Glaciers of Europe–
GLACIERS OF SVALBARD, NORWAY

By OLAV LIESTØL

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

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

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

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Abstract

Svalbard, Norway, an archipelago in the North Atlantic Ocean (74° to 81° N. lat), has a total area of 62,248 square kilometers, mostly contained in the four main islands, Spitsbergen, Nordaustlandet, Edgerøya, and Barentsrøya. More than 2,100 glaciers cover 36,591 square kilometers, or about 59 percent of the total area. All types of glaciers are represented in Svalbard, but the most numerous are the valley and cirque glaciers, especially on Spitsbergen; large ice caps are common on Nordaustlandet, Edgerøya, and Barentsrøya. Glaciological investigations began in the late 19th century and became numerous in the 20th century. They include ice-core studies and research in meteorology, mass balance, glacier flow, glacial erosion, and radio echosounding. Mass-balance measurements in Svalbard show a continuous negative mass balance since 1966–67; the net balance has probably been negative since the end of the last century. The height of the equilibrium line, a good indicator of climatic conditions in Svalbard, is about 150 meters above mean sea level in the southeastern part of the archipelago and greater than 800 meters above mean sea level in the central parts. Many of the glaciers in Svalbard are known to surge (86 since the end of the 19th century), and the frequent surging makes it difficult to use fluctuations of glaciers as climatic indicators. Landsat images have been used successfully to trace equilibrium-line variations, monitor glacier variation and surging events, delineate glacier basins on the basis of ice divides on ice caps, and revise maps for areas in which aerial photographs are not available.

Introduction

Svalbard is a part of Norway that includes the islands between lat 74° N. to 81° N. and long 10° E. to 35° E. (fig. 1). The main area consists of Spitsbergen, by far the largest island at 39,000 km², followed by Nordaustlandet with 14,600 km², Edgeøya at 5,000 km², Barentsøya with 1,300 km², and a number of smaller islands. The total area of the islands is 62,248 km², and, of this total, about 59 percent is covered by more than 2,100 glaciers (table 1). Most of the information provided in this subchapter is also included in the "Glacier Atlas of Svalbard and Jan Mayen" that was compiled by the Norwegian Polar Research Institute (Hagen and others, in press).

Previous Glacier Investigations

Nowhere in the Arctic can ships sail so far north as along the west coast of Spitsbergen. Therefore, numerous expeditions reached and visited the land during the past 300 years. As early as the 17th century, Dutch and English whalers made maps of the islands that contained information of glaciological interest. Swedish scientists were active in the study of Svalbard glaciers during the 19th century with glacial geology investigations and preparation of maps (Nathorst and others, 1909). A few glacier surges also were observed, and Hamberg (1932) described the phenomenon long before the concept was generally known among glaciologists.

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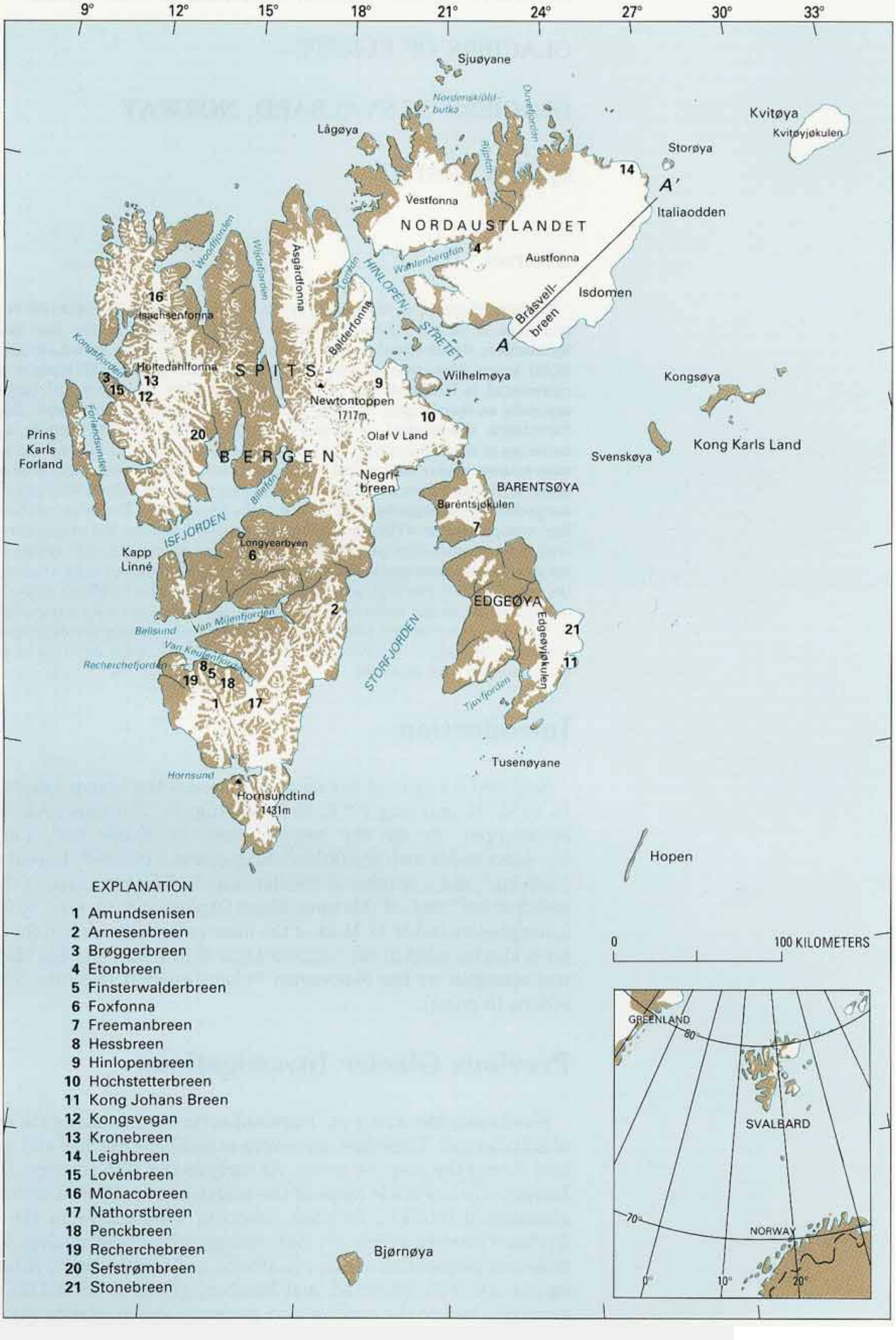


Figure** 1.*–*Thelocation of Svalbard, the islands that make up the archipelago, the areas covered by glaciers, and the glaciers mentioned in the text. Base map courtesy of Norsk* ***Polarinstitutt, *Oslo. The glaciers are indicated in white. (See fig. 4 for cross section.)*

TABLE 1.—*Area encompassed by glaciers on each of the islands in the Svalbard archipelago*

Island	Area (km^2)	Glacier area (km^2)	Glacier cover (percent)	Number of glaciers
Spitsbergen	38,612	21,767	56.4	1,598
Nordaustlandet	15,193	11,309	74.7	210
Edgeøya	5,230	2,130	40.7	110
Barentsøya	1,321	575	43.5	126
Kvitøya	710	705	99.3	1
Prins Karls Forland	622	83.4	13.4	33
Kongsøya	195	13.7	7.0	30
Svenskøya	140	8.0	5.7	20
Bjørnøya	178	0	0	0
Hopen	47	0	0	0
Total	62,248	36,591	58.8	2,128

In the 20th century, numerous expeditions from different countries have done glaciological research as the main objective or as part of a broader scientific program (Ahlmann, 1933). One of the best known is the Norwegian-Swedish expedition to Isachsenfonna in 1934 led by Ahlmann and Sverdrup. The research papers published by this expedition remain as classic works in glacial meteorology (Sverdrup, 1935). German scientists carried out a program of mapping and glaciological studies in Spitsbergen in 1938 (Pillewizer, 1939).

In 1950, the Norwegian Polar Research Institute (Norsk Polarinstitutt) started systematic mass-balance studies on Svalbard glaciers, first on Finsterwalderbreen, a glacier on the south side of Van Keulenfjorden, and later on two glaciers in the Kongsfjorden area. The results have been published annually in the Norsk Polarinstitutt Årbok. Elverhøi and others (1980) also carried out glacial erosion and related studies in the

TABLE 2.—*Specific mass balance (b_w, winter; b_s, summer; b_n, net) in meters per year water equivalent, annual equilibrium line altitude (ELA) given in meters, and accumulation area ratio (AAR) in percent for Austre Brøggerbreen (6.1 km^2) and Midtre Lovénbreen (5.5 km^2), 1967–90 (Hagen and Liestøl, 1990)*

[Both glaciers are at lat 79° N. and long 12° E. in Svalbard; — indicates measurements are not available]

Balance year	Austre Brøggerbreen					Midre Lovénbreen				
	b_w	b_s	b_n	ELA	AAR	b_w	b_s	b_n	ELA	AAR
1966–67	77	142	−65	—	—	—	—	—	—	—
1967–68	57	67	−10	295	54	48	51	−3	295	54
1968–69	40	133	−93	650	0	41	125	−84	650	0
1969–70	37	91	−54	490	7	36	89	−53	500	6
1970–71	65	123	−58	400	23	70	116	−46	385	37
1971–72	95	126	−31	360	32	98	120	−22	350	46
1972–73	74	82	−8	270	60	82	84	−2	310	58
1973–74	75	167	−92	550	2	70	159	−89	550	2
1974–75	78	109	−31	340	35	83	104	−21	340	48
1975–76	72	117	−45	410	20	75	110	−35	420	29
1976–77	76	87	−11	320	45	80	84	−4	300	60
1977–78	75	131	−56	410	20	81	129	−48	420	29
1978–79	77	148	−71	550	2	80	146	−66	480	9
1979–80	75	127	−52	430	17	83	126	−43	415	30
1980–81	46	101	−55	450	14	51	97	−46	435	23
1981–82	64	68	−4	280	56	66	64	2	290	62
1982–83	70	97	−27	345	34	75	92	−17	330	52
1983–84	69	142	−73	500	6	74	142	−68	440	21
1984–85	93	148	−55	450	14	98	146	−48	445	20
1985–86	98	130	−32	380	25	6	127	−21	370	42
1986–87	82	60	22	200	83	82	58	24	225	77
1987–88	61	113	−52	440	15	56	105	−49	425	27
1988–89	56	101	−45	440	15	63	87	−24	375	41
1989–90	75	141	−66	500	8	87	138	−51	450	19
1967–90	71	115	−44	417	19	74	110	−36	400	33

