Glaciological investigations in Norway in 2000

Bjarne Kjøllmoen (Ed.)

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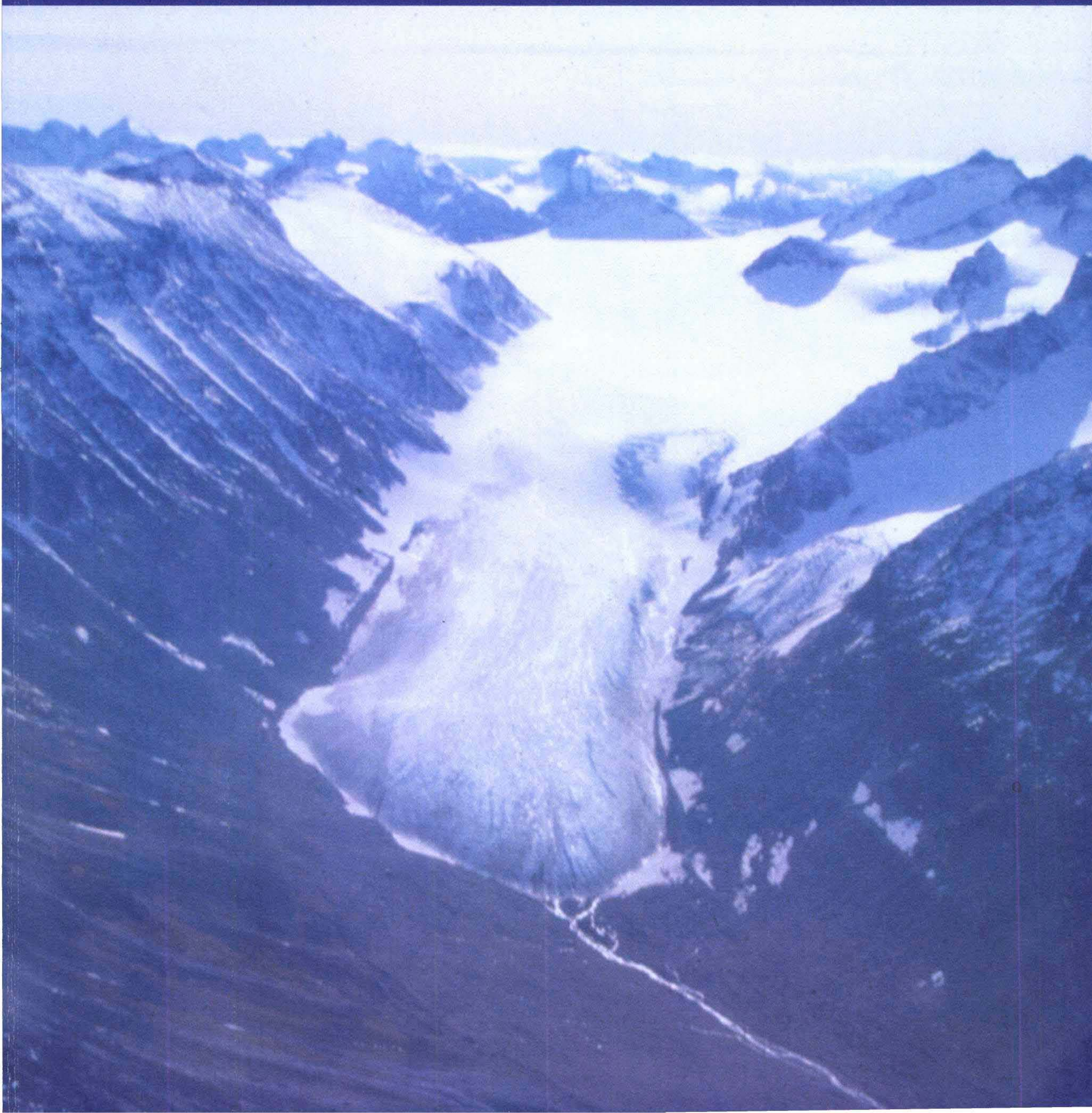
REPORT



Glaciological investigations in Norway in 2000

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Glaciological investigations in Norway in 2000

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Frontpage photo: Hellstugubreen, a north-facing valley glacier situated in central Jotunheimen. The photo is taken on 22nd September 2000 by Nils Haakensen.

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Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2000 are presented in this report. The main part concerns mass balance investigations. Results from investigations of volume change and glacier monitoring are discussed in separate chapters.

Subjects: Glaciology, Mass balance, Front position, Volume change, Glacier velocity.

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Preface

This report is a new volume in the series "Glaciological investigations in Norway" which has been published since 1963.

The report is based on a number of reports about different investigations of Norwegian glaciers. Measurements of mass balance, front position change and volume change and other glaciological investigations are presented.

Most of the investigations are ordered by external employers and published earlier as reports to these.

The report is now published only in English with a minor summary in Norwegian. The purpose of this report is to provide a joint presentation of the investigations and calculations made mainly by NVE, Glacier and Snow section during 2000. Even though the chapters are written by different authors with different objectives, it is aimed at obtaining a uniform pattern. The authors had the professional responsibility for the content of each chapter. The fieldwork and the calculations are mainly a result of co-operative work amongst the employees at Glacier and Snow section.
Bjarne Kjøllmoen was editor and Miriam Jackson made many corrections and improvements.

Oslo, November 2001

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Director of Hydrology Department

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Summary

Mass balance investigations were performed on fourteen glaciers in Norway in the year 2000. Eleven of these glaciers are in southern Norway and three in northern Norway.

The winter balance was higher than average for all the study glaciers in southern Norway. Ålfotbreen had the highest winter balance compared to usual with 149 % (5.6 m w.eqv.) of the mean value, which is the second highest winter balance ever measured since measurements began in 1963. For the 1989/90 winter season the value was 6.0 m w.eqv. In northern Norway, Engabreen had less than average (91 %), while Langfjordjøkelen had more than the mean value (113 %).

The summer balance was lower than average on all the study glaciers with the exception of Ålfotbreen. Engabreen had the lowest comparative summer balance with 56 % of average. This result (-1.3 m w.eqv.) is the second lowest (c.f. -1.2 m in 1977) ever measured on Engabreen since measurements began in 1970.

The final results show a positive net balance for nine of the ten glaciers in southern Norway. Ålfotbreen (2.0 m w.eqv.), Nigardsbreen (1.7 m w.eqv.) and Engabreen (1.5 m w.eqv.) had the greatest surplus. Only Langfjordjøkelen had a significant deficit (-0.6 m w.eqv.).

Front position measurements were performed for 24 Norwegian glaciers in 2000. Twenty of the glaciers are in southern Norway and four in northern Norway. The results show a frontal retreat for the southern and western outlets of Jostedalsbreen during the period from autumn 1999 to autumn 2000. Briksdalsbreen had a marked retreat with 30 metres. Glacier outlets on the eastern side, however, continued the previous years' advance. Nigardsbreen and Fåbergstølsbreen had the greatest advance with 23 and 25 metres, respectively, during this one-year period. Frontal advance was also measured at two outlets from Hardangerjøkulen; Rembesdalskåka (21 m) and Midtdalsbreen (8 m). Measurements from Folgefonna show that Bondhusbrea had a retreat of 24 m during this time. In Jotunheimen the front position changes are small, some outlets have had a slight advance, while other outlets have had a negligible retreat. Measurements at four glaciers in northern Norway show a slight retreat.

Digital terrain models have been used to calculate volume changes for two glaciers in northern Norway and four glaciers in southern Norway. The interval between mappings is different for each glacier. Most of the outlets from Hardangerjøkulen have increased in volume during the period 1961-95. Tverråbreen and Hellstugubreen in Jotunheimen show a marked loss in volume from 1968 to 1997. In northern Norway, both Høgtuvbreen in Nordland and Strupbreen/Koppangsbreen in Troms had a considerable decrease in volume from the 1970's to 1998.

Sammendrag

I 2000 ble det utført massebalansemålinger på 14 breer i Norge – 11 i Sør-Norge og tre i Nord-Norge.

På alle de målte breene i Sør-Norge ble vinterbalansen større enn middelverdiene. Sammenlignet med breens gjennomsnitt hadde Ålfotbreen størst vinterbalanse med 149 % (5.6 m vannekvivalenter) av middelverdien. Siden målingene startet i 1963 er det målt større vinterbalanse bare én gang tidligere - 6,0 m i 1990. I Nord-Norge ble resultatet noe mindre enn middelverdien på Engabreen (91 %) og litt over gjennomsnittet på Langfjordjøkelen (113 %).

Sommerbalansen ble mindre enn gjennomsnittet på alle de målte breene i landet med unntak av Ålfotbreen. Engabreen hadde relativt minst sommerbalanse med 56 % av gjennomsnittet. Dette resultatet (-1,3 m) er den nest laveste sommerbalansen (-1,2 m i 1977) som er målt på Engabreen siden målingene startet i 1970.

En nedbørrik vinter og relativt kjølig sommer resulterte dermed i overskudd på de fleste breene det blir utført målinger. Størst overskudd ble det på Ålfotbreen med 2,0 m, Nigardsbreen med 1,7 m og Engabreen med 1,5 m vannekvivalenter. Bare Langfjordjøkelen fikk et signifikant underskudd (-0,6 m).

Frontmålinger ble utført på 24 norske breer i 2000, 20 i Sør-Norge og fire i Nord-Norge. Resultatene viser at breutløperne på syd- og vestsiden av Jostedalsbreen har gått tilbake fra høsten 1999 til høsten 2000. Briksdalsbreen hadde i denne perioden en markert tilbakegang med 30 meter. På østsiden har derimot flere av utløperne fortsatt de siste åras framgang. Nigardsbreen og Fåbergstølsbreen gikk mest fram med hhv. 23 og 25 m i denne ettårs perioden. Det ble også målt framgang på to utløpere fra Hardangerjøkulen; Rembesdalskåka (21 m) og Midtdalsbreen (8 m). Målinger fra Folgefonna viser at Bondhusbrea gikk tilbake 24 m i denne perioden. I Jotunheimen er endringene små og noen brefronter har gått fram, mens andre har trukket seg tilbake. Målinger på fire breer i Nord-Norge viser at alle har hatt en liten tilbakegang.

Ved hjelp av digitale terrengmodeller er volumendringene i forskjellige tidsperioder beregnet for fire breer i Sør-Norge og to breer i Nord-Norge. På Hardangerjøkulen har de fleste utløperne økt i volum i perioden 1961-95. I Jotunheimen har både Tverråbreen og Hellstugubreen hatt markerte volumtap i perioden 1968-97. I Nord-Norge hadde både Høgtuvbreen i Nordland og Strupbreen/Koppangsbreen i Troms betydelige reduksjoner i brevolum fra 1970-tallet og fram til 1998.

