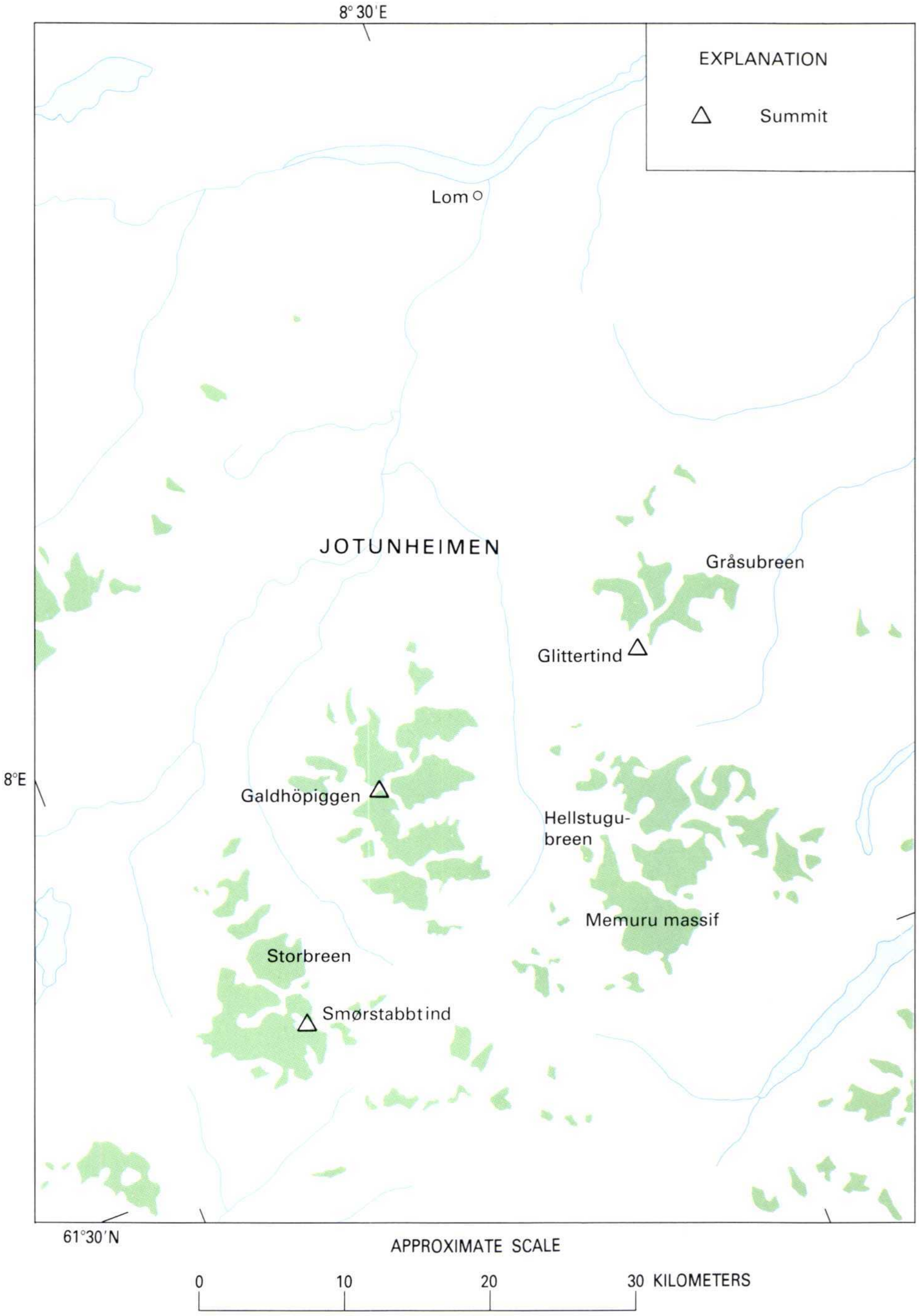


Figure 33.—Part of a special false-color composite Landsat MSS image of the Jotunheimen area (2583–10001; MSS band 4 in blue, MSS band 7 in yellow; 27 August 1976; Path 216, Row 17), covering approximately 45 × 55 km, the same area as the map shown in fig. 34. White regions represent snow-covered areas (mainly on glaciers), and light-blue areas represent exposed ice. The height of the transient snowline can be defined at 15 glaciers by comparison with a topographic map, and it has been determined to lie between 1,690 and 2,130 m above sea level, with a mean value of 1,853 m above sea level. The height of the transient snowline increases eastward (that is, with increasing continentality) (compare with table 5).

sediment has been discharged into an arm of the Sognefjord. Even a very weak concentration of suspended sediment in various lakes is here visible on the special color-coded Landsat image. A digital printout from MSS band 4 shows the plume of sediment in the Gaupnefjord (fig. 36).

During recent years, waterpower engineers have requested that special investigations be directed at suspended sediment transport in glacier streams. Small rock particles cause increased wear in turbines, so data on the amount and characteristics of suspended sediment are of great interest. These investigations require, however, continuous fieldwork, because water samples must be taken several times daily to give data for a reliable calculation. We have seen that Landsat images clearly indicate those lakes and fjords where suspended sediment is present, and the data can also indicate variations in sediment concentration, although the calibration problem is still unsolved. At present the repetition time and weather constraints limit the usefulness of satellite data in this application.