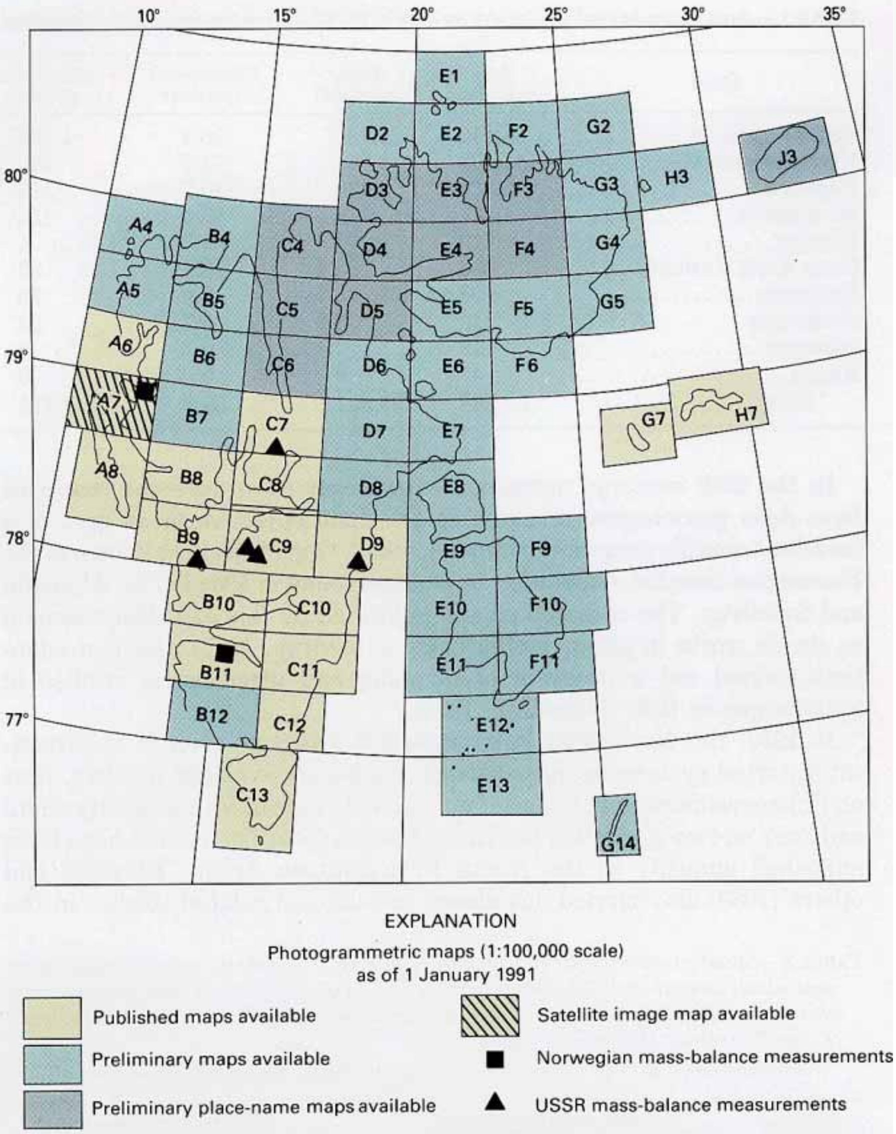


Figure 2.–*Photogrammetric and satellite image map coverage of glaciers of Svalbard and location of mass-balance measurements made by Norwegian (table 2) and Soviet (table 3) glaciologists.*

inner part of the Kongsfjorden area. In 1957 and 1958, a team of Swedish scientists conducted glaciological studies on Nordaustlandet (Schytt, 1964). In 1966, Soviet glaciologists also worked in Spitsbergen (Markin, 1969). They started systematic yearly mass-balance measurements on five glaciers in central Spitsbergen. Their results are published in Gus'kov (1983). Figure 2 shows the location of mass-balance measurements and the map or photo coverage of the areas. The results of the Norwegian measurements are shown in table 2, and Soviet results in table 3. The detailed Polish work on mass balance and flow measurements should be mentioned also (Baranowski, 1977). One of the most extensive and detailed works on glacier flow ever made was carried out by German Democratic Republic (DDR) scientists in 1962-65 in the Kongsfjorden area. The fast-flowing Kongsvegen glacier stream (fig. 3) was the main objective of the research, and photogrammetric methods were used. The flow was of a block-movement type with maximum velocity up to 4 mh^{-1} (meters per hour) (Voight, 1967; Pillewizer and others, 1967, and Voigt, 1979). Core drilling has been carried out on different glaciers by Soviet glaciologists in recent years. The deepest hole (586 m) was drilled through Amundsenisen. A review of the Soviet research on the glaciation of Spitsbergen was published by Troitskiy and others (1975).

Radio-echosounding surveys were also started by Soviet scientists, but later, in 1980 and 1983, scientists from the Norwegian Polar Research

Figure 4.–*Radio-echosounding cross section (A–A') through the southeastern part of the Ausffonna ice cap, Nordaustlandet (see fig. 1 for location of survey traverse line).*

TABLE 3.—*Mass-balance measurements of five glaciers in Svalbard made by the Institute of Geography of the USSR Academy of Sciences during the period 1966–67 to 1979–80*

[Measurements are given in centimeters of water equivalent; — indicates measurements are not available]

Year	Vøringbreen			Bogerbreen			Longyearbreen			Bertilbreen			Daudbreen		
	Average total accumulation	Average total ablation	Average mass balance	Average total accumulation	Average total ablation	Average mass balance	Average total accumulation	Average total ablation	Average mass balance	Average total accumulation	Average total ablation	Average mass balance	Average total accumulation	Average total ablation	Average mass balance
1966–67...	87	107	−20	—	—	—	—	—	—	—	—	—	—	—	—
1973–74...	64	180	−116	—	—	—	—	—	—	—	—	—	—	—	—
1974–75...	73	99	−26	57	57	0	—	—	—	—	—	−29	—	—	—
1975–76...	44	161	−117	—	—	−20	—	—	—	34	106	−72	72	—	—
1976–77...	62	75	−13	62	88	−26	57	99	−42	48	107	−59	—	—	—
1977–78...	50	166	−116	34	115	−81	45	118	−73	44	144	−100	69	135	−66
1978–79...	54	143	−89	61	168	−107	48	171	−123	50	135	−85	54	112	−58
1979–80...	55	105	−50	48	113	−65	50	119	−69	31	123	−73	67	124	−57

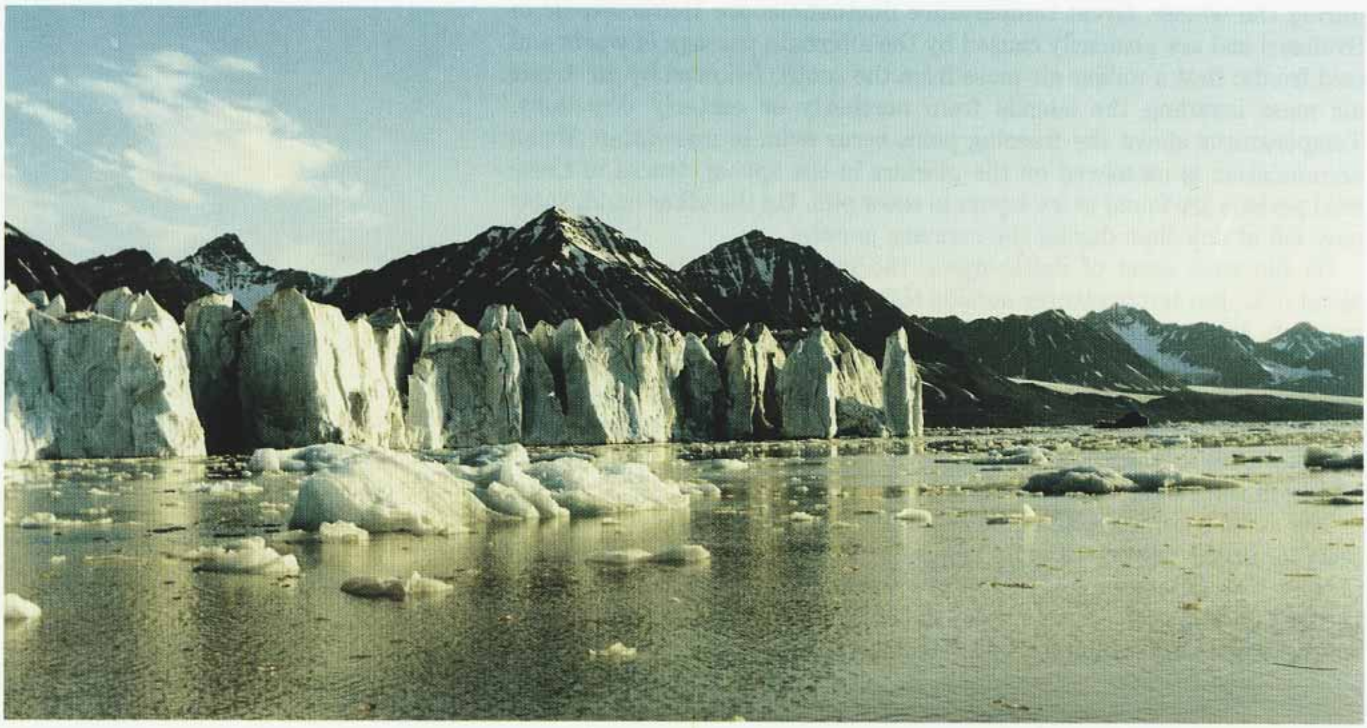
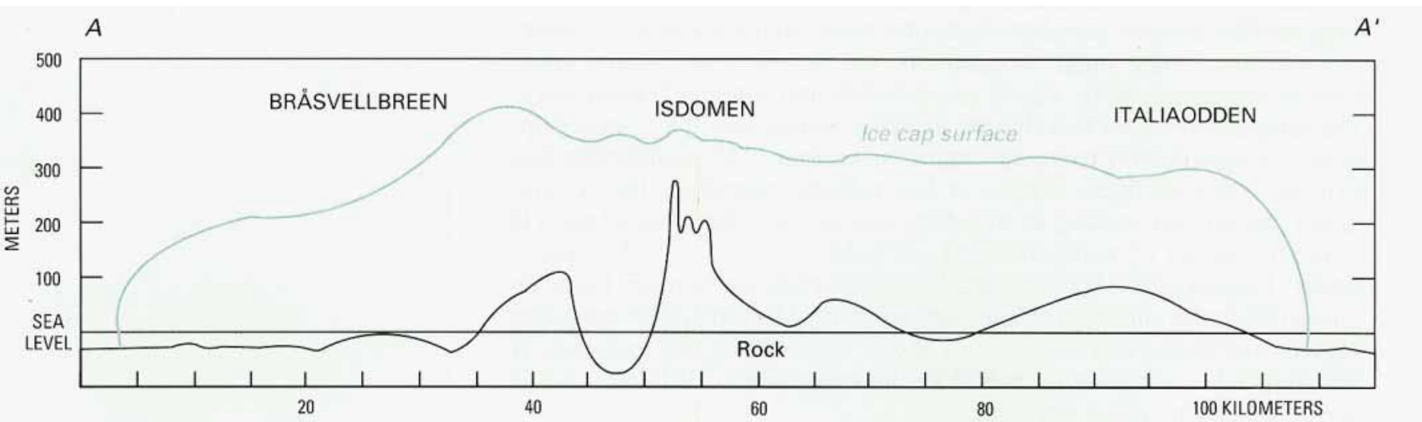


Figure 3.—*Color terrestrial photograph of the grounded front of the Kongsvegen glacier at the head of Kongsfjorden, Spitsbergen, in August 1974. Photograph by Olav Liestøl, Norsk Polarinstitutt, Oslo.*



Institute (NP) and Scott Polar Research Institute (SPRI) sounded more than 100 glaciers, including a detailed survey of Austfonna, the largest ice cap in Svalbard (fig. 4) (Dowdeswell and others, 1984; Drewry and Liestøl, 1985).