1 Glacier investigations in Norway in 2000

1.1 Mass balance

Studies of mass balance include measurements of accumulated snow (winter balance) during the winter season, and measurements of snow and ice removed by melting (summer balance) during the summer season. The difference between these two parameters gives the net balance. If the winter balance is greater than the summer balance, the net balance is positive and the glacier will increase in volume. Alternatively, if the melting of snow and ice during the summer is larger than the winter balance, the net balance is negative and the ice volume will decrease.

Method

The method used to measure mass balance is the same as used in previous years. From the experience gained of many years of measurements, the measurement network was reduced on individual glaciers at the beginning of the 1990s, without affecting the accuracy of the resulting balance calculations and the final results.

The winter balance is normally measured in April or May by probing to the previous year's summer surface along the same profile each year. Stake readings are used to verify the probings in certain areas, where possible. Since the stakes can disappear during particularly snow-rich winters, and since it is often difficult to distinguish the summer surface (S.S.) by probing alone, snow coring is also used to confirm the probing results. Snow density is measured in pits at one or two locations at different elevations on each glacier.

Summer and net balances are obtained from stake measurements, usually carried out in September or October. Below the glacier's equilibrium line the net balance is always negative, meaning that more snow and ice melts during a given summer than accumulates during the winter. Above the equilibrium line, in the accumulation area, the net balance is always positive. Based on past experience snow density of the remaining snow in the accumulation area is typically assumed to be 0.60 g/cm^3. After especially cold summers, or if there is more snow than usual remaining at the end of the summer, snow density is measured using snow-cores, or is assumed to be 0.65 g/cm^3. The density of melted older firn is assumed to be between 0.65 and 0.75 g/cm^3. The density of melted ice is determined to be 0.90 g/cm^3.

The mass balance is calculated using the so-called stratigraphic or "traditional method" (Østrem and Brugman 1991). The balance is calculated between two successive "summer surfaces" (i.e. surface minima).

The accuracy of the mass balance measurements depends on several factors. The accuracy of the winter balance is influenced mainly by the accuracy of the point measurements (soundings, core drillings, stakes and towers and density pit) and how representative they are. The evenness of the snow layer is also of importance. The accuracy of soundings and core drillings is dependent on the number of point measurements, the certainty of identifying the summer surface and the implementation of the measurements (e.g. if the probe penetrates vertically through the snow pack). Overall, the accuracy of winter balance increases with increasing snow depth.

The accuracy of summer balance is primarily dependent on the number of stakes at which melting is measured. Further, it will depend on the representativeness of the stakes and by the state of the stakes. Common sources of error that may occur are stakes sinking becoming slanted.

The accuracy of the net balance is dependent on those factors mentioned above.

As the mass balance is measured and calculated it is very difficult to make a mathematical estimation of the accuracy because it is difficult to quantify the accuracy of the individual factors. Thus, the determined values of accuracy are based on a subjective estimate.

Mass balance program

In 2000 mass balance measurements were performed on fourteen glaciers in Norway - eleven in southern Norway and three in northern Norway. In southern Norway, six of the glaciers have been measured for 38 consecutive years or more. They constitute a west-east profile reaching from the very maritime Ålfotbreen glacier with a middle winter balance of 3.7 m water equivalent, to the very continental Gråsubreen with a middle winter balance of 0.8 m w.eqv. Storbreen in Jotunheimen has the longest series of all glaciers in Norway with 52 years of measurements, while Engabreen has the longest series (31 years) in northern Norway. Measurements were started on Midtdalsbreen in the Hardangerjøkulen ice cap and resumed on Storglombreen in western Svartisen in 2000. The location of the glaciers investigated is shown in Figure 1-1.

In the following chapters mass balance studies performed on Norwegian glaciers in 2000 are reported. The numbers from the Norwegian Hydrological Unit System (REGINE) and from the World Glacier Monitoring Service (WGMS) are given for each glacier in Table 1-1.

The mass balance (winter, summer and net balance) is given both in volume (m^3 water) and specific water equivalents for each 50 or 100 m height interval. The results are given in both tables and diagrams. All diagrams have the same ratio between units on the x- and y-axes in order to make comparison straightforward. Finally, histograms showing the complete mass balance results for each glacier are presented.

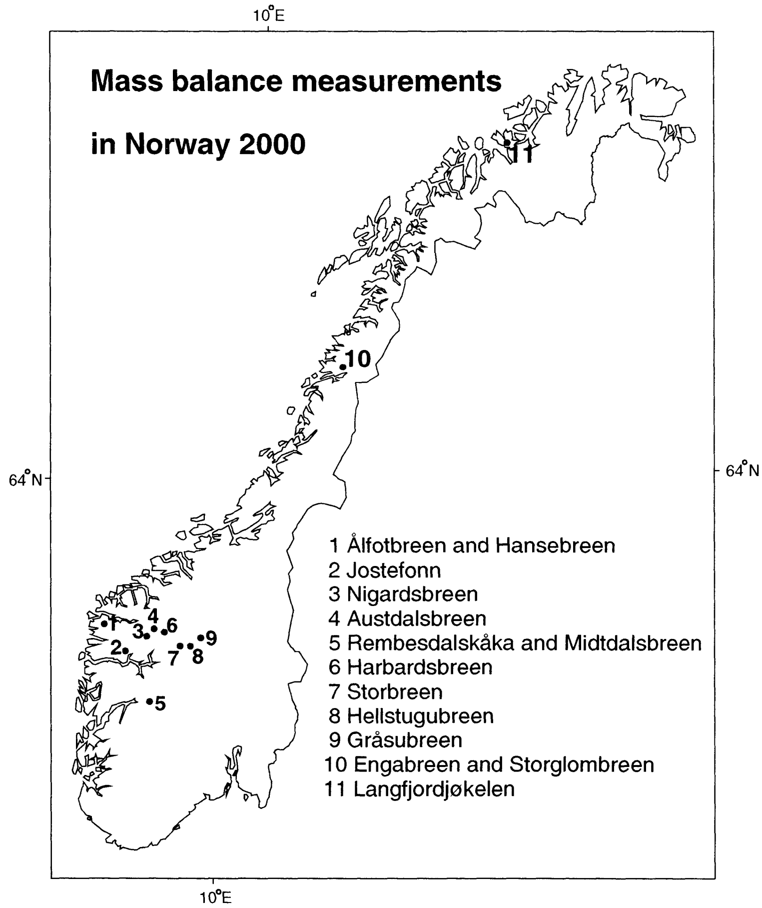


Figure 1-1

Map showing location of the glaciers at which mass balance studies were performed in 2000.

Weather conditions and mass balance results

A relatively dry September and October in 1999 resulted in a late start for snow accumulation on glaciers in both northern and southern Norway. In December, however, the precipitation was higher than normal in southern Norway and in the coastal regions in West-Finnmark. With the exception of some areas in eastern Norway, there was a lot of precipitation at the beginning of 2000, also. In glacier areas in western Norway the precipitation was 200 % of normal in January and February. In some parts of northern Norway there was almost continuous snowfall from January to April with most precipitation during March. In general there was heavy snowfall over most of the country during winter 1999/2000. In the past century it is only during winter 1991/92 that there was more snow than winter 1999/2000 over much of western Norway.

For the glaciers in western Norway winter balance was between 130 and 150 % of the mean values. Ålfotbreen had the highest winter balance compared to normal with 149 % (5.6 m w.eqv.) of the mean value, which is the second highest winter balance ever measured since measurements began in 1963. For the winter season 1989/90 the value was 6.0 m w.eqv. For the glaciers in Jotunheimen winter balance was greater than usual. The result for Storbreen was as much as 141 % of the mean value for the period 1949-99. Hellstugubreen and Gråsubreen had 112 and 115 % of the average winter balance for the period 1962-99. In northern Norway, Engabreen had less (91 %) than average for the period 1970-99, while Langfjordjøkelen in West-Finnmark had more (113 %) than the mean value for the period 1989-99.

In June, the first half of July and August the air temperature was lower than normal in the glacier areas in both southern and northern Norway. The last half of July and September, however, was warmer than normal. Also, October was unusually warm, temperature records showing it was the second warmest October month since 1867 with a mean temperature 3-4 °C higher than normal. The mean temperature for the summer 2000 season was close to mean temperature values over the whole country.

The cool early summer caused only moderate melting and even several snowfalls on glaciers in June. Moderate melting combined with fresh snowfall in the beginning of the melting season results in the albedo remaining high beyond the summer season. This effect decreases the amount of melting and even though September was warmer than usual, the net balance was lower than the mean values for the majority of the glaciers where measurements are carried out. Comparatively, Engabreen had the lowest summer balance with 56 % of average. This result (-1.3 m w.eqv.) is the second lowest (-1.2 m in 1977) ever measured on Engabreen since measurements began in 1970. In southern Norway, Austdalsbreen (75 %) and Hardangerjøkulen (77 %) had the lowest summer balance compared to normal. For most maritime glaciers (Ålfotbreen and Hansebreen) the summer balance was slightly higher than average. It is, however, necessary to emphasize that ablation was measured in the middle of September for glaciers in southern Norway, except Ålfotbreen and Hansebreen. As mentioned in the previous paragraph the last half of September and October were warmer than normal. Thus there may have been some melting after the ablation measurements were performed, and accordingly the absolute value in summer balance should be higher.

The final results show positive net balance for ten of the eleven glaciers in southern Norway. Ålfotbreen (2.0 m w.eqv.) and Nigardsbreen (1.7 m w.eqv.) had the greatest surplus. Only Gråsubreen had a negative net balance (<-0.1 m w.eqv.). In northern Norway, there was a surplus at Engabreen (+1.5 m w.eqv.) and Storglombreen (+1.1 m w.eqv.), while Langfjordjøkelen had a significant deficit (-0.6 m w.eqv.).

The results from the mass balance measurements in Norway in 2000 are shown in Table 1-1. Winter ($\mathbf{b_w}$,), summer ($\mathbf{b_s}$) and net balance ($\mathbf{b_n}$) are given in meter water equivalents (m w.eqv.) smoothly distributed over the entire glacier surface. The figures in the **% of average** column show the current results in percent of the average for the previous years with measurements (minimum 8 years of measurements). The net balance results are compared with the mean net balance in the same way. **ELA** is the equilibrium line altitude.

Figure 1-2 gives a graphical presentation of the mass balance results in southern Norway for 2000. The west-east gradient is evident for both winter and summer balance.