Figure 34.*—Map of the Jotunheimen high-mountain area in the central part of southern Norway. The highest summits reach about 2,400 m above sea level, and the area includes many cirque glaciers and small valley glaciers (from Østrem and Ziegler, 1969). Compare with figure 33, a Landsat image of the same area. The transient snowlines were determined for 15 of the glaciers in this area. They are listed in table 5.*



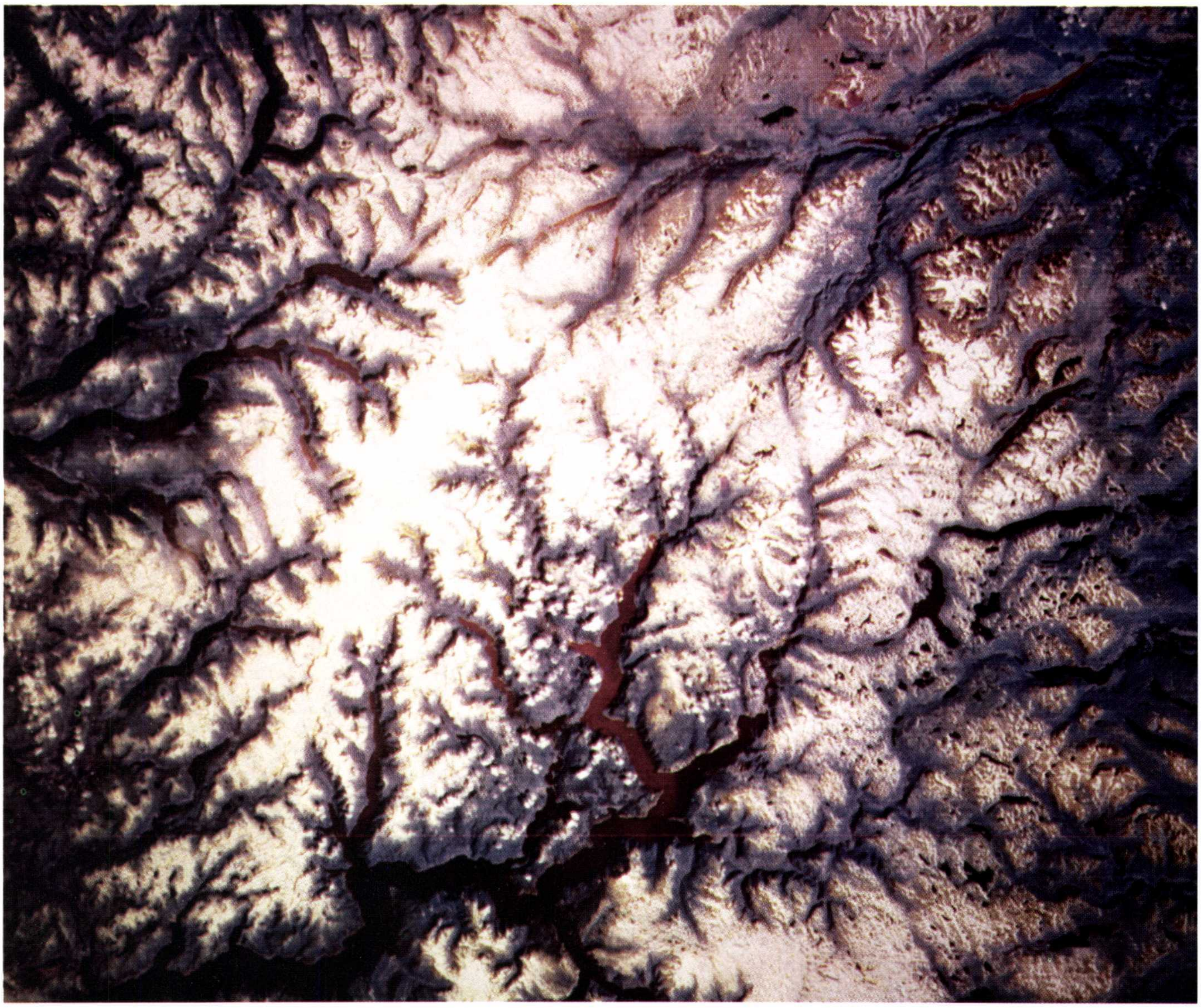
The special map shown in figure 37 demonstrates the economic importance of glaciers in waterpower-producing catchments. The map shows the specific water yield near a small ice cap (Hardangerjøkulen) in southwestern Norway; it also indicates an increasing quantity of water yield near the glacier. The water yield from a glacierized basin determines, of course, the production at a power station. Such basins are therefore very attractive for hydroelectric power developments. The map shows a very water-rich area, an area also shown on figure 29 in the previous section. The data on water discharge were taken from hydrological sources; satellite images cannot give such information as yet, but data collection platforms (DCP's) equipped with stream-gaging sensors have been used to transmit stream discharge measurements from field sites to a hydrological service. Polar-orbiting or geostationary weather satellites are used to relay the information.