Climate

The mean temperature during the winter is remarkably high, considering Svalbard's northern position. The immediate reason for the favorable temperature is the frequent transport of milder air from lower latitudes, usually in connection with the passage of low-pressure frontal systems over or near the Svalbard area. The North Atlantic Current transports warmer Atlantic water to the west coast of Spitsbergen. This current also influences the climate and keeps the sea free from ice even during the winter. Great temperature fluctuations are characteristic of Svalbard and are primarily caused by the alternate passage of warm and cold fronts: first a milder air mass from the south, followed by an Arctic air mass invading the islands from northerly or easterly directions. Temperatures above the freezing point occur even in midwinter. When accumulation is measured on the glaciers in the spring, traces of these mild periods are found as ice layers in snow pits. On the other hand, snow may fall at any time during the summer months.

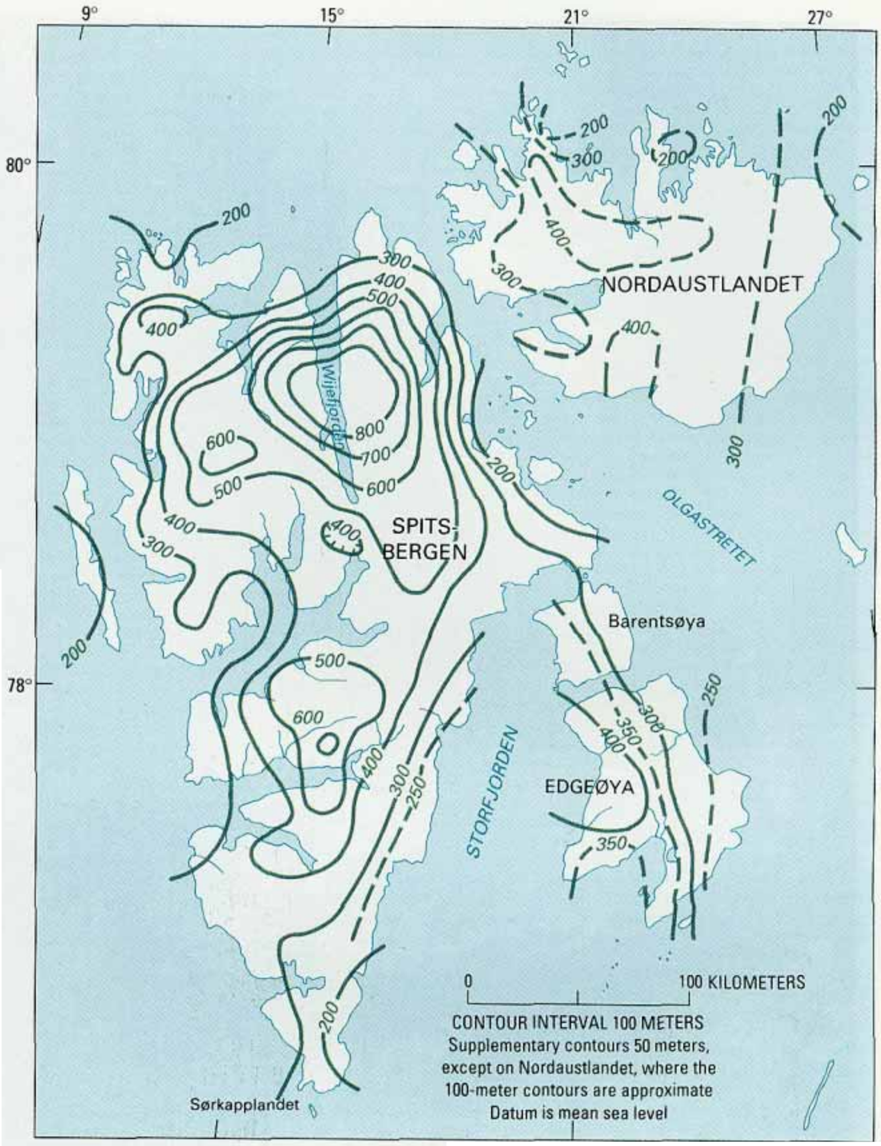
On the west coast of Spitsbergen, the mean temperature in July is about 5 °C, but temperatures outside the range of 1 to 10 °C are not very common. In the same area, the mean temperature for February–March, normally the coldest part of the year, is usually between –8 and –16 °C, although the temperature is somewhat lower toward the east and north. In the inner fjord areas, the climate is slightly more continental, with temperatures 2 to 4 °C lower during wintertime and a couple of degrees higher in the summer.

The amount of precipitation is small, normally not more than 400 mm per year on the west coast of Spitsbergen and even less in the inner parts of the fjords. The greatest amount of precipitation, more than 1,000 mm, is found over glacier and mountain slopes freely exposed to winds in the southeastern part of Spitsbergen (Hisdal, 1985).

The Equilibrium Line

The height of the equilibrium line, the boundary between areas of acumulation and areas of ablation, is a good indicator of climatic conditions throughout Svalbard. Figure 5, which shows the height of the equilibrium line in Svalbard, is based on a combination of data derived from satellite images, aerial photographs, maps, and mass-balance observations. As a very rough assumption, we can say that glacier mass balance is determined by winter precipitation and summer temperature. The temperature, and thereby the ablation, varies less than the precipitation (accumulation) from one region to another. The equilibrium line altitude shown on figure 5 more or less reflects, therefore, the precipitation pattern. By looking at this map, one can see that precipitation is primarily caused by moisture-laden southeasterly winds. On Nordaustlandet, Edgeøya, and Spitsbergen, the equilibrium line is much lower on the southeastern side than on the northwestern side. On Spitsbergen, the equilibrium line is less than 200 m above sea level on the east side of Sørkapplandet, whereas its height in the inner part of Wijdefjorden is more than 800 m above sea level.

Figure 5.–*Isolines of the height of the equilibrium line (the boundary between areas of accumulation and areas of ablation) in Svalbard. Compiled by Olav Liestøl and Erik Roland, Norwegian Polar Research Institute.*



Glacier Fluctuations

As previously discussed, some information on glacier extent is available from rather early observations by sailors. In the 17th and 18th centuries, Dutch and English whalers plotted glacier fronts, or "ysbergs," on their maps. Though the maps are often quite poor, they do provide some evidence that the glacier fronts were then situated in about the same position as they are today. There are, however, some interesting exceptions. For example, on Dutch maps dating from about 1620, a valley and a river are indicated at the head of Recherchefjord on the west coast of Spitsbergen. The river even had a name: "Sardammer rivier." Today the large Recherchebreen fills the entire valley and the inner part of the fjord. Scientists on the Recherche Expedition in 1838 also commented on this fact. According to their quite accurate map, the glacier then covered the entire fjord, and their drawings showed an extremely crevassed glacier. This was, in fact, the first account of a surging glacier, a relatively common phenomenon in Svalbard and a characteristic of many of its glaciers (figs. 6–9). Table 4 lists 86 of Svalbard's glaciers that have been observed to surge in the last century. It is obvious that many more have surged but have not been observed.

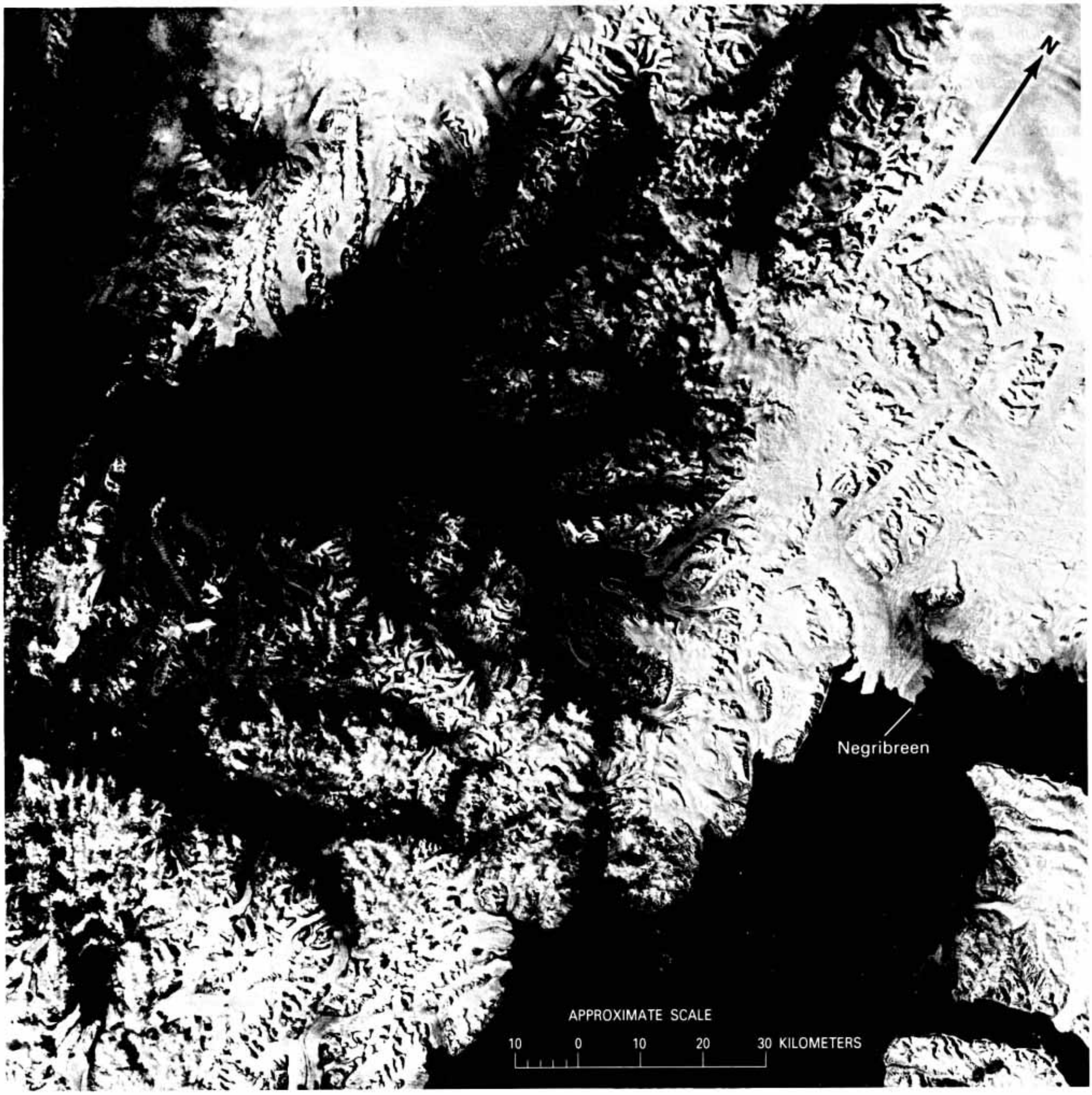


Figure 6.–*Landsat image (24 August 1979; band 7; Path 235, Row 3) of the central part of Spitsbergen showing the grounded front of the surging glacier Negribreen in the right center. The image was acquired on 24 August 1979 by the Swedish Landsat receiving station at Kiruna. Negribreen advanced about 12 km between 1935 and 1936 and has now retreated about the same distance. Note the difference in area covered by glacier ice between the eastern coastal and central parts of this part of Spitsbergen.*

The frequent surging makes it difficult to use glaciers as climatic indicators. The surging glaciers have their own fluctuation pattern, which depends primarily on their size, variations in mass balance, and dynamics of flow. Quick, violent advance followed by long periods of retreat, at intervals of perhaps 20 to 100 years, is a normal pattern of behavior. The only way to register shorter term variations in glacier volume, therefore, is to do mass-balance measurements.