Glacier	Number of WGMS	REGINE	Period	Area (km²)	b_w (m)	% of average	b_s (m)	% of average	b_n (m)	b_n middle	ELA
Ålfotbreen	36204	086.6C1B	1963-00	4.4	5.57	149	-3.58	106	1.99	0.35	1025
Hansebreen	36206	086.6E	1986-00	2.9	4.69	132	-3.82	106	0.87	-0.04	1075
Jostefonn	31905	078.5Z	1996-00	3.8	3.49	-	-2.47	-	1.02	0.02[1)]	1050
Nigardsbreen	31014	076.EZ	1962-00	47.8	3.38	141	-1.66	86	1.72	0.47	1250
Austdalsbreen	37323	076.H	1988-00	11.6	2.77	117	-1.66[2)]	75	1.11	0.16	1315
Hardangerjøkulen	22303	050.4C1Z	1963-00	17.2	2.93	138	-1.50	77	1.43	0.18	~~1400~~ 1425
Midtdalsbreen	04302	012.CK2	2000-	7.1	2.89	-	-1.57	-	1.32	-	1500
Harbardsbreen	30704	075.DC	1997-00	13.2	2.30	-	-1.52	-	0.78	-0.28[3)]	1250
Storbreen	00541	002.DHBBZ	1949-00	5.3	2.04	141	-1.49	90	0.55	-0.22	1650
Hellstugubreen	00511	002.DHBAZ	1962-00	3.0	1.29	112	-1.10	86	0.19	-0.26	1840
Gråsubreen	00547	002.DGDC	1962-00	2.2	0.87	112	-0.92	89	-0.05	-0.26	Undef.
Storglombreen	67313/	160.C	1985-88	59.0						-0.75	
	67314		2000-	62.4	2.66	-	-1.55	-	1.11	-	1000
Engabreen	67011	159.81	1970-00	38.0	2.76	91	-1.27	56	1.49	0.76	970
Langfjordjøkelen	85008	211.33Z	1989-93	3.7						-0.10	
			1996-00	3.7	2.51	-	-3.12	-	-0.61	-0.92	~~1000~~ 860

1) Mean value for the period 1966-93 estimated by map comparison.
2) Contribution from calving amounts to 0.20 m for b_s.
3) Mean value for the period 1966-96 estimated by map comparison.

Table 1-1

Review of the results from mass balance measurements performed in Norway in 2000. The glaciers in southern Norway are listed from west to east. Each glacier is reported in two different number systems. The first column denotes the numbers used in the reports to the World Glacier Monitoring Service (WGMS), while the second column gives numbers from the Norwegian Hydrological Unit System (REGINE).

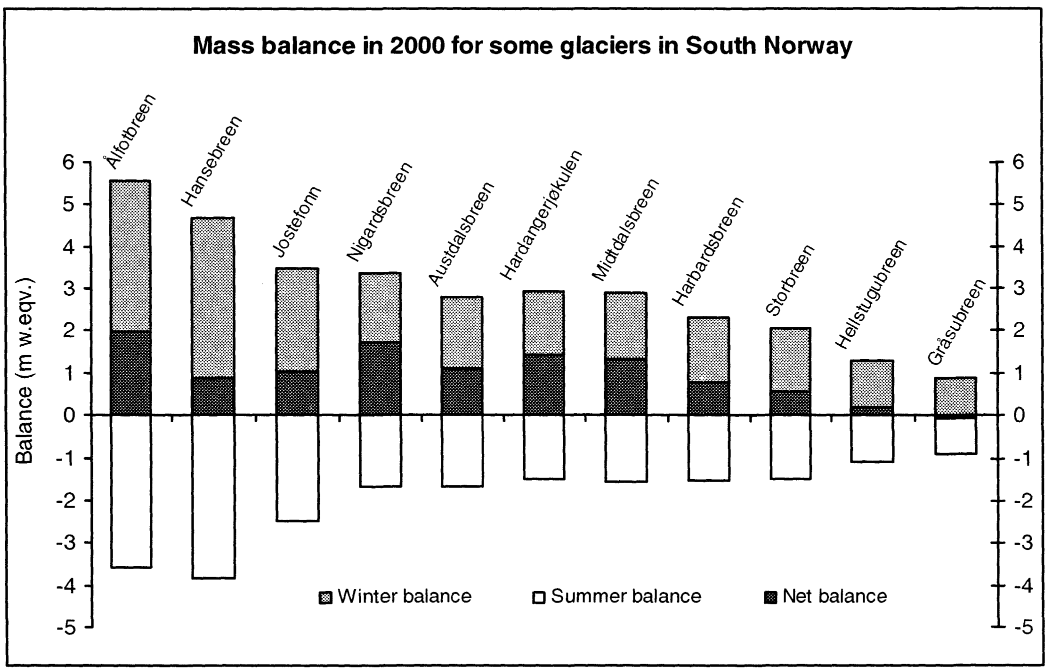


Figure 1-2

Bar graph showing mass balance for 2000 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for some of the glaciers in southern Norway during the period 1963-2000 is shown in Figure 1-3. The maritime glaciers – Ålfotbreen, Nigardsbreen and Hardangerjøkulen – have increased in volume, whilst Storbreen and Gråsubreen in Jotunheimen show a distinct decrease in net balance. The considerable surplus for the maritime glaciers is a result of some high snowfall winter seasons over the last 12 years.

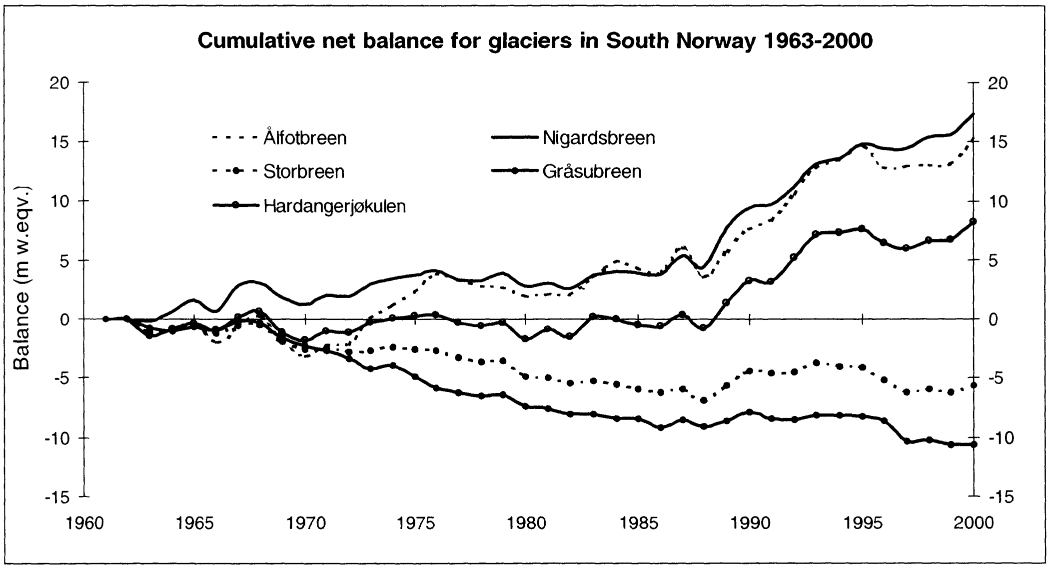


Figure 1-3

Cumulative net balance for Ålfotbreen, Nigardsbreen, Hardangerjøkulen, Storbreen and Gråsubreen during the period 1963-2000. Ålfotbreen and Nigardsbreen have a considerable surplus, and most of this has occured since 1988.

1.2 Other investigations

Front position measurements were performed at 26 glaciers in Norway in 2000. Some of these have measurements going back to ca. 1900. As well as being presented in a separate chapter (chap. 17), the front position changes are described for each glacier within that respective chapter.

Volume calculations based on map comparison are performed for seven glaciers. The results are presented in chapter 16.

The ice dynamics at Briksdalsbreen were studied by measuring front position, surface elevation, ice motion and melting (chap. 4). The measurements were initiated in 1996 and completed in 2000.

An ice-dammed lake at Harbardsbreen has been observed since the early 1990's. The observations were continued in 2000 with photography being performed in April, July and September (chap. 8).

A number of measurements were performed at Svartisheibreen during the period 1988-94 (Kjøllmoen & Kennett 1995). Mass balance, ice movement, front position change, surface elevation and water level in a small lake in front of the glacier terminus (Heiavatnet) were measured. Annual observations of water level in Heiavatnet, equilibrium line altitude and changes in ice thickness on the snout have been performed since 1995 and were continued in 2000 (chap. 12).

Meteorological observations were performed at Nigardsbreen, Engabreen, Harbardsbreen and Langfjordjøkelen.

Svartisen Subglacial Laboratory was initiated in 1992 and since then has been used by researchers from several different countries (Jackson 2000). An overview of activities in the laboratory is given in chapter 13.

A historical note about mass balance measurements at Kjølbreen and Glombreen (Gudevang 2000) during the years 1954-1956 is presented in chapter 18.

2 Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45'N, 5°40'E) is 17 km^2 and it is the westernmost and the most maritime glacier in Norway. Mass balance studies have been carried out on two adjacent north-facing outlet glaciers - Ålfotbreen (4.4 km^2) and Hansebreen (2.9 km^2). The westernmost of these has been the subject of mass balance investigations since 1963, and has always been reported as Ålfotbreen. On Hansebreen the investigations started in 1986. None of the outlet glaciers from the icecap are given a name on the official maps. To distinguish the two different glaciers the last one has been given the name Hansebreen. Ålfotbreen including its component parts and its surroundings is shown in Figure 2-1.