TABLE 5.—*Results of height determinations of the transient snowline (TSL) level on 27 August 1976 from a Landsat image of the Jotunheimen area, central southern Norway (compare with figs. 33 and 34)*

[Height of transient snowline on 27 August 1976 increased more than 300 m toward continental areas (D) in the Jotunheimen area (fig. 34). Heights were taken from topographic maps]

Glacier group (fig. 34)	Glacier name	Number of height determinations	Height of TSL (meters)
A. Smørstabbtind massif		3	1,720±22
	Bøverbreen		1,740
	Storbreen		1,730
	Veslebreen		1,690
B. Galdhøpiggen massif		6	1,835±47
	South Illåbre		1,800
	Tverråbreen		1,770
	North Illåbre		1,870
	Svellnosbreen		1,800
	Styggebreen		1,870
	Storgjuvbreen		1,900
C. Memuru massif		4	1,855±23
	Hellstugubreen		1,860
	West Memurubre		1,830
	Veobreen		1,890
	Blåbreen		1,840
D. Glittertind		2	2,100±30
	West Grotbre		2,070
	Gråsubreen		2,130

***Figure 35.**—A Landsat MSS special false-color composite image (2187–10082; 28 July 1975; Path 216, Row 17) of the high-altitude areas of the central part of southern Norway (MSS band 4 in red, MSS band 5 in green, and MSS band 7 in blue). The Jostedalsbreen ice cap is situated in the left-central part of the image. Glacier sediment in lakes and fjords appears a very distinct red. Exposed ice appears yellow.*



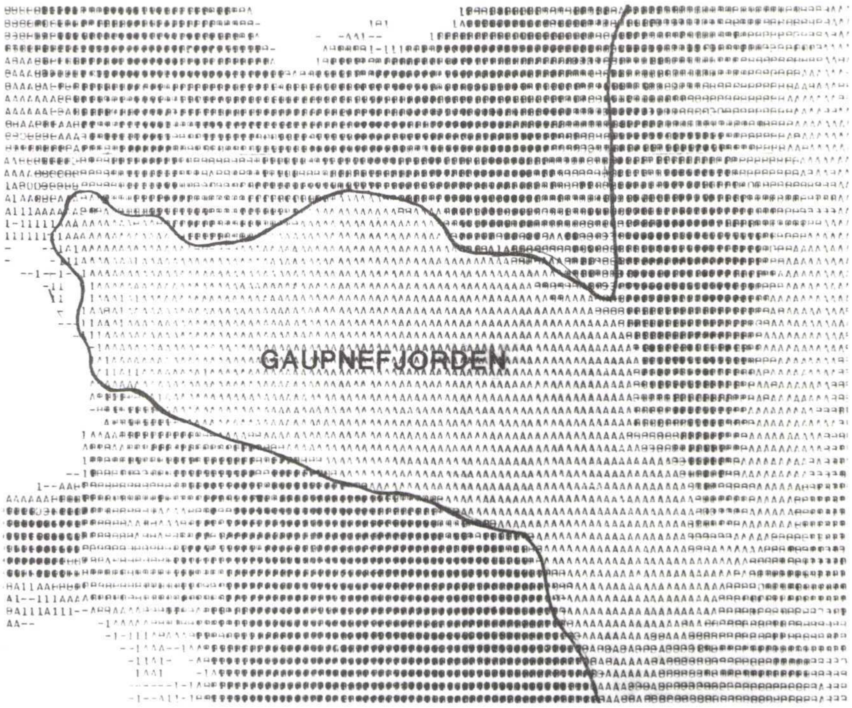


Figure 36.—*A digital printout (dotprint) from Landsat MSS image 1336–10260; band 4; 24 June 1973; Path 217, Row 17. The coast is indicated by a heavy line. The Jostedal River, which drains the eastern part of the Jostedalsbreen ice cap, carries a large sediment load into the Gaupnefjord (center). Sediment-laden water is indicated by light areas, whereas dark areas represent clear water. The white areas are clouds. Each character represents one pixel (about 60 × 80 m). The scale is approximately 1:66,000 (from Østrem, 1976).*

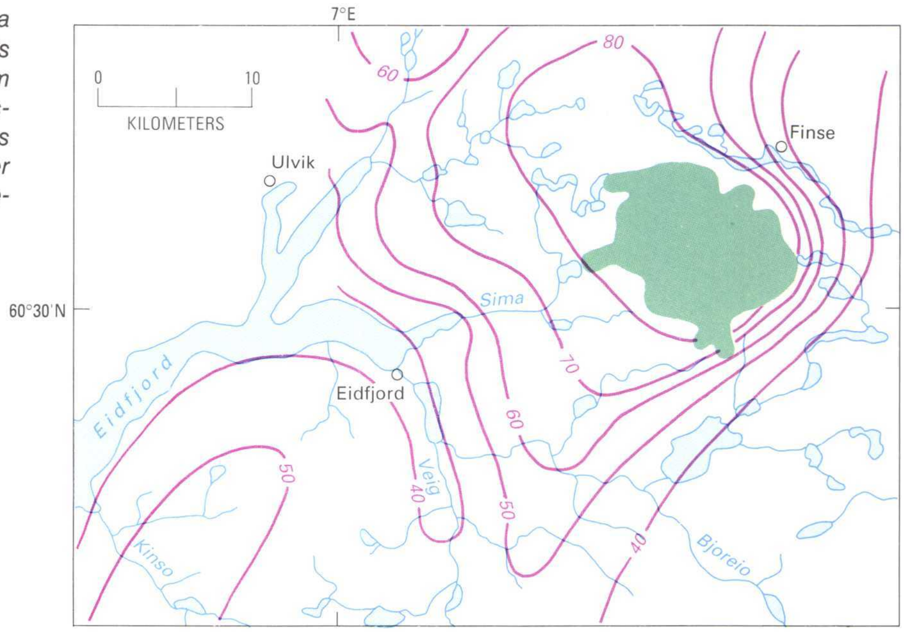


Figure 37.—*Specific discharge in the area around the Hardangerjøkulen ice cap. This map clearly shows that the water yield from the glacierized areas is large and is increasing toward the glacier. Contours are in liters per second per square kilometer. One liter per second per square kilometer corresponds to 66 acre-feet per square mile.*