The largest glacier surge observed was that of Bråsvellbreen, an outlet glacier from Austfonna on Nordaustlandet. The glacier advanced about 10 km along about a 30-km-wide front within less than a year (Schytt, 1969).

Negribreen, at the head of Storfjorden (fig. 6), advanced about 12 km within a year's time (1935-36), which gives a minimum velocity of approximately 30 m per day. Taking into account that the surge most probably was of a much shorter duration, the velocity may have reached as much as 100 m per day at its maximum (Liestøl, 1969).

Until the first Landsat images became available, the monitoring of surge events within the entire archipelago was impossible. The slow advance of glaciers known from studies of areas with temperate glaciers is almost unknown in Svalbard.

If terrestrial photographs used in the topographic survey at the beginning of this century are compared with more recent terrestrial and aerial photographs, it becomes obvious that most of the glaciers in Spitsbergen have decreased considerably during this period. Some of the smaller cirque glaciers have lost more than half their volume.

The mass-balance measurements on Brøggerbreen and Lovénbreen in the Kongsfjorden area show a continuous negative mass balance since investigations were begun in 1966 (Hagen and Liestøl, 1990) (table 2). The net mass balance has probably been negative in the majority of the years since the end of the last century (Lefauconnier and Hagen, 1990). Because the summer temperature during the same period has remained relatively constant, the cause of the decrease in glacier volume is most likely a result of lower annual precipitation; that is to say, below what is needed to keep the present volume constant (Steffensen, 1969).

Figure 7.- Oblique aerial photograph of the grounded front of Freemanbreen on the southern coast of Barentsøya in August 1956 showing the heavily crevassed section of the lower part of the glacier during a surge. Approximate width of the glacier at its narrowest (before it fans out) is 2.5 km. Photograph No. S56 1393 from Norsk Polarinstitutt, Oslo.

Figure 8.–*Oblique aerial photograph of Penckbreen on the south side of Van Kueulen-fjorden, Spitsbergen, in August 1936. The glacier has advanced into and folded marine sediments during a surge. A small cirque glacier and one of many glacier-dammed lakes common in Spitsbergen, Ny- Märjelen, is visible just to the right of the center of the photograph. Approximate width of the glacier is 3 km. Photograph No. S36 3207 from Norsk Polarinstitutt, Oslo.*

TABLE 4–*Glaciers of Svalbard that have been observed to surge in the last century*

[Identification number according to UNESCO's World Glacier Monitoring Service; c, circa; b, between]

Glacier	Year(s) of surge
East-central Spitsbergen	
1 11 01 Pedasjenkobreen	b 1925–35
1 11 02 Ganskijbreen	b 1925–35
1 11 03 Sonklarbreen	c 1910
1 11 05 Negribreen	1935–36
1 12 01 Hayesbreen	1901
1 12 04 Usherbreen	1978–85
1 12 04 Ulvebreen	b 1896–1900
1 13 07 Elfenbeinbreen	1903
1 13 08 Skruisbreen	1920
1 13 09 Sveigbreen	1960
1 14 06 Inglefieldbreen	1952
1 14 07 Arnesenbreen	b 1925–35
1 14 12 Thomsonbreen	b 1950–60
1 15 02 Strongbreen	b 1870–76
1 15 05 Jemelianovbreen	1971
1 15 06 Anna Margrethebreen	1970
1 15 09 Davisbreen	c 1960
Southern Spitsbergen	
1 21 02 Markhambreen	b 1930–36
1 21 03 Staupbreen	c 1960
1 21 04 Hambergbreen	c 1890 and c 1960
1 22 02 Vasilievbreen (tributary)	c 1961
1 24 04 Körberbreen	1938
Bellsund	
1 31 11 Scottbreen	c 1880
1 31 16 Recherchebreen	1838 and 1945
1 32 01 Hessbreen	1974
1 32 02 Finsterwalderbreen	c 1900
1 32 07 Siegerbreen	1940
1 32 26 Martinbreen	b 1898–1936
1 32 27 Charpentierbreen	c 1890
1 34 10 Bakaninbreen	1985–90
1 35 05 Hyllingebreen	1970–80
1 35 12 Skutbreen	1930
1 35 13 Upper Storknausen E.	1960
1 35 14 Upper Slottsmøya SW.	1960
1 36 13 Marthabreen	c 1925
1 36 15 Lunckebreen	c 1930
1 36 18 Arebreen	1985
1 37 08 Fridtjovbreen	1861
Isfjorden	
1 42 11 Scott Turnerbreen	c 1930
1 42 17 Drønbreen	1900
1 42 16 Moysalbreen (part of Gløttfjellbreen)	c 1925
1 43 12 Vendombreen	c 1934
1 43 18 Marmorbreen	1965–70
1 44 02 Von Postbreen	1870
1 44 02 Bogebreen (part of Von Postbreen)	1980
Isfjorden—Continued	
1 44 03 Tunabreen	1930 and 1970
1 45 22 Skansdalsbreen (part of Frostisen)	c 1930
1 46 17 Fyrisbreen	1960
1 46 22 Upper Brenna NW	c 1937
1 47 16 Sefströmbreen	1896
1 48 05 Wahlenbergbreen	1908
1 49 02 Nansenbreen	1947
Northwestern Spitsbergen	
1 53 13 Osbornebreen	1987
1 55 04 E. Brøggerbreen	c 1890
1 55 06 Midre Lovénbreen	c 1890
1 55 10 Kongsvegen	1948
1 55 11 Kronebreen	1869
1 55 15 Blomstrandbreen	1960
Woodfjorden/Wijdefjorden	
1 64 11 Elnabreen	c 1930
1 64 17 Abrahamsenbreen	1978
1 64 26 Upper Svelgfjellet S.	1969
1 69 10 Longstaffbreen (part of Åsgårdsfonna)	1960
Northeastern Spitsbergen	
1 72 14 Unnamed part of Odinjøkulen	b 1965–70
1 73 05 Kosterbreen	c 1930
1 73 10 Hinlopenbreen	1969–72
1 74 02 N. Karpinskifjellet	b 1970–80
1 74 06 Hochstetterbreen	b 1895–1900
Nordaustlandet	
2 11 08 Part of Austfonna	b 1850–73
2 11 10 Bråsvellbreen	1937–38
2 21 01 Clasebreen (part of Glitnbreen)	1938
2 21 02 Palanderbreen	1969–70
2 22 03 Etonbreen	1938
2 22 06 Bodleybreen	1973–80
2 32 03 Søre Franklinbreen	1956
2 42 01 Rijpbreen	1938
Eastern islands	
3 11 01 Kvitkåpa SW.	c 1965
3 12 27 Kvitisen E.	1936
3 13 06 Bergfonna SE.	1930
3 13 12 Marsjørreen	b 1936–71
3 13 18 Stonebreen	b 1936–71
3 13 19 Kong Johans Bre	b 1925–30
3 13 22 Pettersenbreen	c 1925
3 21 01 Freemanbreen	1956–56
3 21 02 Duckwitzbreen	1918
3 22 07 Reymondbreen	1956
3 22 08 Hübnerbreen	b 1930–36

Figure 9.–*Oblique aerial photograph of glaciers on the east coast of Spitsbergen in, August 1936. The long, crevassed glacier in the center of the photograph, Arnesenbreen, is surging. Photograph No. S36 1766 from Norsk Polarinstitutt, Oslo.*

Glacier Types

If classified morphologically, all types of glaciers are represented in Svalbard, although the most common are valley and cirque glaciers. It has been difficult to classify the complex glacier system because of the intricate network of ice that covers the large inland areas of Spitsbergen, however (figs. 6, 9, and 10). Tyrrell (1922) used the term “reticular glaciers” and Ahlmann (1948) proposed “transection glaciers” for parts of the glaciated areas. Some typical piedmont glaciers are also found along the west coast, with especially fine examples resting on the strandflatof Prince Karls Forland. Ice caps are common on the relatively flat islands on the eastern half of the archipelago: Edgeøya, Barentsøya and Nordaustlandet (see fig. 16). Ice shelves, such as are common in Antarctica, do not exist, because all glacier fronts terminating in the sea are grounded (figs. 3 and 7). Cirque glaciers are most common in the high

Figure 10.—Oblique aerial photograph of the typical glacierized landscape of north western Spitsbergen in August 1936. To the left of center is the stagnant valley glacier, Sefstrømbreen, which last surged in 1896. Since that time, however, it has been undergoing steady retreat. Supraglacial lakes are evident on the surface of the glacier. Photograph No. S36 628 from Norsk Polarinstitutt, Oslo.

mountain (alpine) ranges along the west coast, but even the flat mountains of sedimentary-rock origin in the central part of Spitsbergen have, to a large extent, been eroded by cirque glaciers.

If classified geophysically, the majority of Svalbard's glaciers belong to the subpolar type; that is, the accumulation area is at the pressure-melting point, and the ablation zone is below the freezing point and partly frozen to the ground. When this type of glacier surges, the lateral parts of the glacier remain frozen to the valley walls (fig. 11). Many of the small cirque and valley glaciers could be classified as polar glaciers, because the entire ice mass is below 0 °C in winter (fig. 12). In summer, however, melting takes place on the surface of all the glaciers even at the highest elevations. Subpolar glaciers can be distinguished from polar ones by large accumulations of ice (icings) in front of their termini, which are produced by the drainage of subglacial water throughout the entire winter season.