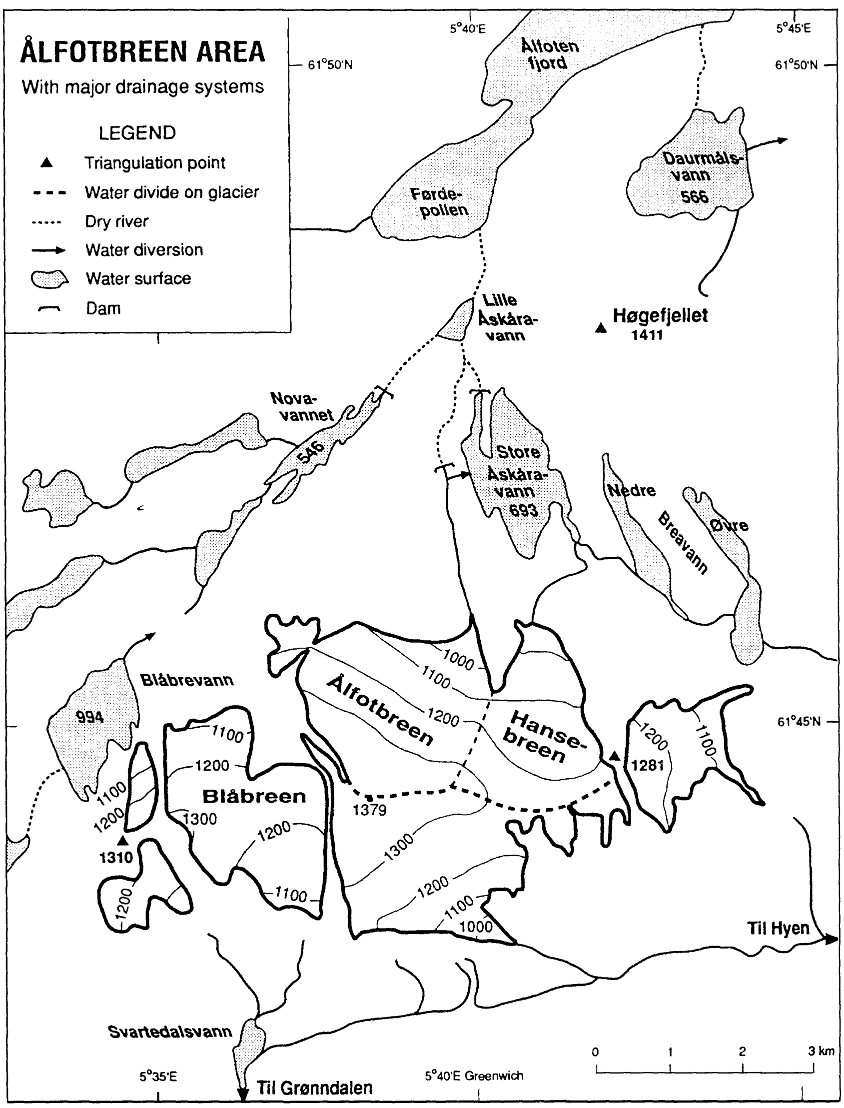


Figure 2-1

Ålfotbreen ice cap and its surrounding areas showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.

The measurements at Hansebreen were initiated in order to investigate whether mass balance results at Ålfotbreen were representative of the region. Gradually it became clear that there was an explicit difference in snow accumulation between the two glaciers. Ålfotbreen receives more snow than Hansebreen, particularly in years with large accumulation. The difference is probably due to wind drift, which lead to increased accumulation on Ålfotbreen. Accordingly, it seems that Hansebreen is the most representative of these two glaciers (Haakensen 1999), for the region.

1.2 Mass balance 2000

Field work

Accumulation measurements were performed between 30th April and 4th May. Calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Direct measurement of tower T49 (1380 m a.s.l.) showing a snow depth of 10.0 m. It was also possible to make a correlation between a substitute stake and a stake that emerged by melting during the summer at position 12 (970 m a.s.l.). The snow depth was 6.9 m at this position.
- 94 snow depth soundings along a total of 13 km of profiles at Ålfotbreen and 65 snow depth soundings along 10 km of profiles at Hansebreen. For Ålfotbreen the number of point measurements above 1100 m a.s.l. is more than sufficient but rather poor below this level. For Hansebreen, point measurements are well-represented over the entire glacier surface. Snow depth varied between 6 and 12 m at Ålfotbreen and from 6½ to about 11 m at Hansebreen. In spite of a snow depth of more than 10 m, the summer surface (SS) could be easily identified over the entire glacier.
- Snow density was measured down to SS (7.4 m) at position 37 (1205 m a.s.l.).

The location of stakes and tower, density pit and sounding profiles are shown in Figure 2-2.

Ablation was measured on 8th November. The net balance was directly measured at stakes in eight different positions between 970 and 1380 m a.s.l. at Ålfotbreen, and at two stake positions (60 - 1070 m a.s.l. and 80 - 1130 m a.s.l.) at Hansebreen. There was about 4 m of snow remaining in the uppermost parts of the glacier, and approximately 2 m in the intermediate parts (ca. 1200 m a.s.l.). At the lowest stake position (970 m a.s.l.) as well as all the snow having melted, about 1 m of ice had melted also. At the time of ablation measurements about 50 cm of fresh snow had come at both Ålfotbreen and Hansebreen. The fresh snow is not included in this years mass balance calculation.

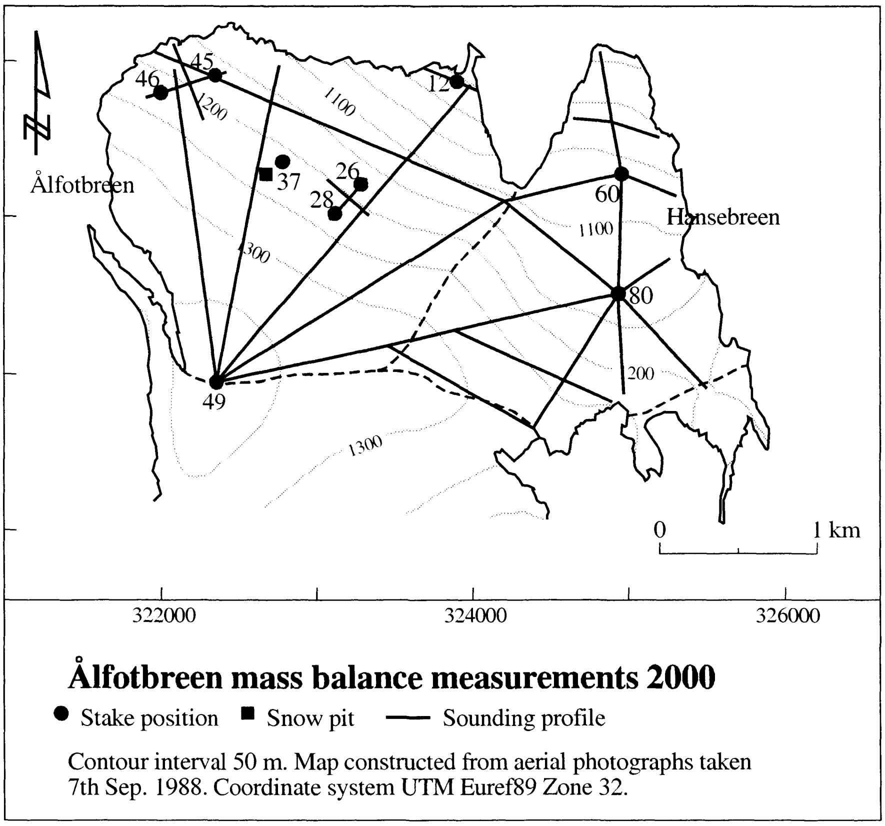


Figure 2-2

Location of tower and stakes, sounding profiles and density pit at Ålfotbreen and Hansebreen in 2000.

Results

The mass balance is calculated using the traditional method, which means the balance between two successive "summer surfaces". The calculations are based on a glacier map from 1988.

Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes, tower and probings) and on measurement of snow density in one location.

A density profile is modelled from the snow density measured at 1205 m a.s.l. The mean snow density of 7.4 m snow was 0.56 g/cm^3, which is an unusually high density for winter. The density profile is assumed to be representative for both Ålfotbreen and Hansebreen.

The calculation of winter balance is performed by plotting the point measurements (water equivalents) in a diagram. Based on a visual evaluation the curve was drawn and a mean value for each 50 m height interval was estimated.

Winter balance at Ålfotbreen in 2000 was 5.6 ±0.3 m w.eqv., corresponding to a volume of 24 ±2 mill. m^3 of water. The result is 149 % of the mean winter balance for

1963-99, and 134 % of the mean for 1986-99 (for comparison with Hansebreen). This winter balance was exceeded only in 1990 (6.0 m w.eqv.).

The winter balance at Hansebreen was 4.7 ±0,3 m w.eqv., corresponding to a volume of 14 ±2 mill. m^3 of water. The result is 132 % of the mean value for the period of investigation, and this is the largest winter balance ever measured at Hansebreen.

Summer balance

The density of the remaining snow is estimated to be 0.60 g/cm^3, while the density of melted ice is estimated to 0.90 g/cm^3.

The summer balance at Ålfotbreen was measured and calculated directly at eight stakes, and increases from about -3 m w.eqv. in the upper parts of the glacier, to nearly -5 m at the tongue. Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as -3.6 ±0.3 m w.eqv. corresponding to -16 ±1 mill. m^3 of water. The result is 106 % of the average between 1963 and 1999, and 102 % of the average between 1986 and 1999.

The summer balance for Hansebreen was measured and calculated at two stakes, both ca. -4 m w.eqv. Based on these two stakes the summer balance was -3.8 ±0.5 m w.eqv. or -11 ±2 mill. m^3 of water. The result is 106 % of the mean value over 1986-99. Because of the low number of stakes at Hansebreen, the result is more uncertain than that for Ålfotbreen.

Net balance

The net balance at Ålfotbreen for 2000 was calculated as +2.0 ±0.4 m w.eqv., or a surplus of 9 ±2 mill. m^3 of water. Since 1988, Ålfotbreen has had only one year with a negative net balance (1996). The accumulated net balance is 15.1 m w.eqv. for the period 1963-2000, and 10.8 m w.eqv. for the period 1986-2000. The mean net balance is +0.35 m w.eqv. during 1963-99, and +0.63 m during 1986-99. The diagram in Figure 2-3 shows that the equilibrium line altitude (ELA) was 1025 m a.s.l., which is about 200 m lower than a year with zero net balance. The Accumulation Area Ratio (AAR) was 96 %.

The net balance at Hansebreen was calculated as +0.9 ±0.4 m w.eqv., or a surplus of 3 ±1 mill. m^3 of water. The accumulated net balance since 1986 is slightly positive (+0.3 m w.eqv.). The mean value for the period 1986-99 (-0.04 m) shows that the glacier has been close to balance during the last 14 years. According to the diagram in Figure 2-4, ELA was 1075 m a.s.l., and hence, AAR was 81 %.

The mass balance results are shown in Tables 2-1 (Ålfotbreen) and 2-2 (Hansebreen). The corresponding curves for specific and volume balance are shown in Figures 2-3 (Ålfotbreen) and 2-4 (Hansebreen). The historical mass balance results from Ålfotbreen are presented in Figure 2-5 and those from Hansebreen in Figure 2-6.