Glaciers on Landsat Images

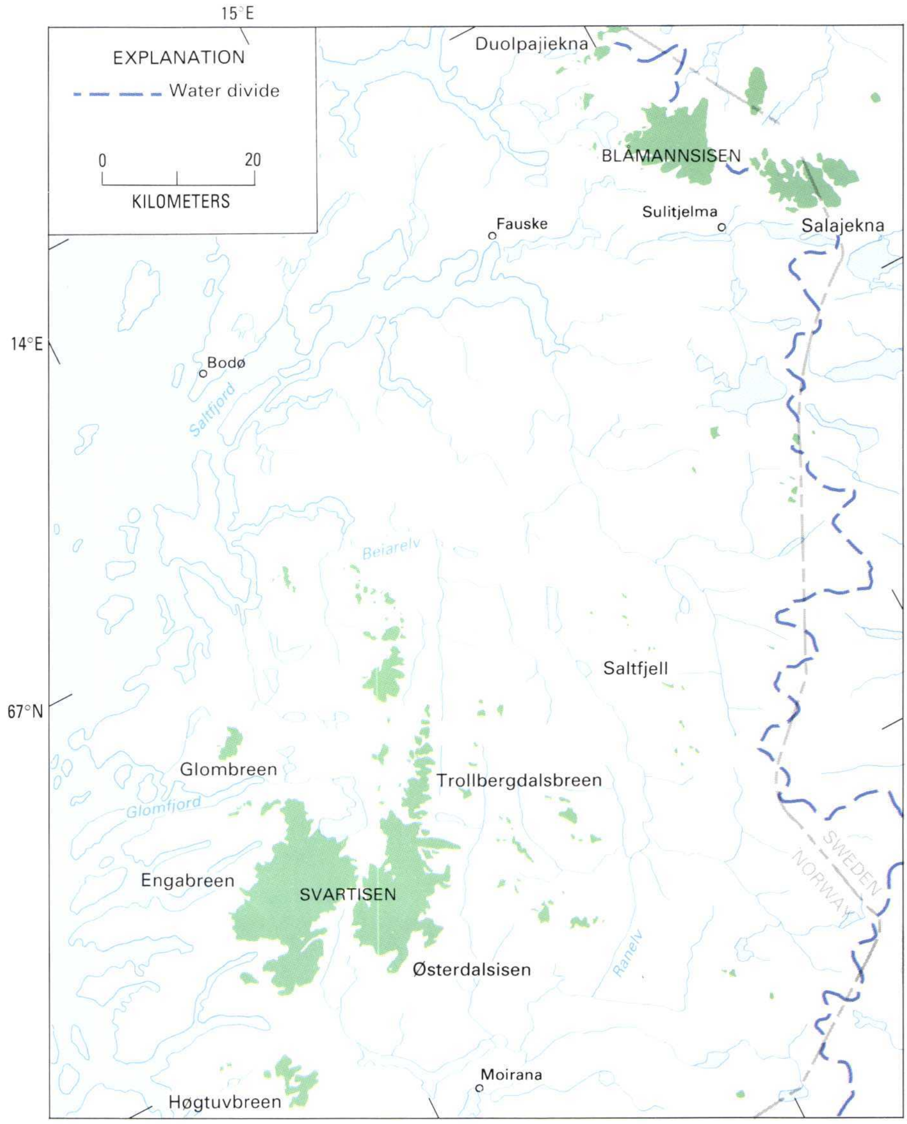
Good coverage with high-quality aerial photographs is available for nearly all glacierized areas in Norway. A detailed inventory of all ice masses in Norway has been made, and the results have been published in two glacier atlases (Østrem and Haakensen, 1980). These atlases, containing data for all glaciers on the Scandinavian peninsula, were produced before detailed satellite images were commonly available. Both aerial photographs and topographic maps formed the source of information for this inventory. For inventory purposes, no presently available satellite data can replace the excellent vertical aerial photography available in Norway. Some types of glaciological phenomena, however, can be better obtained from satellite imagery. These phenomena have been discussed earlier in this section.