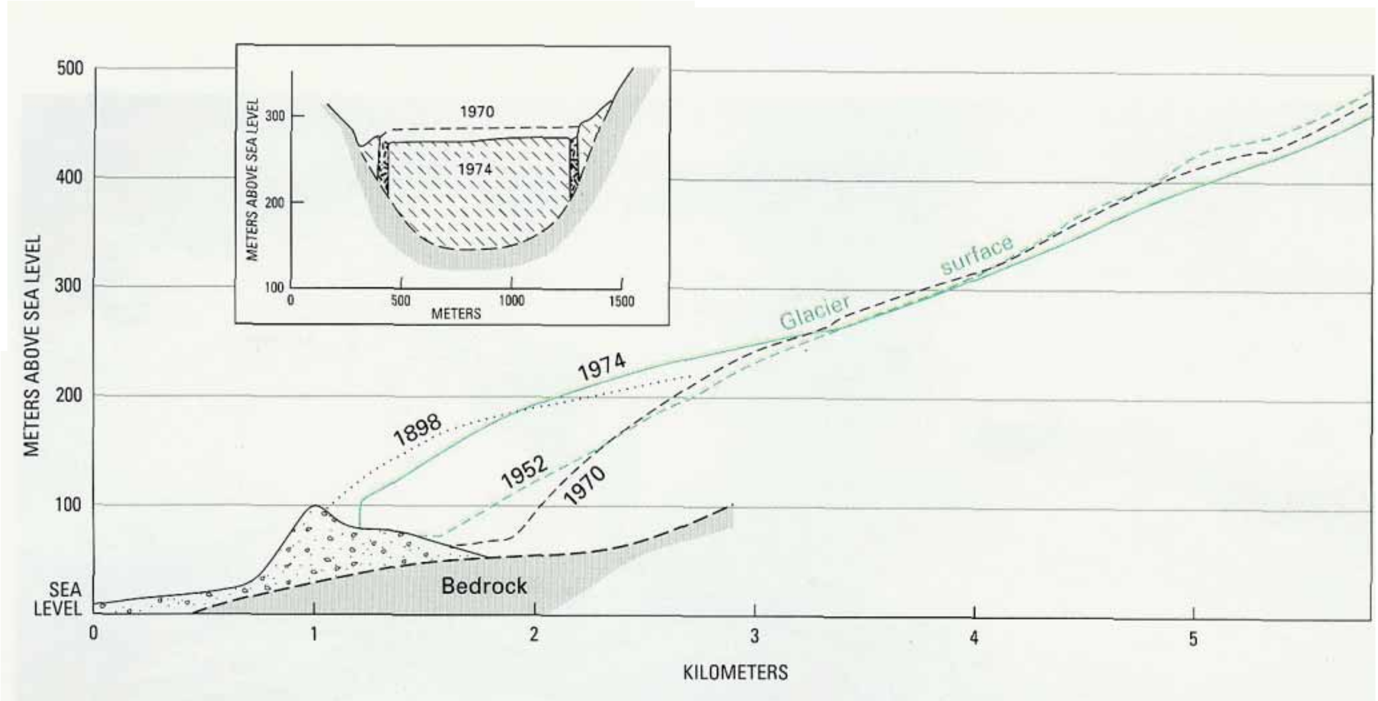


Figure 17.–Vertical profile along the center line of Hessbreen, southern Spitsbergen, surveyed during 4 different years: 1898, 1952, 1970, and 1974. The glacier had been decreasing in the lower part and increasing in the upper part until 1974, when a surge occurred. In the transverse profile in the inset diagram, the lateral parts of the glacier are shown to have frozen to the valley walls, while the main body of the glacier surged (Liestøl, 1976).

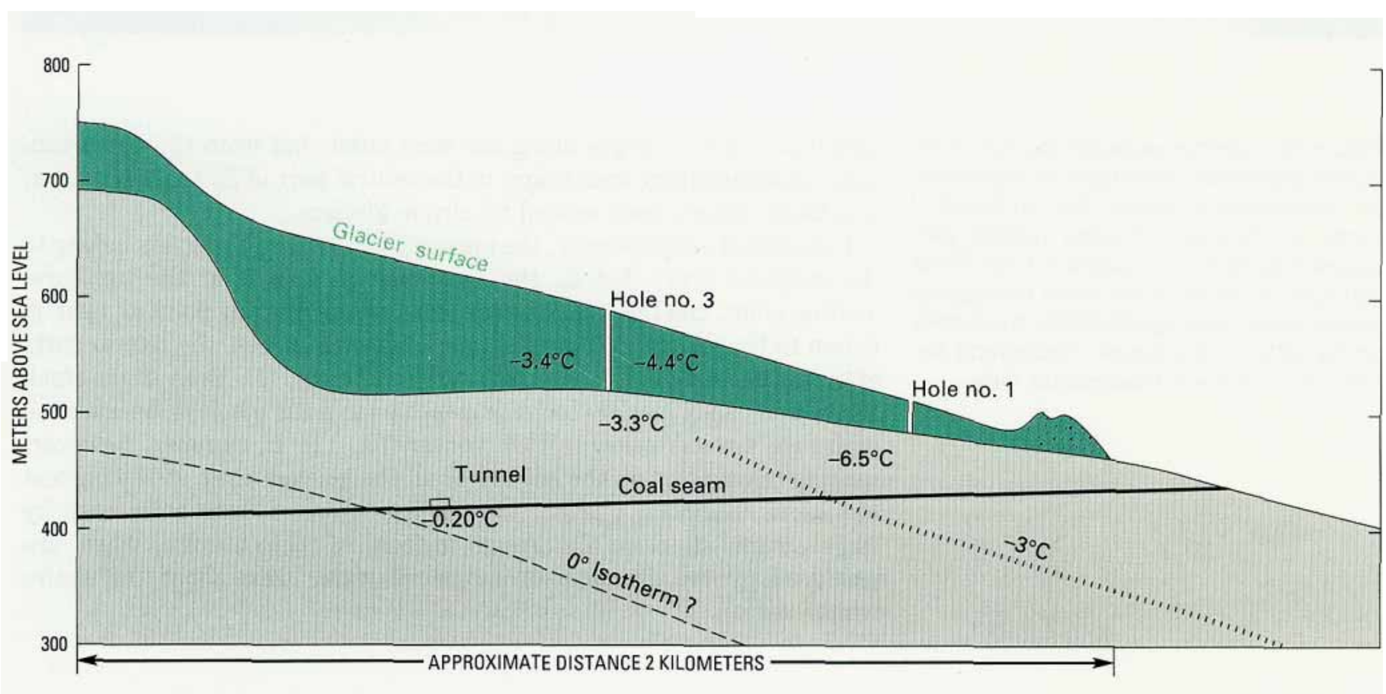


Figure 12.–Cross-sectional view of the Foxfonna glacier, central Spitsbergen. Temperature measurements in boreholes are negative from the surface to the bed of the glacier. During the summer, melting occurs over all the surface of the glacier. The bottom profile is drawn from a radio-echosounding survey of ice thickness (Liestøl, 1974).

Areas of Principal Glaciers of Svalbard

Table 1 provides information on the area of glaciers on each of the islands in the Svalbard archipelago. Kvitøya has a single glacier, the Kvitøyjøkulen ice cap, which covers 99.3 percent of the island (Bamber and Dowdeswell, 1990). Svenskøya has 20 glaciers, which cover only 5.7 percent of the area. Spitsbergen has 1,598 glaciers, which cover 56.4 percent of its area. The two small, low-lying islands of Bjørnøya and Hopen have no glaciers.

Table 5 provides information on the area of the 9 largest ice caps and ice fields in Svalbard; table 6 gives the same information about Svalbard's 10 largest outlet glaciers and ice streams.

Use of Landsat Images

Vertical aerial photographs are available for the entire archipelago except the eastern part of Nordaustlandet and Kvitøya. The older maps were very inaccurate in this part of Svalbard, and Landsat images were used to improve the maps. Figure 13 shows coastline changes in these areas. New maps prepared from Landsat images, such as the 1:1,000,000-scale Norsk Polarinstitutt map of Svalbard (1983), added 500 km^2 to the

TABLE 5.—*Areas of the largest ice caps and ice fields in Svalbard*

Name	Area (km^2)
Austfonna	8,413
Ice field in Olav V Land	~3,000
Vestfonna	2,505
Åsgårdfonna	1,645
Edgeøyjøkulen	1,300
Holtedahlfonna and Isachsenfonna	~900
Kvitøyjøkulen	705
Barentsjøkulen	571
Balderfonna	543

TABLE 6.—*Areas of the largest outlet glaciers and ice streams in Svalbard*

Name	Area (km^2)
Hinlopenbreen	1,248
Negribreen	1,182
Bråsvellbreen	1,160
Etonbreen	1,070
Leighbreen	925
Stonebreen	700
Kronebreen	693
Hochstetterbreen	581
Nathorstbreen	489
Monacobreen	408

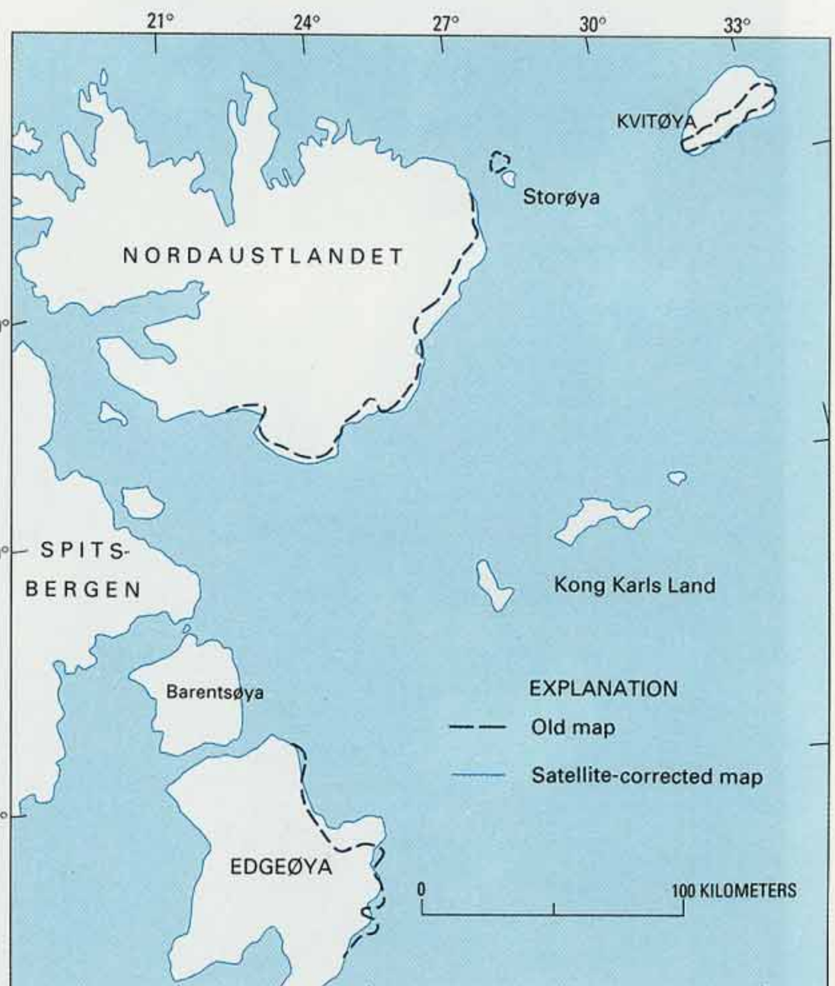


***Figure 13.**—Islands in the eastern part of Svalbard for which new maps have been published that used Landsat images to correct older, inaccurate maps. Most of the corrected coastlines are represented by grounded glacier fronts. The changes are not, however, the result of glacier fluctuations but rather the result of the poor quality of the older maps.*

area of Nordaustlandet (Dowdeswell and Cooper, 1986). The area of Kvitøya, an island that is almost totally ice covered, was more than doubled, and its geometric configuration totally altered from a cigar-shaped to a more egg-shaped island. In the early 1980's, Fjellanger Widerøe A-S of Oslo produced a digital mosaic of Svalbard by using Landsat imagery. The mosaic is shown in figure 14, and the imagery used is listed in table 7.