Mass balance Ålfotbreen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 4th May 2000: Specific (m w.eq.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 8th Nov 2000: Specific (m w.eq.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surfaces 1999 - 2000: Specific (m w.eq.)	Net balance: Volume (10^6 m^3)
1350 - 1380	0,27	6,10	1,6	-3,15	-0,9	2,95	0,8
1300 - 1350	0,99	6,20	6,2	-3,25	-3,2	2,95	2,9
1250 - 1300	0,77	6,10	4,7	-3,35	-2,6	2,75	2,1
1200 - 1250	0,70	5,55	3,9	-3,50	-2,5	2,05	1,4
1150 - 1200	0,58	5,15	3,0	-3,70	-2,2	1,45	0,8
1100 - 1150	0,47	4,90	2,3	-3,90	-1,8	1,00	0,5
1050 - 1100	0,29	4,80	1,4	-4,15	-1,2	0,65	0,2
1000 - 1050	0,18	4,40	0,8	-4,40	-0,8	0,00	0,0
950 - 1000	0,09	3,90	0,3	-4,70	-0,4	-0,80	-0,1
890 - 950	0,02	3,60	0,1	-5,10	-0,1	-1,50	0,0
890 - 1380	**4,36**	**5,57**	**24,3**	**-3,58**	**-15,6**	**1,99**	**8,7**

Table 2-1

Distribution with altitude of specific and volumetric winter, summer and net balance for Ålfotbreen in 2000. The mean values for the period 1963-99 are b_w=3.74 m, b_s=-3.39 m and b_n=+0,35 m w.eqv.

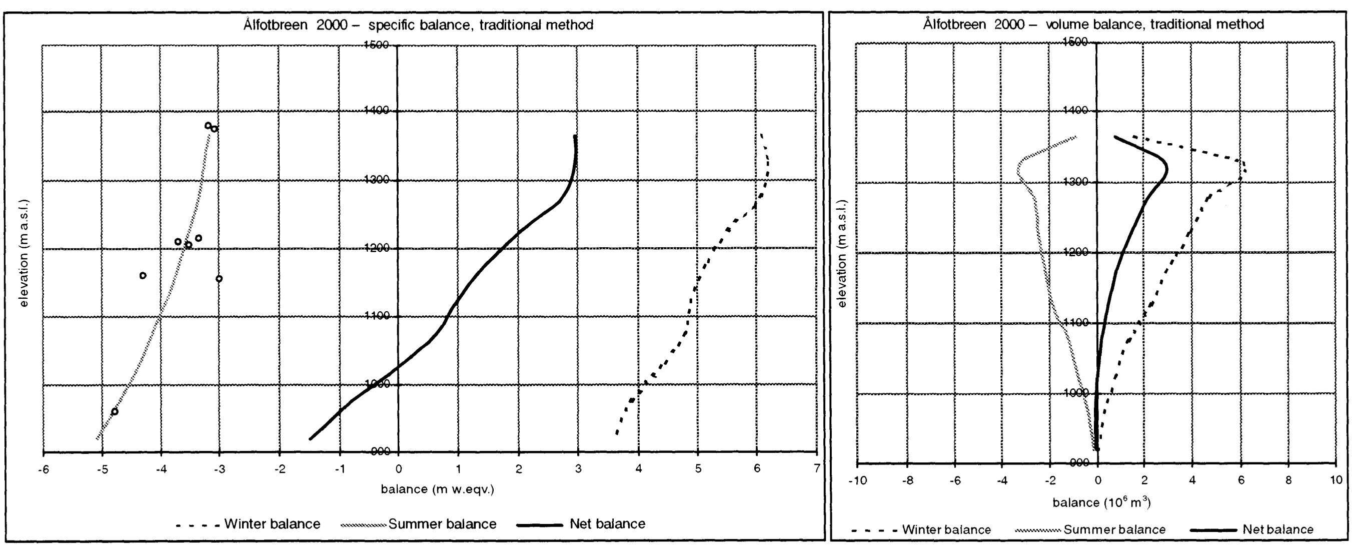


Figure 2-3

Mass balance diagram showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance for Ålfotbreen in 2000. Specific summer balance at eight stakes is shown (○). The net balance curve intersects the y-axis and defines the ELA to 1025 m a.s.l. Accordingly, the AAR was 96 %.

Mass balance Hansebreen1999/00 – traditional method							
		Winter balance Measured 4th May 2000		Summer balance Measured 8th Nov 2000		Net balance Summer surfaces 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1300 - 1320	0,11	4,90	0,55	-3,25	-0,36	1,65	0,18
1250 - 1300	0,43	4,90	2,09	-3,35	-1,43	1,55	0,66
1200 - 1250	0,45	5,20	2,35	-3,50	-1,58	1,70	0,77
1150 - 1200	0,49	5,40	2,65	-3,70	-1,82	1,70	0,83
1100 - 1150	0,63	4,40	2,75	-3,90	-2,44	0,50	0,31
1050 - 1100	0,43	4,15	1,78	-4,15	-1,78	0,00	0,00
1000 - 1050	0,22	4,00	0,88	-4,45	-0,98	-0,45	-0,10
950 - 1000	0,13	3,80	0,48	-4,75	-0,59	-0,95	-0,12
930 - 950	0,02	3,70	0,09	-5,00	-0,12	-1,30	-0,03
930 - 1320	**2,91**	**4,69**	**13,6**	**-3,82**	**-11,1**	**0,86**	**2,5**

Table 2-2

Distribution with altitude of specific and volumetric winter, summer and net balance for Hansebreen in 2000. The mean values for the period 1986-99 is b_w=3.56 m, b_s=-3.61 m and b_n=-0.04 m w.eqv.

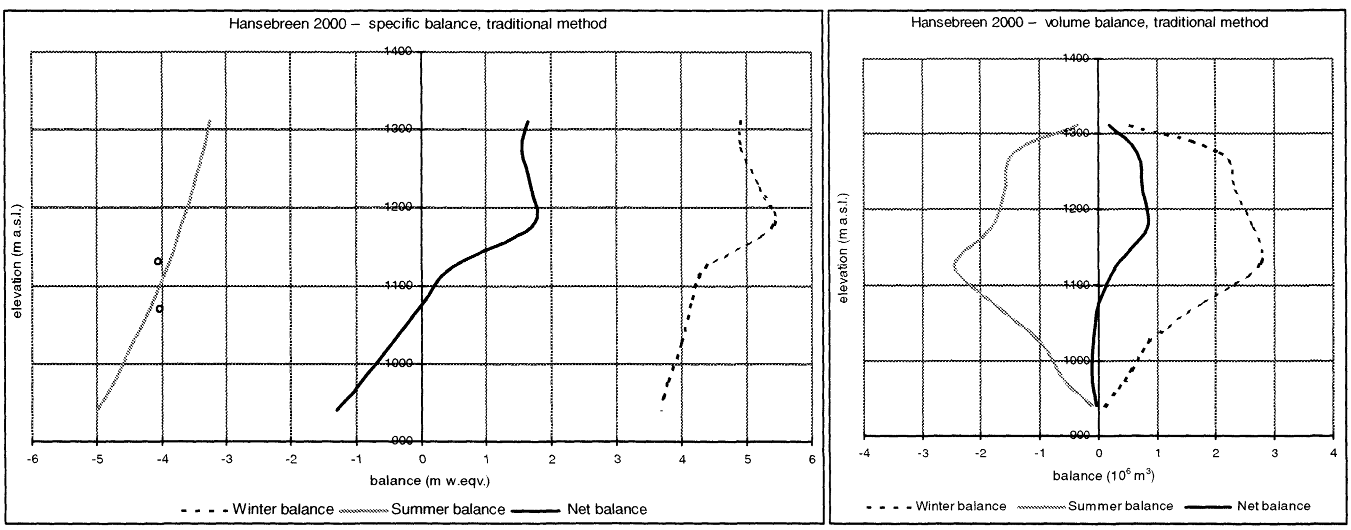


Figure 2-4

Mass balance diagram showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance for Hansebreen in 2000. Specific summer balance at two stakes is shown (○). The net balance curve intersects the y-axis and defines the ELA to 1075 m a.s.l. Accordingly, the AAR was 81 %.

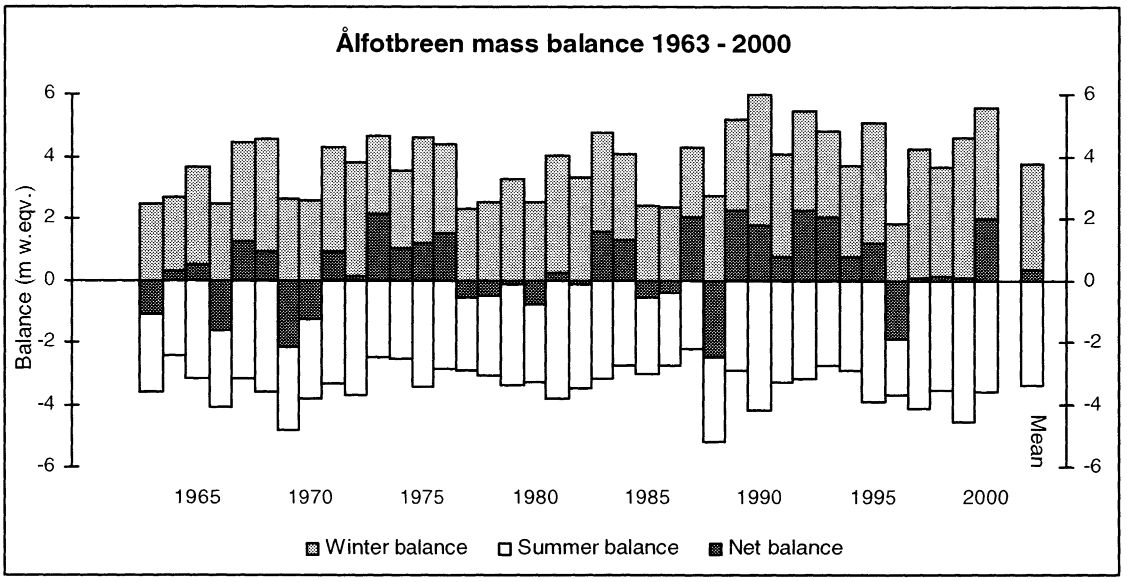


Figure 2-5

Mass balance at Ålfotbreen during 1963-2000. The accumulated surplus during this period amounts to 15.1 m w.eqv., while the accumulated net balance for 1986-2000 (for comparison with Hansebreen) is 10.8 m w.eqv.