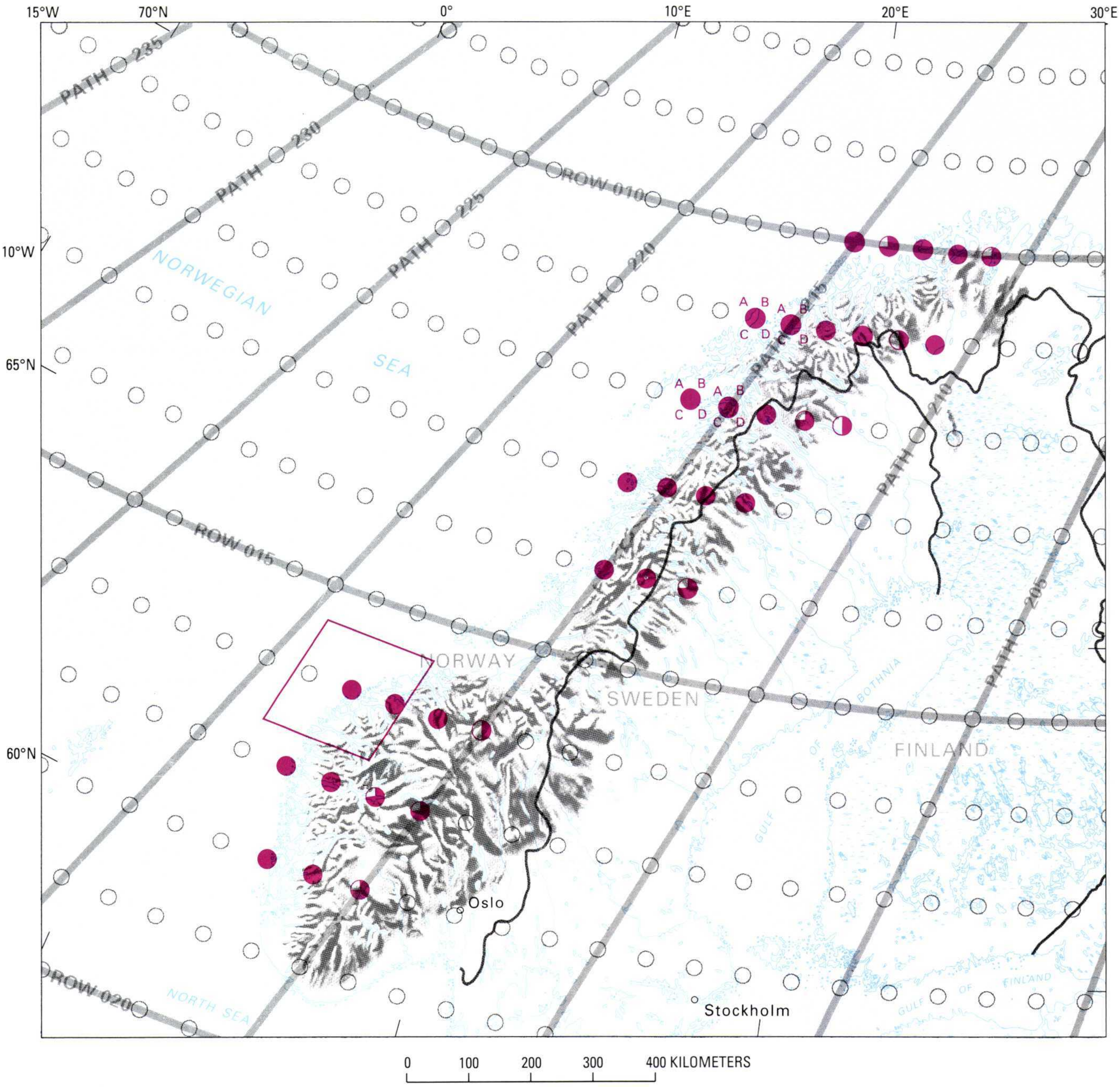
Figure 38.—*Landsat MSS image (2186–10005; band 7; 27 July 1975; Path 215, Row 13) showing glaciers in the southern part of northern Norway. Svartisen is situated in the lower part and Blåmannsisen and the Sulitjelma glaciers (near the Swedish border) in the upper part. The image covers approximately 120 × 150 km. (See map of area in figure 39.)*

To demonstrate the potential of using Landsat imagery for glacier inventories, an enlarged part of a Landsat image showing valley glaciers and cirque glaciers in the Jotunheimen area (fig. 33) can be compared with the field observations and a map taken from the glacier atlas that is based upon aerial photographs (fig. 34). Another example is demonstrated in figure 38 for glaciers in northern Norway. The true glacier distribution is shown on the map, figure 39. It is clear that even relatively small glaciers are easily determined on images of good quality; their outline can be drawn and transferred to a map. This method is certainly valuable in areas where other sources of information are lacking.

For all Norwegian glacier areas, a survey was made to find the most useful Landsat images for glaciological work. The result is shown on the map of the Path/Row positions (fig. 40) and in table 6. Table 7 provides information on the availability of optimum Landsat 1, 2, and 3 images for all nominal scene centers of glacierized areas of Norway. Percent cloud cover refers only to glacierized part of image.

__Figure 39.__—Map of the Svartisen-Blåmannsisen area in northern Norway showing the second, fourth, and fifth largest glaciers in Norway (from Østrem and others, 1973). (See Landsat image of area in figure 38.)





EXPLANATION OF SYMBOLS

Evaluation of image usability for glaciologic, geologic, and cartographic applications. Symbols defined as follows:

- Excellent image (0 to ≤5 percent cloud cover)
- Good image (>5 to ≤10 percent cloud cover)
- Fair to poor image (>10 to ≤100 percent cloud cover)
- A B C D Usable Landsat 3 return beam vidicon (RBV) scenes. A, B, C, D refer to usable RBV subscenes
- Nominal scene center for a Landsat image outside the area of glaciers
- Approximate size of area encompassed by nominal Landsat MSS image

Figure 40.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Norway. The vertical lines represent nominal paths. The rows (horizontal lines) have been established to indicate the latitude at which the imagery has been acquired.*

TABLE 6.—*A list of the most useful Landsat images of the glaciers of Norway as of the end of 1980*