Satellite imagery makes it possible to carry out simultaneous observations over large areas. It is, therefore, a useful tool in tracing the variation of the transient snowline in different localities (Dowdeswell and Drewry, 1989) (fig. 15). With the large amount of superimposed ice, the equilibrium line is not identical with the snowline but lies farther down the glacier. With some experience it is, however, possible even on the

Figure 14.–*Landsat MSS false-color composite digital image mosaic of Svalbard giving cloud-free coverage of the glaciers. Mosaic was produced by Fjellanger Widerøe A-S, Norway, and is reproduced here with permission. Images used to produce the mosaic are included in table 7.*

satellite imagery to locate the border between the old glacier ice and the superimposed ice. As noted earlier, Landsat images are used to monitor glacier variations and especially to detect and to monitor any surging events (Dowdeswell, 1986; Dowdeswell and, others, 1991). Landsat images can also be used to delineate glacier basins and ice divides on ice caps (fig. 16) (Dowdeswell, 1984; Dowdeswell and Drewry, 1985). The imagery is useful for qualitatively evaluating or monitoring sediment-laden meltwater discharged into coastal waters (Dowdeswell and Drewry, 1989; Pfirman and Solheim, 1989) (fig. 17). An important aspect of several of these studies of Svalbard ice masses is the integration of evidence from the analysis of Landsat digital and photographic imagery

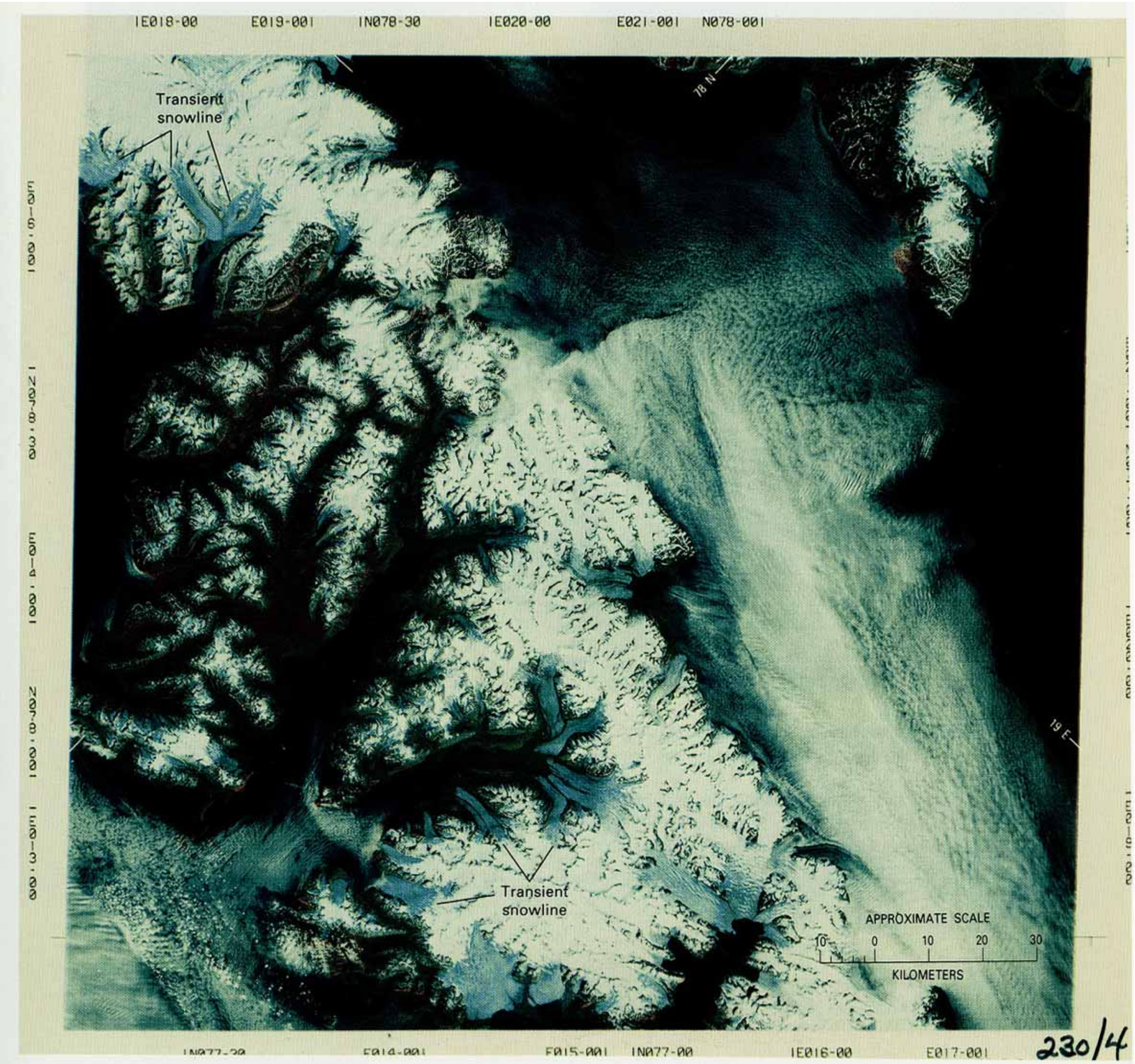


Figure 15.–*Landsat MSS false-color composite image (**2543–11162;** 18 July 1976; Path 230, Row 4) of the southern and central part of Spitsbergen and the western part of Edgeøya showing the transient **snowline** on the glaciers.*

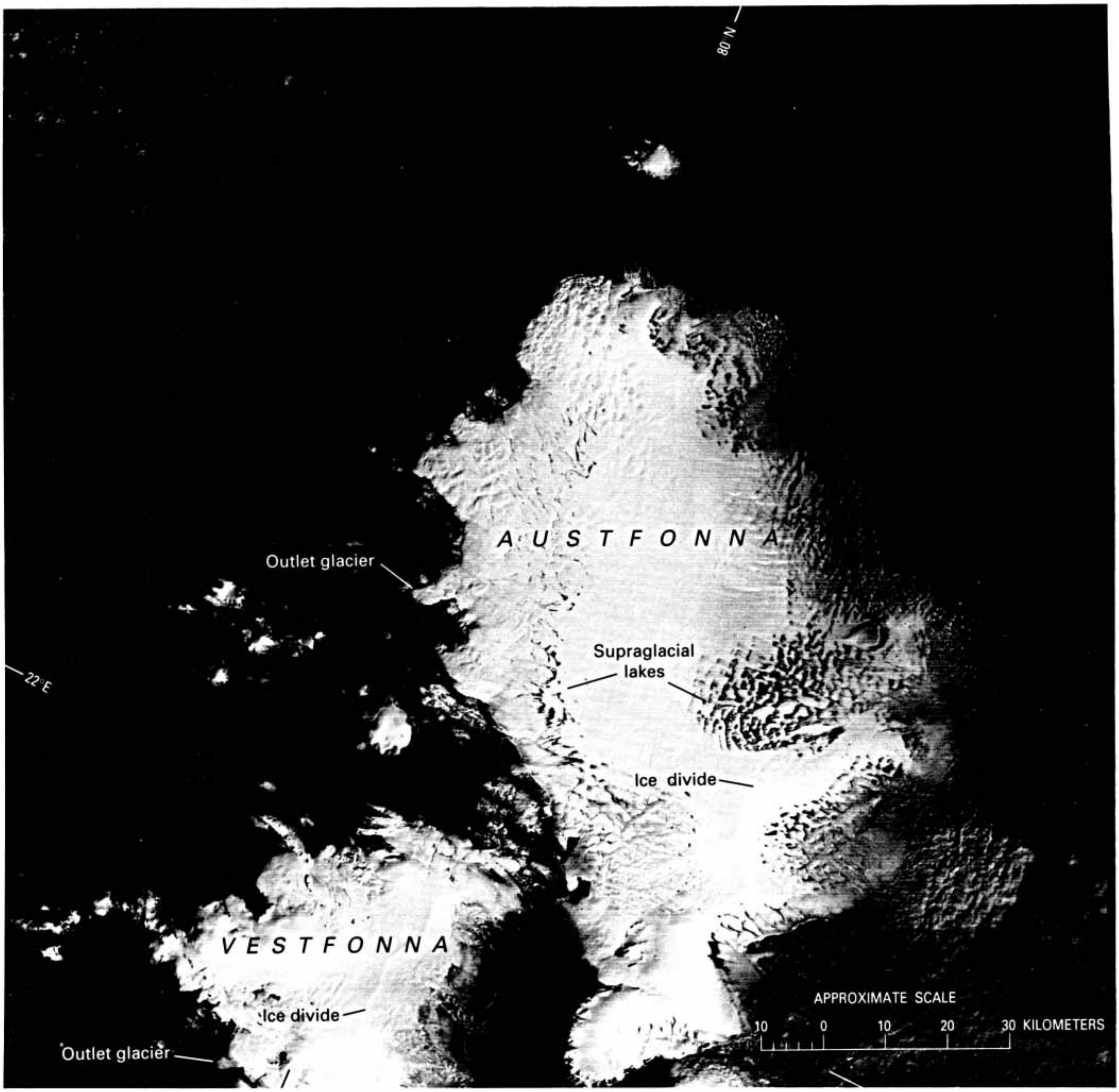


Figure 16.–Landsat MSS image (30161–72743; 13 August 1978; path 238, Row 1) of Nordaustlandet showing supraglacial lakes On Austfonna and outlet glaciers and ice divides on Austfonna and Vestfonna. This image was used to delineate outlet-glacier basins and ice divides on these two ice caps.

with other glaciological datasets in order to investigate the dynamics of these ice masses (Dowdeswell and Drewry, 1989; Dowdeswell and Collin, 1990).