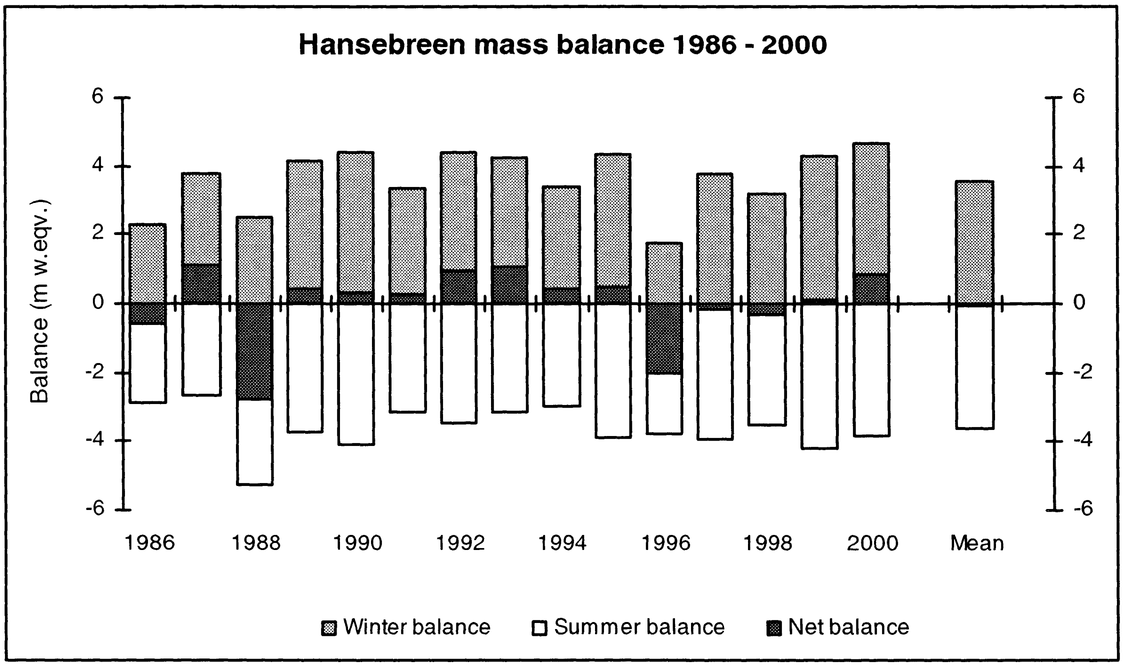


Figure 2-6

Mass balance at Hansebreen for 1986-2000. The surplus in this period (0.3 m w.eqv.) is substantially less than for Ålfotbreen.

3 Jostefonn (Hallgeir Elvehøy)

Jostefonn (61°25'N, 6°35'E) is a small plateau glacier (12.5 km^2) located 10 km south-west of Jostedalsbreen in western Norway (Fig. 3-1). The altitude range of this glacier is 960-1620 m a.s.l. Mass balance measurements have been carried out on two south-east facing outlets (Fig. 3-1) covering an area of 3.8 km^2. Mass balance measurements were initiated in the autumn of 1995 and were terminated in the autumn of 2000.

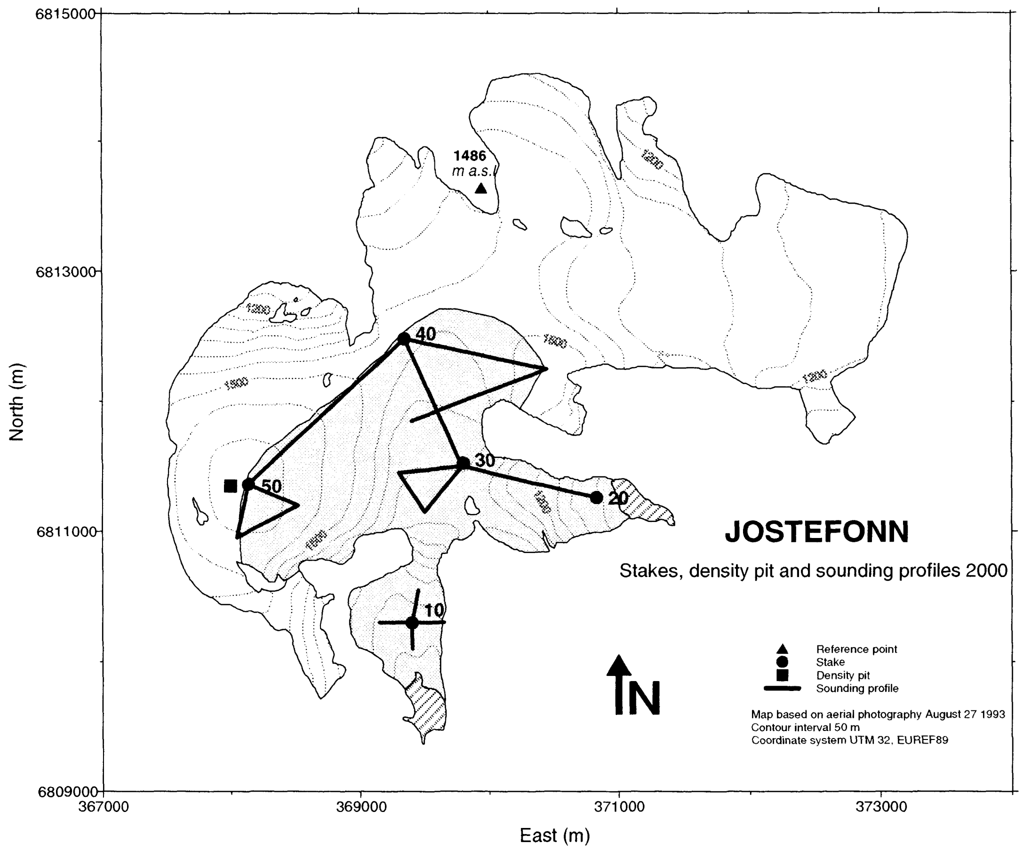


Figure 3-1

Location of stakes, density pit and sounding profiles at Jostefonn in 2000.

3.1 Mass balance 2000

Field work

Winter accumulation was measured on 29th April. The calculation of winter balance is based on the following data (Fig. 3-1):

- Snow depth measurements by coring at 1035 m a.s.l. (stake 10), 1050 m a.s.l. (stake 20), 1355 m a.s.l. (stake 30), 1460 m a.s.l. (stake 40) and 1620 m a.s.l. (stake 50) showing snow depths of 6.9, 6.6, 6.5, 5.6 and 5.8 metres respectively.

- Snow density measured down to 4.2 m depth at stake 50 (1620 m a.s.l.). The mean snow density was 0.46 g/cm^3. The summer surface (SS) was at a depth of 5.8 m.
- Snow depth measured by sounding at 73 locations along 10 km of profiles (Fig. 3-1). The SS was fairly easy to detect except at the summit, near stake 50. The snow depth was between 6 and 8 meter.

Summer ablation and net balance was measured on 14th September. There was up to 0.5 m fresh snow on the glacier above 1300 m a.s.l.. The net balance was measured at five locations between 1035 and 1620 m a.s.l. At stake locations 50, 40 and 30, there were 1.75, 1.30 and 1.75 – 2.20 meter of snow respectively remaining from last winter. At locations 10 and 20 on the glacier tongues there were several stakes, some with snow remaining and some with blue ice exposed. The temporary snow line could not be detected, but the temporary snow line altitude was estimated as approximately 1050 m a.s.l. based on stake measurements and the distribution of exposed blue ice.

The second half of September and most of October was unusually warm in western Norway, and there was thus further melting after the ablation measurements. Ablation after 14th September is not included in the calculations.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive "summer surfaces" excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements. The calculations are performed using a map from 1993.

Winter balance

A snow depth - water equivalent profile was calculated based on snow density measurements down to 4.2 m depth at stake 50 (1620 m a.s.l.) and geometric extrapolation down to 9 m. The mean density of 9 m of snow in this profile was 0.50 g/cm^3. Snow depth measurements were reduced to water equivalents using this profile.

Snow depth water equivalent values are plotted against altitude. An altitudinal winter balance curve was drawn based on averaging values over 50 m altitudinal intervals and visual evaluation. The greater snow accumulation in the steep, east-facing area between stakes 50 and 30 than on the ridge between stakes 50 and 40 was taken into account. Lower accumulation in the western ice fall between stakes 10 and 30 than at the eastern glacier tongue was also considered. From this curve a mean value for each 100 m height interval is determined. The winter balance was 13 ±1 million cubic metres water equivalent or 3.5 ±0.2 meter. This is 132 % of the 1996 – 99 average, 2.6 m w. eqv.

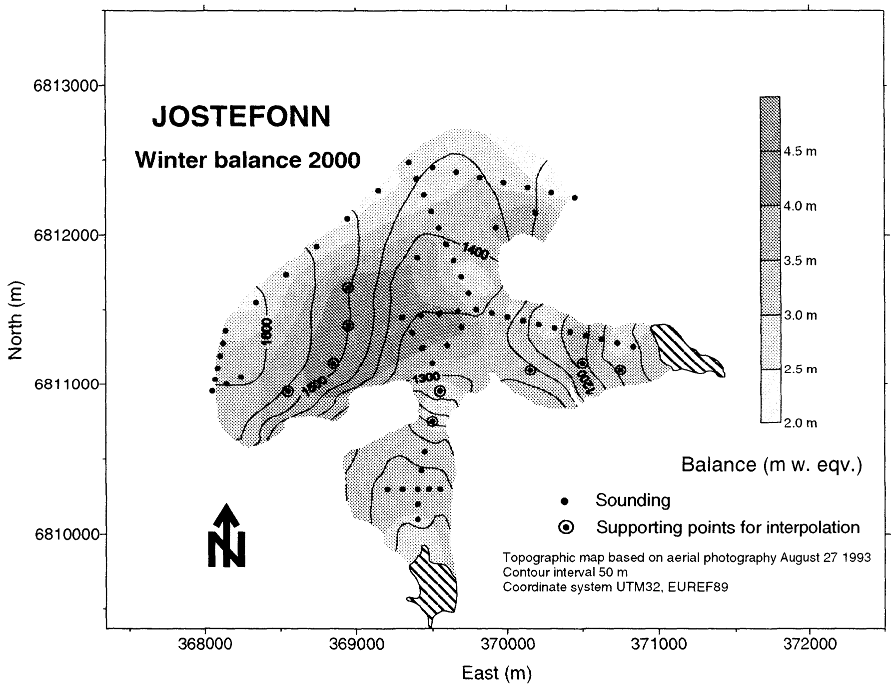


Figure 3-2

Winter balance on the studied part of Jostefonn as observed on 29th April 2000, interpolated by kriging from 73 soundings and cores, and nine extrapolate points. Mean winter balance for this spatial distribution is 3.7 m water equivalent; the winter balance calculated from the altitudinal distribution gives 3.5 m water equivalent.