Path-Row	Date	Landsat identification number	Cloud cover[1] (in percent)	Remarks
211–10	29 Jul 72	1006–09481	10	
211–11	29 Jul 72	1006–09484	0	
213–12	8 Jul 73	1350–10005	10	
214–12	25 Jul 73	1367–09545	50	
215–13	9 Jul 75	2168–10012	20	
	27 Jul 75	2186–10005	5	
	28 May 75	2492–09552	10	
215–14	9 Jul 75	2168–10014	10	
215–17	6 Mar 73	1226–10151	20	
	17 Jun 74	1694–10071	25	
	15 Feb 75	2024–10031	0	Completely snow covered
	9 Jul 75	2168–10030	10	
215–18	15 Feb 75	2024–10034	0	Excellent; completely snow covered
	9 Jul 75	2168–10032	0	
216–16	23 Jun 73	1335–10195	10	
	18 Jun 74	1695–10123	10	
	9 Aug 76	2565–10002	10	
	27 Aug 76	2583–09595	0	
216–17	18 May 73	1299–10204	0	
	18 Jun 74	1695–10125	30	
	22 Jun 75	2151–10085	20	
	10 Jul 75	2169–10084	20	
	28 Jul 75	2187–10082	0	Excellent; good snowline; sediment in lakes and fjords
	9 Aug 76	2565–10004	10	
	27 Aug 76	2583–10001	0	Excellent
216–18	22 Jun 75	2151–10091	20	
	28 Jul 75	2187–10084	20	
	9 Aug 76	2565–10011	10	
	27 Aug 76	2583–10004	10	
	11 Aug 80	22059–10083	0	Excellent
217–16	5 Jul 76	2530–10070	0	
217–17	24 Jun 73	1336–10260	0	Excellent; sediment in lakes and fjords visible
	5 Jul 76	2530–10073	0	
217–18	27 Sep 72	1066–10255	10	
	24 Jun 73	1336–10263	0	Excellent
	5 Jul 76	2530–10075	5	
218–16	25 Jun 73	1337–10312	0	

[1] Cloud cover given only for glacierized parts of image.

TABLE 7.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Norway*

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
211–10	070°35′N. 025°20′E.	1006–09481	29 Jul 72	38	◕	10	Seilandsjøkulen, Øksfjordjøkulen, east part of Langfjordjøkulen; image used for figure 23
211–11	069°17′N. 023°18′E.	1006–09484	29 Jul 72	39	●	0	
212–10	070°35′N. 023°54′E.	22019–09420	02 Aug 80	36	●	0	Archived by ESA[1]
212–11	069°17′N. 021°52′E.	22019–09422	02 Aug 80	37	◑	30	Strupbreen, Jiekkevarri; archived by ESA
212–12	067°59′N. 020°03′E.	1367–09545	25 Jul 73	40	◑	50	
213–10	070°35′N. 022°28′E.	22020–09474	03 Aug 80	36	●	0	Archived by ESA
213–11	069°17′N. 020°26′E.	22434–09442	21 Sep 81	20	●	0	Archived by ESA
213–12	067°59′N. 018°37′E.	1350–10005	08 Jul 73	43	◕	10	Blåisen, Storsteinsfjellbreen, Frostisen
213–13	066°40′N. 016°59′E.	20940–09255	19 Aug 77		●	0	Archived by ESA; not physically examined
213–14	065°20′N. 015°30′E.	1422–10003	18 Sep 73	25	◕	10	Børgefjell
214–10	070°35′N. 021°02′E.	31612–09573	03 Aug 82	36	◕	10	Partial scene includes all glacier areas; archived by ESA
214–11	069°17′N. 019°00′E.	22075–09541	27 Sep 80	18	●	0	Archived by ESA
214–12	067°59′N. 017°11′E.	22075–09543	27 Sep 70	19	◑	20	Archived by ESA
214–12	067°59′N. 017°11′E.	31612–09582	03 Aug 82	38	●	0	Partial scene; archived by ESA
214–13	066°40′N. 015°33′E.	22075–09550	27 Sep 80	20	◑	30	Archived by ESA
214–13	066°40′N. 015°33′E.	31612–09585	03 Aug 82	39	●	0	Partial scene, does not include western glacier area; archived by ESA
214–14	065°20′N. 014°04′E.	20941–09320	20 Aug 77		●	0	Archived by ESA; not physically examined
215–10	070°35′N. 019°36′E.	21302–09404	16 Aug 78	32	●	0	Archived by ESA
215–11	069°17′N. 017°34′E.	21302–09410	16 Aug 78	32	●	0	Archived by ESA
215–11	069°17′N. 017°34′E.	30893–09500 A,B,C,D	14 Aug 80	34	A B ○ C D	10–50	Landsat 3 RBV images
215–12	067°59′N. 015°45′E.	30893–09503 A,B,C,D	14 Aug 80	35	A B ○ C D	10–70	Landsat 3 RBV images
215–12	067°59′N. 015°45′E.	31613–10041	04 Aug 82	38	●	5	Partial scene, includes all glacier areas; archived by ESA

TABLE 7.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Norway*—Continued

[See fig. 40 for explanation of symbols used in "Code" column]