Figure 18 is an index map showing the nominal scene centers and evaluation of the optimum Landsat images of Svalbard. Table 7 provides more-detailed information on each of the optimum Landsat images.

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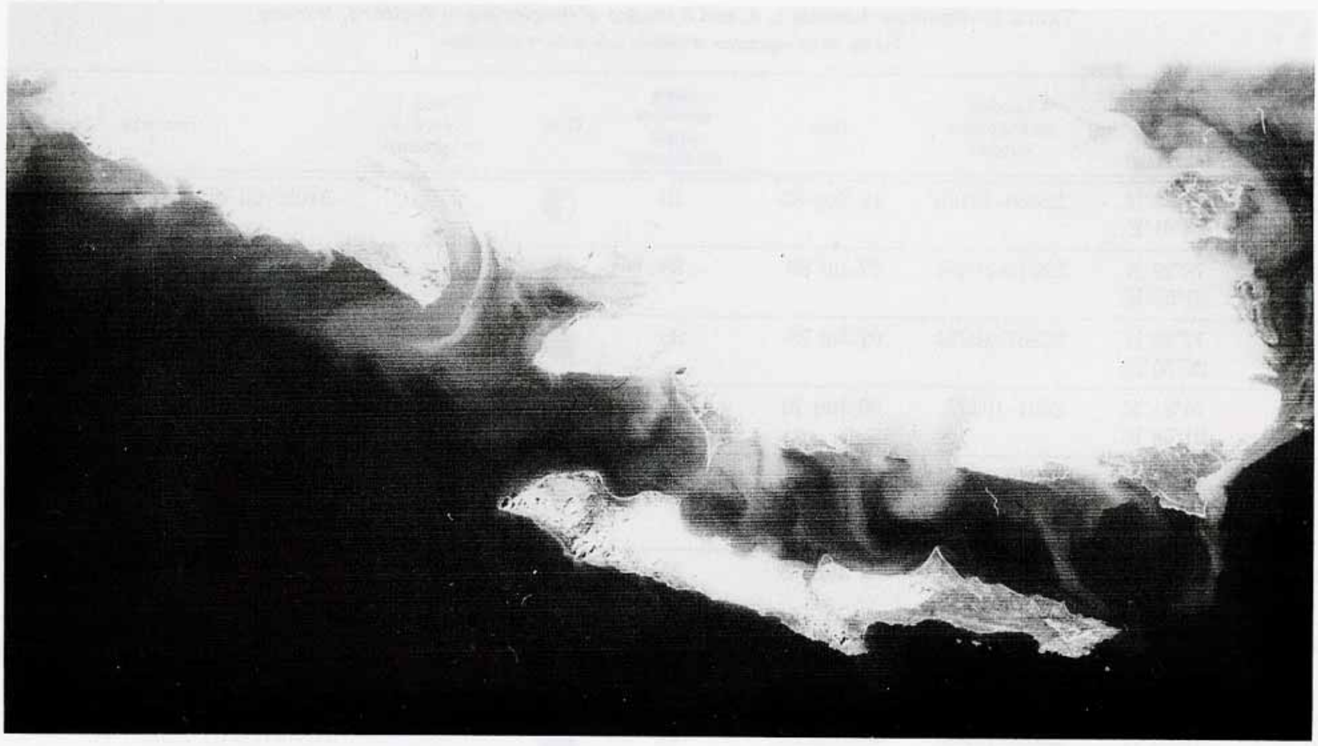


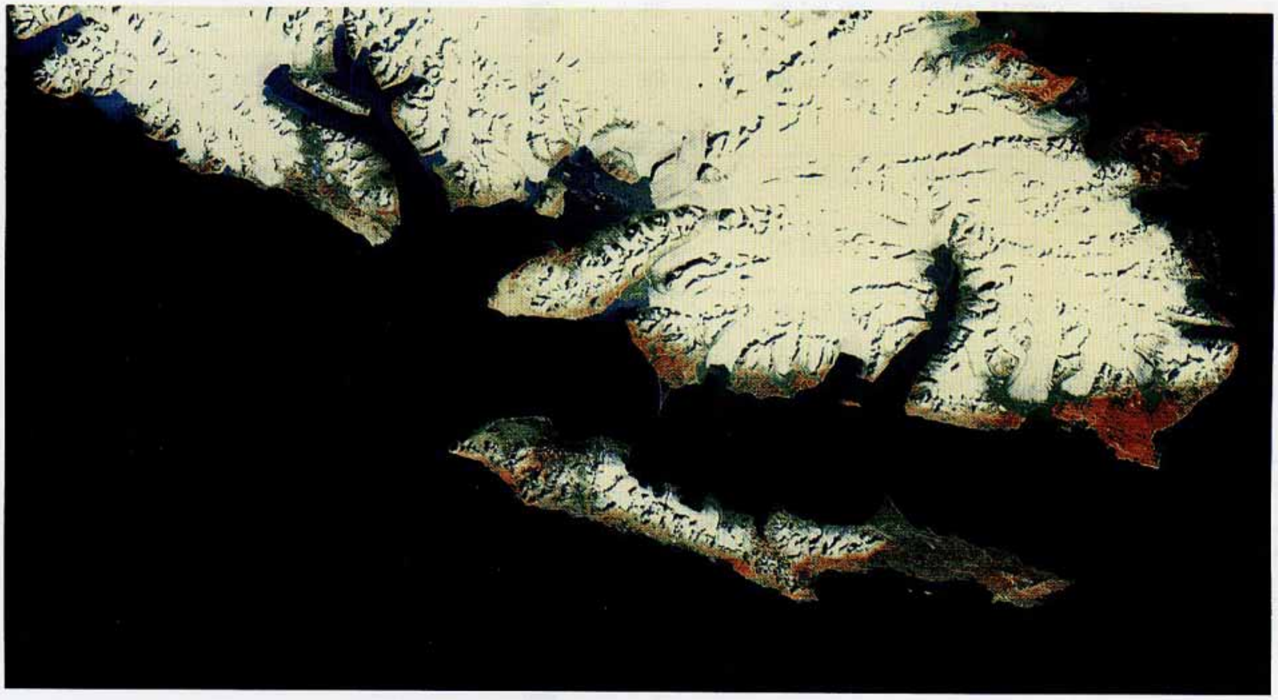


Figure 17.**–***Landsat MSS image (2534–12074; 9 July 1976; Path 239, Row 3) of Prins Karls Forland, Svalbard, showing sediment-laden meltwater discharging into coastal waters. The sediment can be seen as lighter blue patterns in the water on the false-color composite. It can be seen more clearly on the black-and-white print of MSS band 4 data.*

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

[See fig. 18 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
223-4	77°33'N. 28°01'E.	22066–10425	18 Sep 80	13	◑	70	Archived by ESA'
224-3	78°29'N. 31°58'E.	22013–10474	27 Jul 80	30	◑	20	Good image of Kongsøya archived by ESA
224-4	77°33'N. 26°35'E.	21257–10274	02 Jul 78	35	●	0	Edgeøya-Kong Johans Breen; archived by ESA
224-5	76°31'N. 21°58'E.	2501–10432	06 Jun 76	36	◕	10	
225-3	78°29'N. 30°32'E.	30849–10461	01 Jul 80	34	●	0	Cloud free, but several line drops over islands; archived by ESA
225-4	77°33'N. 25°09'E.	2502-10484	07 Jun 76	35	◑	30	
225-4	77°33'N. 25°09'E.	30849-10464	01 Jul 80	35	◑	40	Several line drops; used to produce digital mosaic shown in figure 14; archived by ESA
225-5	76°31'N. 20°32'E.	22068-10545	20 Sep 80	14	●	0	Archived by ESA
226-3	78°29'N. 29°05'E.	22015–10591	29 Jul 80	29	◕	10	Archived by ESA
226-4	77°33'N. 23°43'E.	22015–10594	29 Jul 80	30	●	0	Used to produce digital mosaic shown in figure 14; archived by ESA
226-5	76°31'N. 19°05'E.	21637–10543	17 Jul 79	34	●	0	Southern tip of Spitsbergen; archived by ESA
227-3	78°29'N. 27°39'E.	22016–11050	30 Jul 80	29	◑	20	Archived by ESA
227-4	77°33'N. 22°17'E.	22016–11052	30 Jul 80	30	◕	10	Archived by ESA
227-5	76°31'N. 17°39'E.	21278–10461	23 Jul 78	33	●	0	Used to produce digital mosaic shown in figure 14; archived by ESA
228-1	80°01'N. 39°39'E.	30151–11170	03 Aug 78	26	◑	20	
228-2	79°19'N. 32°28'E.	2541–11040	16 Jul 76	31	◑	60	
228-3	78°29'N. 26°13'E.	22017–11105	31 Jul 80	29	◕	10	Good image of Svenskøya; archived by ESA
228-4	77°33'N. 20°51'E.	22017–11111	31 Jul 80	30	◕	10	Archived by ESA
228-5	76°31'N. 16°13'E.	22017–11114	31 Jul 80	31	◑	20	Archived by ESA
229-1	80°01'N. 38°12'E.	30152–11224	04 Aug 78	26	●	0	Good image of eastern part Kvitøya
229-2	79°19'N. 31°02'E.	2201–11220	11 Aug 75	25	◑	70	Kvitøya
229-3	78°29'N. 24°47'E.	22018–11163	01 Aug 80	28	◑	30	Used to produce digital mosaic shown in figure 14; archived by ESA

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

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
229-4	7T°33'N. 19°24'E.	22018–11170	01 Aug 80	30	◕	10	Archived by ESA
229-5	76°31.N. 14°47'E.	22018–11172	01 Aug 80	31	◑	30	Archived by ESA
230-1	80°01'N. 36°46'E.	30152–11224	04 Aug 78	25	●	0	Partial image (90%); archived by ESA
230-1	80°01'N. 36°46'E.	21641–11155	21 Jul 79	29	◑	60	Used to produce digital mosaic shown in figure 14; archived by ESA
230-2	79°19'N. 29°36'E.	2543–11153	18 Jul 76	31	●	5	
230-2	79°19'N. 29°36'E.	22055–11221	07 Sep 80	15	◑	20	Used to produce digital mosaic shown in figure 14; archived by ESA
230-3	78°29'N. 23°21'E.	2543–11155	18 Jul 76	32	◕	10	Good image of northern Edgeøya, Barentsøya, and Negribreen on Spitsbergen
230-4	77°33'N. 17°58'E.	2543–11162	18 Jul 76	33	◕	10	Good image of Spitsbergen from Billefjorden to Hornsund
230-5	76°31'N. 13°21'E.	2543–11164	18 Jul 76	34	◑	20	
231-1	80°01'N. 35°20'E.	30154–11341	01 Jul 78	31	●	0	Very good image of Kvitøya; subglacial drainage divides visible
231-2	79°19'N. 28°10'E.	22020-11274	03 Aug 80	27	◑	30	Archived by ESA
231-3	78°29'N. 21°55'E.	2077–11344	09 Apr 75	18	◑	70	
231-4	77°33'N. 16°32'E.	2472–11235	08 May 76	29	◕	10	
231-5	76°31'N. 11°55'E.	2472–11242	08 May 76	30	◑	40	
232-1	80°0l'N. 33°54'E.	22021–11325	04 Aug 80	25	◑	30	
232-2	79°19'N. 26°44'E.				◔		
232-3	78°29'N. 20°29'E.	2456–11352	22 Apr 76	23	◑	50	
232-4	77°33'N. 15°06'E.	2473–11293	09 May 76	29	◑	25	
233-1	80°01'N. 32°28'E.	2528–11324	03 Jul 76	31	◑	25	
233-2	79°19'N. 25°18'E.	2528–11330	03 Jul 76	33	◑	50	
233-3	78°29'N. 19°03'E.	2528–11333	03 Jul 76	34	◑	60	
233-4	77°33'N. 13°40'E.	2474–11352	10 May 76	29	◑	30	