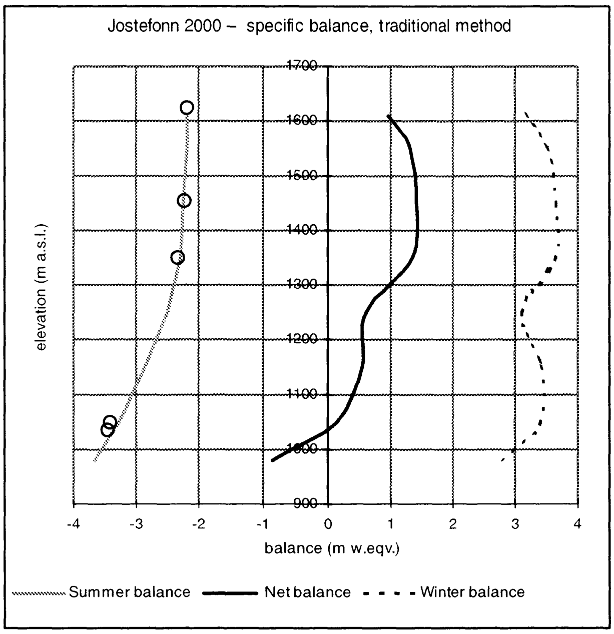
The measurement program does not cover the eastern slopes of the western, highest part of the glacier (Fig. 3-1). Winter snow accumulation in this region is probably higher than measured elsewhere on the glacier, thus causing an underestimate of the true winter balance. The spatial distribution of winter balance was calculated by krieg-interpolation using measurements from 29th April and nine extra points estimated from nearby measurements and assumed wind and topography effects (Fig. 3-2). The average winter balance based on this map was 3.7 m w.eqv.

Summer balance

The summer balance was calculated at five stake positions between 1035 and 1620 m a.s.l., and varied from –2.2 at the summit to –3.5 m w. eqv. on the glacier tongues. From these values a summer balance curve was drawn (Fig. 3-2). The summer balance was calculated as -2.5 ±0.3 m w.eqv., which is -9 ±1 million cubic metres of water. The result is 85 % of the 1995-99 average, -2.9 m w.eqv.

Net balance

The net balance at Jostefonn was calculated as 4 ±1 mill. m^3 water or +1.0 ±0.3 m w.eqv. The 1996-99 average is -0.3 meter. The ELA for 2000 determined from the net balance curve in figure 3-2 is 1050 m a.s.l. The corresponding AAR is 90 %. The altitudinal distribution of winter-, summer- and net balances is shown in Figure 3-3 and Table 3-1. Results from 1996-2000 are shown in Figure 3-4.



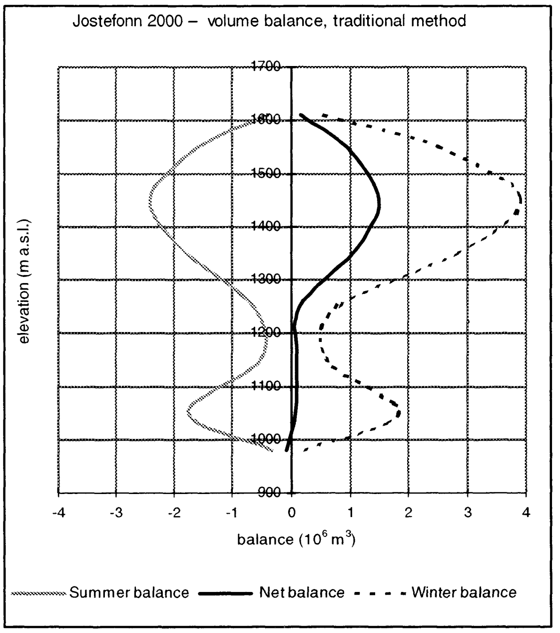


Figure 3-3

Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right). Specific summer balance at five locations is shown (o).

Mass balance Jostefonn 1999/00 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 29th Apr 2000		Measured 14th Sep 2000		Summer surfaces 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eqv.)	Volume (10^6 m^3)	Specific (m w.eqv.)	Volume (10^6 m^3)	Specific (m w.eqv.)	Volume (10^6 m^3)
1600 - 1622	0,18	3,15	0,6	-2,20	-0,4	0,95	0,2
1500 - 1600	0,72	3,50	2,5	-2,20	-1,6	1,30	0,9
1400 - 1500	1,07	3,65	3,9	-2,25	-2,4	1,40	1,5
1300 - 1400	0,78	3,65	2,8	-2,30	-1,8	1,35	1,1
1200 - 1300	0,25	3,10	0,8	-2,50	-0,6	0,60	0,2
1100 - 1200	0,18	3,40	0,6	-2,85	-0,5	0,55	0,1
1000 - 1100	0,54	3,40	1,8	-3,25	-1,8	0,15	0,1
960 - 1000	0,09	2,80	0,3	-3,65	-0,3	-0,85	-0,1
960-1622	**3,81**	**3,49**	**13,3**	**-2,47**	**-9,4**	**1,03**	**3,9**

Table 3-1

Altitudinal distribution of winter-, summer- and net balances at Jostefonn in 2000.

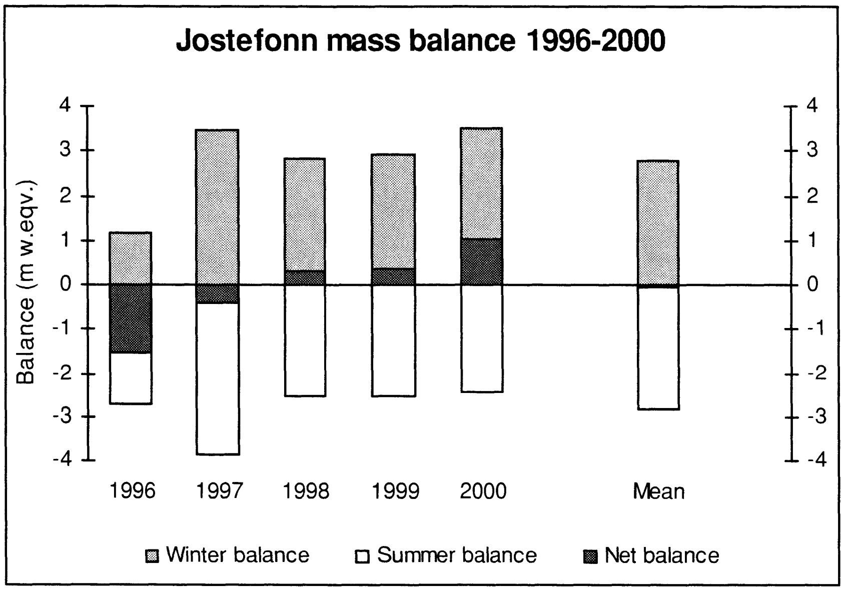


Figure 3-4

Winter-, summer and net balances at Jostefonn during the period 1996-2000. Mean values for the period are b_w=2.78 m, b_s=-2.83 m and b_n=-0.05 m water equivalents.

4 Briksdalsbreen (Hallgeir Elvehøy)

Briksdalsbreen (61°40'N, 6°57'E) is a western outlet glacier (10.4 km^2) from the Jostedalsbreen ice cap. Most of its areal extent is on the plateau between 1500 and 1915 m a.s.l., with only 12 % of the glacier area below 1500 m a.s.l. Until recently the glacier terminated in the proglacial Lake Briksdalsvatnet at 346 m a.s.l.
The glacier advanced 390 metres between 1988 and 1996 and now covers the former lake (Fig. 4-1).

Figure 4-1

The lower part of Briksdalsbreen on 2nd May 2000. Velocity measurements were made in the gently sloping area between the icefall and the terminus. This part of the glacier covers former Lake Briksdalsvatn. The river outlet has started to form on the right side of the terminus. The terminus position between the river outlet and the first prominent boulder to the left of the river outlet (arrow) has been surveyed on several occasions (Fig. 4-2 and 4-4).
Photo: Hallgeir Elvehøy.

Velocity measurements and surface profiling started in the autumn 1996 and were closed down in the spring of 2000 covering four winter seasons and tree summer seasons. Figure 4-2 summarises the measurements in May 2000.

4.1 Front position change

Front position measurements began in 1900 (Rekstad, 1904). Between 1946 and 1951 the glacier front position retreated quickly and Lake Briksdalsvatnet became exposed. Between 1973 and 1996 the glacier advanced about 500 metres and filled the lake again. This last advance culminated in 1996. After three years in approximately the same position, the glacier front retreated 30 metres in 2000 (Fig. 4-3). This is the largest annual retreat since 1951.

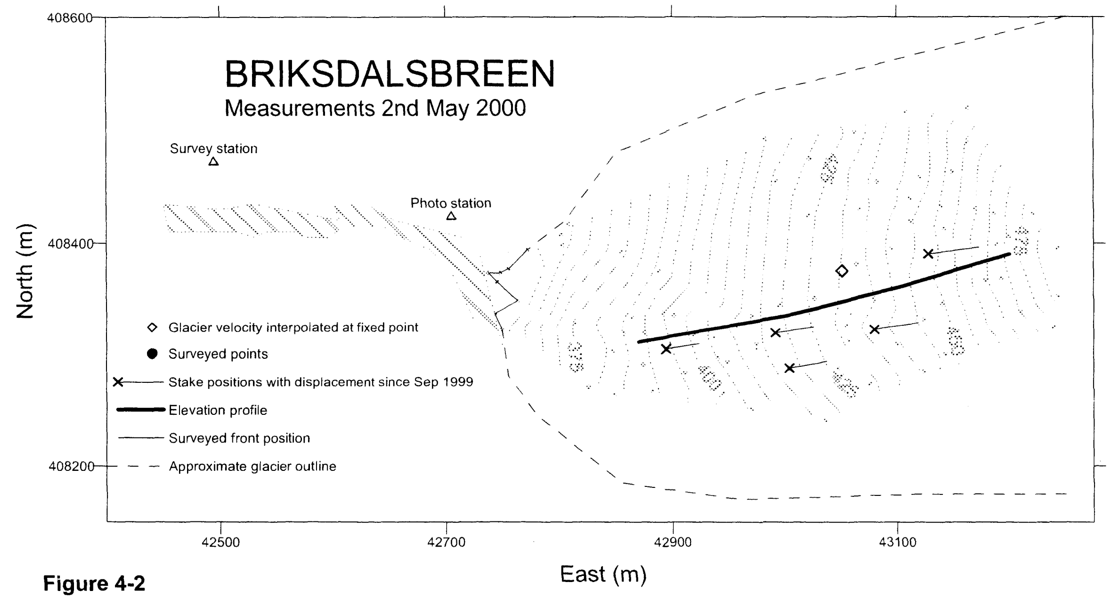


Figure 4-2

Surface topography (5 metres contour lines) interpolated from surveyed points 2nd May 2000 (grey lines and dots) and stake positions with displacement since 27th September 1999. Elevation profile used to compare terrain models (Chapter 4.2) and fixed point for velocity time series (Chapter 4.3) are also shown.