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
215–13	066°40′N. 014°06′E.	2186–10005	27 Jul 75	41		5	Blåmannsisen, Svartisen; image used for figure 38
215–14	065°20′N. 012°38′E.	2186–10012	27 Jul 75	42		0	Okstindbreen
215–16	062°38′N. 010°03′E.	21626–09554	06 Jul 79	47		30	Archived by ESA
215–17	061°16′N. 008°56′E.	2168–10030	09 Jul 75	48		10	Jotunheimen
215–18	059°54′N. 007°52′E.	2168–10032	09 Jul 75	49		10	Folgefonni, Hardangerjøkulen
216–11	069°17′N. 016°08′E.	21321–09474	04 Sep 78	26		0	Archived by ESA
216–11	069°17′N. 016°08′E.	30894–09554 A,B,C,D	15 Aug 80	33	A B C D	0– 50	Landsat 3 RBV images
216–12	067°59′N. 014°19′E.	21321–09481	04 Sep 78	27		0	Archived by ESA
216–12	067°59′N. 014°19′E.	30894–09561 A,B,C,D	15 Aug 80	34	A B C D	10– 50	Landsat 3 RBV images
216–13	066°40′N. 012°40′E.	31614–10102	05 Aug 82	38		0	Partial scene, includes all glacier areas; archived by ESA
216–16	062°38′N. 008°37′E.	2583–09595	27 Aug 76	34		0	Adelsbre
216–17	061°16′N. 007°30′E.	2565–10004	09 Aug 76	41		10	Jostedalsbreen, Jotunheimen; image used for figure 28
216–18	059°54′N. 006°27′E.	22059–10083	11 Sep 80	31		0	Folgefonni, Hardangerjøkulen; image used for figure 29; archived by ESA
217–16	062°38′N. 007°11′E.	2530–10070	05 Jul 76	47		0	Adelsbre
217–17	061°16′N. 006°04′E.	2530–10073	05 Jul 76	48		0	Jostedalsbreen
217–18	059°54′N. 005°01′E.	21682–10091	31 Aug 79	35		0	Folgefonni; archived by ESA
218–16	062°38′N. 005°45′E.	21305–10003	19 Aug 78			0	Archived by ESA; not physically examined
218–17	061°16′N. 004°38′E.	21305–10010	19 Aug 78			0	Ålfotbreen; archived by ESA; not physically examined

[1] ESA is the European Space Agency, which archives Landsat imagery in Fucino, Italy, and Kiruna, Sweden.

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References Cited

Ahlmann, H.W:son, 1922, Glaciers in Jotunheimen and their physiography: Geografiska Annaler, v. 4, no. 1, p. 1–57.

Andersen, J.L., and Sollid, J.L., 1971, Glacial chronology and glacier geomorphology in the marginal zones of the glaciers Midtdalsbreen and Nigardsbreen, south Norway: Norsk Geografisk Tidsskrift, v. 25, no. 1, p. 1–38.

de Seue, C., 1870, Le nevé de Justedal et ses glaciers (Publié par S.A. Sexe) [The firn of Justedal and its glaciers (Published by S.A. Sexe)]: University Programme, Christiania, 55 p.

Faegri, K., 1933, Über die Längenvariation einiger Gletscher des Jostedalsbre und die dadurch bedingten Pflanzensukzessionen [The fluctuation of some outlet glaciers of Jostedalsbre and the resulting plant succession]: Bergens Museums Årbok 1933, no. 2, p. 1–255.

———1940, Forandringer ved norske breer 1937–39 [Changes of Norwegian glaciers]: Bergens Museums Årbok 1939–40, Naturvitenskapelig rekke, no. 3, 9 p.

Forbes, J.D., 1853, Justedalen-Fillefield, *in* Norway and its glaciers visited in 1851; followed by journals of excursions in the high Alps of Dauphiné, Berne, and Savoy: Edinburgh, A. & C. Black (Publishers) Ltd., Chap. 7, 349 p.

Foss, M., 1803, Justedalens kortelige Beskrivelse [Short description of the Jostedalen valley]: Magazin for Danmarks og Norges topografiske, oeconomiske og statistiske Beskrivelse, v. 2, p. 1–42.

Friis, P.C., 1632, Om Quindhaerrit oc Fuglesand [On the parish Kvinnherad and Folgefonni], *in* Storm, Gustav, ed., Norriges Bescrifuelse: Samlede Skrifter, v. 83, 493 p.

Haakensen, N., 1982, Glasiologiske undersøkelser i Norge 1980 [Glaciological investigations in Norway]: Hydrologisk avdeling, Norges vassdrags- og elektrisitetsvesen, Oslo, Report No. 1–82, 87 p. [In Norwegian with a summary in English.]

Haakensen, N., and Elvehøy H., 1992, Massebalansemålinger på norske breer 1990 [Mass-balance measurements on Norwegian glaciers, 1990]: NVE-Publikasjon no. XX fra Hydrologisk avdeling, Norges vassdrags- og energiverk (In Norwegian with a summary in English).

Hoel, A., and Norvik, J., 1962, Glaciological bibliography of Norway: Norsk Polarinstitutt, Skrifter No. 126, 242 p.

Hoel, A., and Werenskiold, W., 1962, Glaciers and snowfields in Norway: Norsk Polarinstitutt, Skrifter No. 114, 291 p.

Illustreret Nyhedsblad, 1864, Nigaardsbraeen i Justedalen [Woodcut]: 13th year, no. 10 (6 March 1864), p. 51.

Liestøl, O., 1962a, List of the area and numbers of glaciers, *in* Hoel, A., and Werenskiold, W., eds., Glaciers and snowfields in Norway: Norsk Polarinstitutt, Skrifter No. 114, p. 35–54.