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

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
234–1	80°01'N. 31°02'E.	30049–11502	23 Apr 78	21	●	0	Very good image of Kvitøya; subglacial drainage divides visible
234–2	79°19'N. 23°52'E.	2529–11385	04 Jul 76	32	◑	30	Prominent ablation features, Nordaustlandet
234–2	79°19'N. 23°52'E.	22383–11413	01 Aug 81	27	◑	20	Used to produce digital mosaic shown in figure 14; archived by ESA
234-3	78°29'N. 17°37'E.	1245–11583	25 Mar 73	12	●	5	
234-3	78°29'N. 17°37'E.	22041–11453	24 Aug 80	21	◑	50	Used to produce digital mosaic shown in figure 14; archived by ESA
234–3	78°29'N. 17°37'E.	22383–11415	01 Aug 81	28	◕	10	Archived by ESA
234-4	77°33'N. 12°14'N.	21645–11400	25 Jul 79	31	◑	20	Used to produce digital mosaic shown in figure 14; archived by ESA
235–1	80°01'N. 29°36'E.	30122–11564	05 Jul 78	31	◑	50	
235–2	79°19'N. 22°26'E.	2530–11443	05 Jul 76	32	◑	15	Prominent ablation features, Nordaustlandet
235-3	78°29'N. 16°11'E.	2476-11462	12 May 76	29	◕	10	
235-4	77°33'N. 10°48'E.	2476–11464	12 May 76	30	◑	20	
236–1	80°01'N. 28°10'E.	22007–11554	21 Jul 80	29	◑	40	Archived by ESA
236–2	79°19'N. 21°00'E.	2549-11494	24 Jul 76	29	◑	30	Good image of northeastern Spitsbergen
236-3	78°29'N. 14°45'E.	2549–11501	24 Jul 76	31	◑	70	
236-4	77°33'N. 09°22'E.				◔		
237–1	80°01'N. 26°44'E.	22008–12013	22 Jul 80	28	◑	20	Archived by ESA
237–2	79°19'N. 19°34'E.	2496–11565	01 Jun 76	32	◑	40	Northeastern Spitsbergen
237–3	78°29'N. 13°19'E.	2496–11572	01 Jun 76	33	◕	10	Northwestern Spitsbergen and Prins Karls Forland
238–1	80°01'N. 25°18'E.	30161–12143	13 Aug 78	23	◑	15	Prominent ablation features, subglacial drainage divides, Nordaustlandet
238–1	80°01'N. 25°18'E.	21667–12015	16 Aug 79	22	◑	20	Used to produce digital mosaic shown in figure 14; archived by ESA
238–1	80°01'N. 25°18'E.	30736–12032	10 Mar 80	5	●	0	Subglacial drainage divides, Nordaustlandet; some line drops; archived by ESA

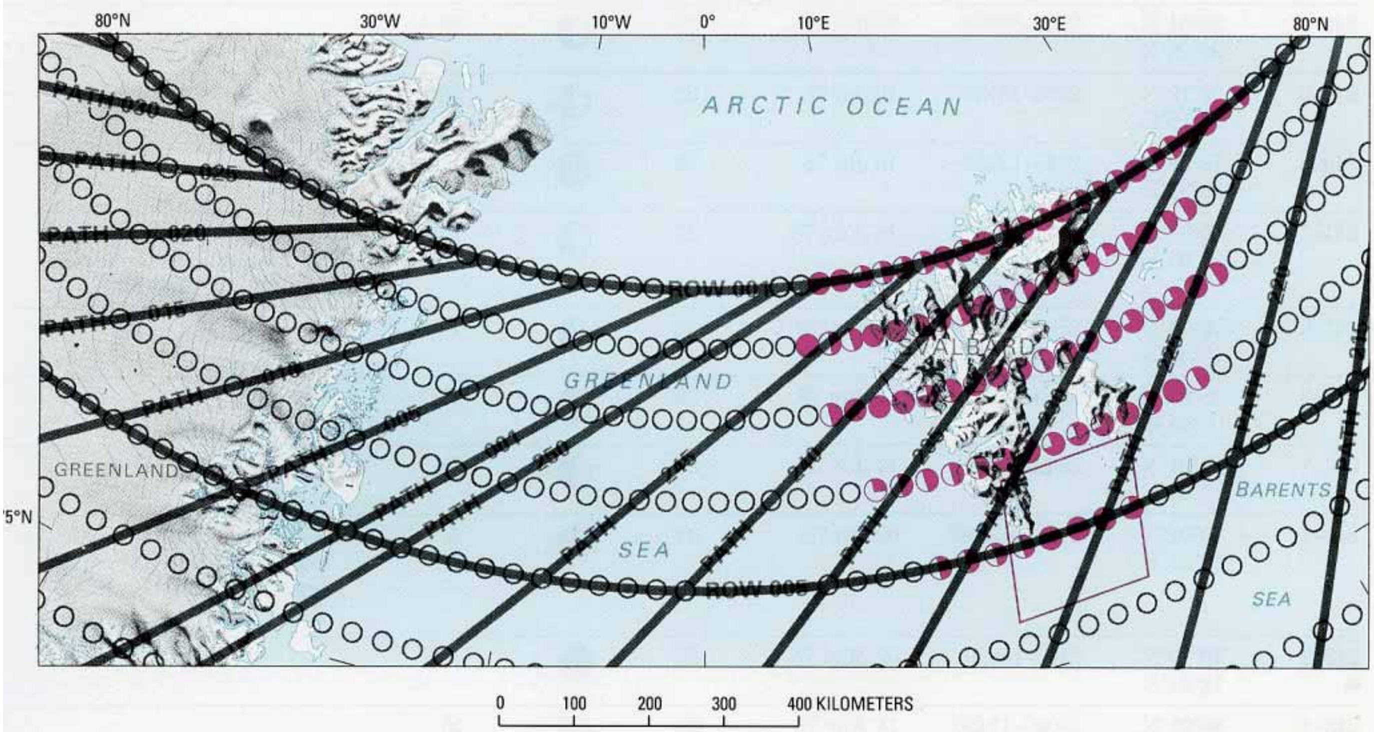
TABLE 7.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Svalbard, Norway—Continued*

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
238–2	79°19'N. 18°08'E.	21631–12020	11 Jul 79	32	●	0	Used to produce digital mosaic shown in figure 14; archived by ESA
238-3	78°29'N. 11°53'E.	2462–12094	28 Apr 76	25	◑	20	
238-3	78°29'N. 11°53'E.	30160–12094	12 Aug 78	25	◑	30	Used to produce digital mosaic shown in figure 14; archived by ESA
238–3	78°29'N. 11°53'E.	21631–12022	11 Jul 79	33	●	0	Partial image (90%); archived by ESA
239–1	80°01'N. 23°52'E.	30036–12190	10 Apr 78	16	◕	10	
239–2	79°19'N. 16°42'E.	2534–12072	09 Jul 76	32	◑	20	Good image of northern Spitsbergen
239-3	78°29'N. 10°27'E.	2534–12074	09 Jul 76	33	●	0	Good image of western Spitsbergen-Prins Karl Forland
240-1	80°01'N. 22°26'E.	2541–12463	16 Jul 76	29	◑	20	
240-2	79°19'N. 15°16'E.	2535–12130	10 Jul 76	32	◑	30	Good image of northwestern Spitsbergen
240-3	78°29'N. 09°01'E.	2535–12133	10 Jul 76	33	●	0	
241–1	80°01'N. 21°00'E.	30164–12314	16 Aug 78	22	◑	15	Prominent ablation features; subglacial drainage divides, Nordaustlandet
241–2	79°19'N. 13°50'E.	2500–12194	05 Jun 76	32	◑	40	
241–3	78°29'N. 07°35'E,	2500-12201	05 Jun 76	33	◑	15	
242–1	80°01'N. 19°34'E.	2542–12521	17 Jul 76	29	◑	40	Northern Nordaustlandet
242–1	80°01'N. 19°34'E.	21257–12093	02 Jul 78	31	●	5	Used to produce digital mosaic shown in figure 14; partial image (75%); archived by ESA
242–2	79°19'N. 12°24'E.	2466–12320	02 May 76	25	●	5	
243–1	80°01'N. 18°08'E.	30040–12420	14 Apr 78	18	◕	10	
243–2	79°19'N. 10°57'E.	2467–12374	03 May 76	25	●	0	
244–1	80°01'N. 16°42'E.	2486–12423	22 May 76	29	●	0	
244–2	79°19'N. 09°31'E.	30868–12335	20 Jul 80	30	◑	40	Archived by ESA
245–1	80°01'N. 15°16'E.	30150–12543	02 Aug 78	26	◑	35	

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

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
245–2	79°19'N. 08°05'E.	248612430	22 May 76	30	◑	15	
246–1	80°01'N. 13°49'E.	30025–12590	03 Mar 78	12	◕	10	
2462	79°19'N. 06°39'E.	2470–12545	06 May 76	26	●	5	
247–1	80°01'N. 12°23'E.	2489–12594	25 May 76	29	◑	25	
248–1	80°01'N. 10°57'E.	30027–13103	01 Apr 78	13	◕	10	
249–1	80°01'N. 09°31'E.	2473–13113	09 May 76	26	●	0	
250–1	80°01'N. 08°05'E.	2474–13172	10 May 76	26	●	0	

[1] Data archived by the Swedish Space Corporation in Kiruna, Sweden, in cooperation with the European Space Agency.



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)
- ◔ Unusable image (100 percent cloud cover)
- ○ Nominal scene center for a Landsat image outside the area of glaciers
- ▱ Approximate size of area encompassed by nominal Landsat MSS image

Figure 18.–Optimum Landsat 1, 2, and 3 images of the glaciers of Svalbard, 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.

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