———1962b, Glacier fluctuations, *in* Hoel, A., and Werenskiold, W., eds., Glaciers and snowfields in Norway: Norsk Polarinstitutt, Skrifter No. 114, p. 57–79.

———1967, Storbreen Glacier in Jotunheimen, Norway: Norsk Polarinstitutt, Skrifter No. 141, 63 p.

Liestøl, O., and Østrem, G., 1963, Brekart over Sør-Norge [Glacier map of southern Norway]: 1:500,000-scale map mostly compiled from aerial photographs from the year 1955, Norges vassdrags- og elektrisitetsvesen, Oslo [In Norwegian and English].

Østrem, G., 1960, Breer og morener i Jotunheimen: Norsk Geografisk Tidsskrift, no. 17, p. 210–243.

———1963, Oversikt over breer i Skandinavia. [Glaciers in Scandinavia]: 1:1,800,000-scale map, Hydrologisk avdeling, Norges vassdrags- og elektrisitetsvesen, Oslo [In Norwegian and English].

———1964, Ice-cored moraines in Scandinavia: Geografiska Annaler, v. 46, no. 3, p. 282–337.

———1966, The height of the glaciation limit in southern British Columbia and Alberta: Geografiska Annaler, Series A, v. 48, no. 3, p. 126–138.

———1975, ERTS data in glaciology-An effort to monitor glacier mass balance from satellite imagery: Journal of Glaciology, v. 15, no. 73, p. 403–415.

———1976, Fjernanalyse [Remote sensing]: Naturen, v. 100, no. 5–6, p. 329–338.

Østrem, G., Andersen, T., Ødegaard, H., and del Llano, R., 1979, Snow and ice mapping: Norwegian examples for run-off prediction, *in* Use of data from meteorological satellites, Proceedings of a Technical Conference, Lannion, September 1979, European Space Agency Special Publication 143, p. 177–181.

Østrem, G., Dale Selvig, K., and Tandberg, K., 1988, Atlas over breer i Sør-Norge [Atlas of glaciers in south Norway] (revised ed.): Meddelelse No. 61 fra Hydrologisk avdeling, Norges Vassdrags- og Energiverk, Oslo, 248 p. [in Norwegian and English].

Østrem, G., and Haakensen, N., 1980, The Scandinavian glacier inventory-Two glacier atlases, *in* Proceedings of the Workshop on the World Glacier Inventory (Riederalp, Switzerland; September 1978): International Association of Hydrological Sciences-Association Internationale des Sciences Hydrologiques Publication No. 126, p. 161–171.

Østrem, G., Haakensen, N., Kjøllmoen, B., Laumann, T., and Wold, B., 1991, Massebalansemålinger på norske breer 1988 og 1989 [Mass-balance measurements on Norwegian glaciers, 1988 and 1989]: NVE-Publikasjon no. 11 fra Hydrologisk avdeling, Norges vassdrags- og energiverk, 78 p. (In Norwegian with a summary in English).

Østrem, G., Haakensen, N., and Melander, O., 1973, Atlas over breer i Nord-Skandinavia [Atlas of glaciers in northern Scandinavia]: Meddelelse No. 22 fra Hydrologisk avdeling, Norges vassdrags- og elektrisitetsvesen, 315 p. [In Norwegian and English].

Østrem, G., Liestøl, O., and Wold, B., 1976, Glaciological Investigations at Nigardsbreen, Norway: Norsk Geografisk Tidsskrift, v. 30, p. 187–209.

Østrem, G., and Ziegler, T., 1969, Atlas over breer i Sør-Norge [Atlas of glaciers in southern Norway]: Meddelelse No. 20 fra Hydrologisk avdeling, Norges vassdrags- og Elektrisitetsvesen, Oslo, 207 p. [In Norwegian and English].

Øyen, P.A., 1898, Norvège—Les variations periodique des glaciers. 3^e rapport. [Norway—The periodic variations of its glaciers, Report 3]: Archives Sciences et Physique Naturelle, Tome 6, Genève, p. 40–41.

———1907, Klima und Gletscherschwankungen in Norwegen [Climate and glacier variations in Norway]: Zeitschrift für Gletscherkunde, v. 1, no. 1, p. 46–61.

———1915, Norvège—Les variations periodique des glaciers. 19^e rapport. [Norway—The periodic variations of its glaciers, Report 19]: Zeitschrift für Gletscherkunde, v. 9, p. 53–55.

Pillewizer, W., 1950, Bewegungsstudien an Gletschern des Jostedalsbre in Sud-Norwegian [Studies of the movement on glaciers of Jostedalsbreen in southern Norway]: Erdkunde, v. 4, no. 3/4, p. 201–206.

Rekstad, J.B., 1905, Fra Jostedalsbreen [From Jostedalsbreen]: Bergens Museums Aarbog 1904, Naturvidenskabelig rekke No. 1, 95 p.

Roland, E., and Haakensen, N., 1985, Glasiologiske undersøkelser i Norge 1982 [Glaciological investigations in Norway 1982]: Hydrologisk avdeling, Norges vassdrags- og elektrisitetsvesen: Oslo, Report No. 1–85, 102 p. [In Norwegian with a summary in English].

Sexe, S.A., 1864, Om Sneebraeen Folgefond [About the Folgefonni ice cap]: University Programme, Christiania, 36 p.

UNESCO, 1970, Combined heat, ice and water balance at selected glacier basins: Technical Papers in Hydrology, no. 5, 20 p.

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