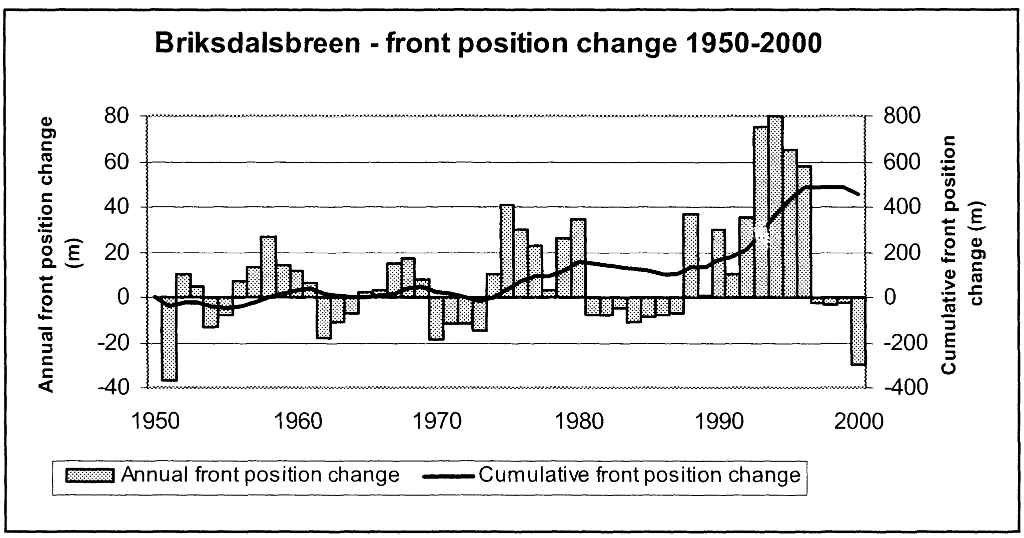


Figure 4-3

Front position change at Briksdalsbreen 1950-2000 as measured along lines on both sides of the lake. After 1980 only the northern line was used.

During the period of apparent standstill the terminus position was surveyed twice a year. The inter-annual variations are shown in Figure 4-4. The most advanced position was recorded in May 1998.

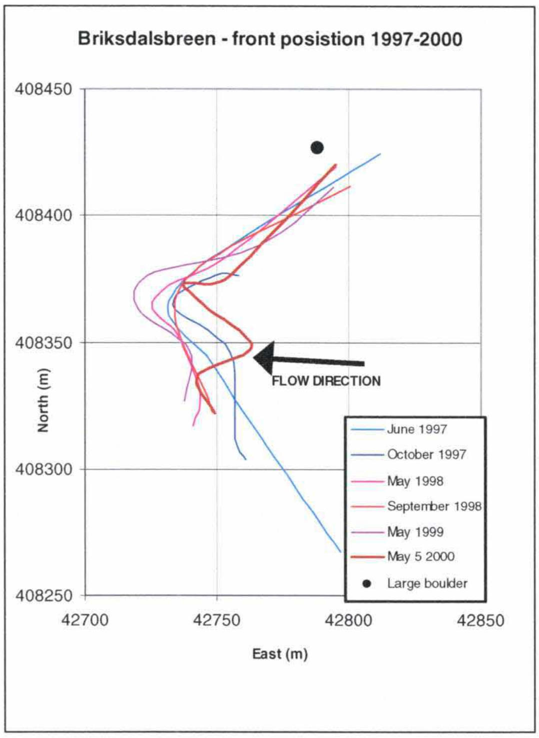


Figure 4-4

Surveyed terminus positions between 1997 and 2000. The most advanced position was recorded in May 1998. The large boulder is shown in Figure 4-1.

4.2 Surface elevation change

The lower part of the glacier has been surveyed several times between 1997 and 2000. The surveyed area was limited by crevasses on the left side of the tongue (as seen from the valley) and the ice fall from the plateau (Fig. 4-1 and 4-2). This was done to avoid large temporal changes in elevation due to collapse of ice blocks in crevassed regions. Surface undulations in the surveyed area were 1-2 metres vertically and 20-30 metres horizontally. The surveying was carried out to show these variations.

From point elevations regular 5 x 5 metres grids have been calculated by TIN (Triangulation with linear INterpolation) interpolation. A total of six grids from 18th June and 15th October 1997, 9th May and 24th September 1998, 9th May 1999 and 2nd May 2000 were calculated. The results from 2000 are shown in Figure 4-2.

A representative elevation profile has been calculated from the grids. Changes in surface elevation are shown in figure 4-5. From June 1997 to May 2000, surface lowering along the profile was 7 metres. The elevation was highest in June 1997 and lowest in September 1998 (a lowering of ten metres compared with June 1997). After an increase in elevation from September 1998 to May 1999 (+7 metres along the profile), the thinning continued from May 1999 to May 2000 (-5 metres). In the summers of 1997 and 1998 the surface elevation change along the profile was –8 and –4 metres. During the two summers the ice melting at two stakes in the area was 13 and 9 metres. This indicates that the glacier flow compensated for about 5 metres of ice melting during the summer seasons.

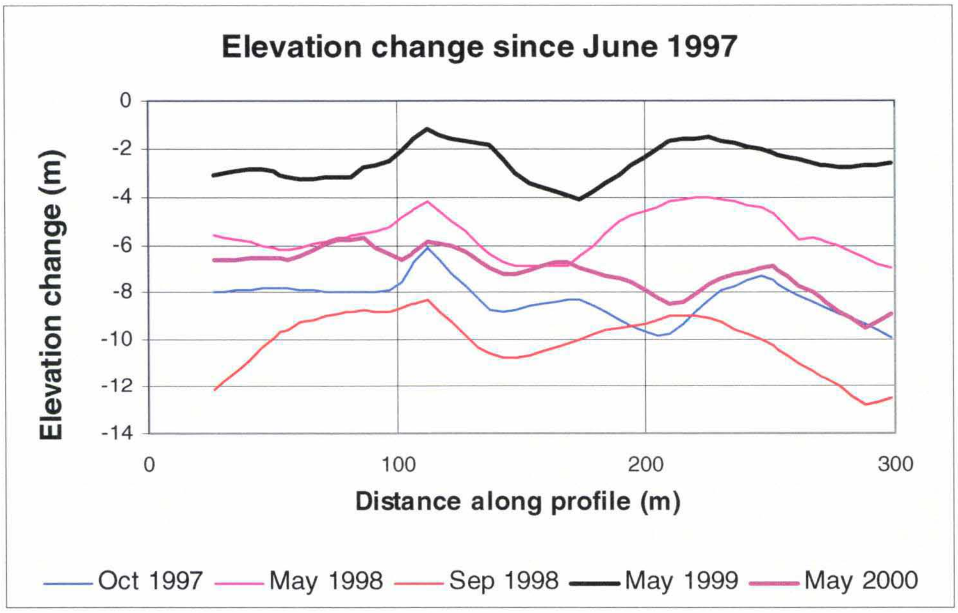


Figure 4-5

Elevation change since 18th June 1997 along the profile shown in Figure 4-2, upwards to the right.

4.3 Glacier velocity

The glacier velocity has been calculated from repeated surveys of stakes drilled into the ice. The average velocity has been calculated for periods between surveys, and the velocity is plotted between two surveyed positions.

Due to intense melting during the summer (10 – 12 metres of ice) and glacier movement of 0.2 – 0.3 metres per day, the stakes had to be re-positioned and surveyed several times during a summer season. Varying dates of survey and varying glacio-hydrological conditions from year to year makes comparison of summer velocities difficult. To assess the changes in glacier flow we therefore look at winter velocities which are calculated for periods of 7 – 8 months, thus making the values less dependent on the various survey dates and the glacio-hydrological conditions.

Figure 4-6 shows velocities calculated at stakes as a function of distance from the terminus. The effect of variations in front position during the period of measurements was ignored since the total front position change during this period was small. The glacier velocity decreases up to 50 % from the foot of the ice fall to within 100 metres of the terminus. The 1996-97 velocities are significantly higher than those in later periods. In 1998-99 the velocity was slightly higher than in 1997-98 and 1999-2000. The surface elevation change too was higher in 1998-99 than in 1997-98 and 1999-2000, indicating a higher dynamic activity this winter.

To obtain a time series of glacier velocity we used a fixed point 325 metres up glacier from the terminus and about 430 m a.s.l., and calculated the glacier velocity at this position by interpolation between velocities measured at stakes (Fig. 4-7). The calculated velocities were significantly higher in 1996-97 than later periods. The winter velocity in 1996-97 was 44 % higher than in 1997-2000, and the highest velocity (0.36 m/d) was found in the first part of summer 1997. Since autumn 1997 the glacier velocity seems to have stabilised at a lower level.

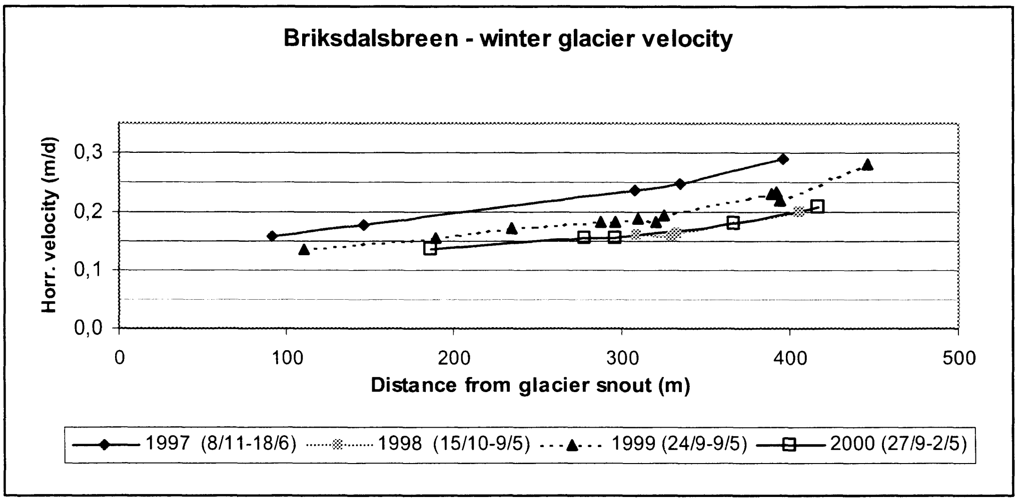


Figure 4-6

Glacier velocity (m/d) at stakes during winter and spring of 1997, 1998, 1999 and 2000. The slight difference in the period between the years can account for some of the difference, mainly due to higher glacier velocity in late spring/early summer. The reduction in velocity corresponds well with the stagnation of the glacier front position and the lowering of the glacier surface.

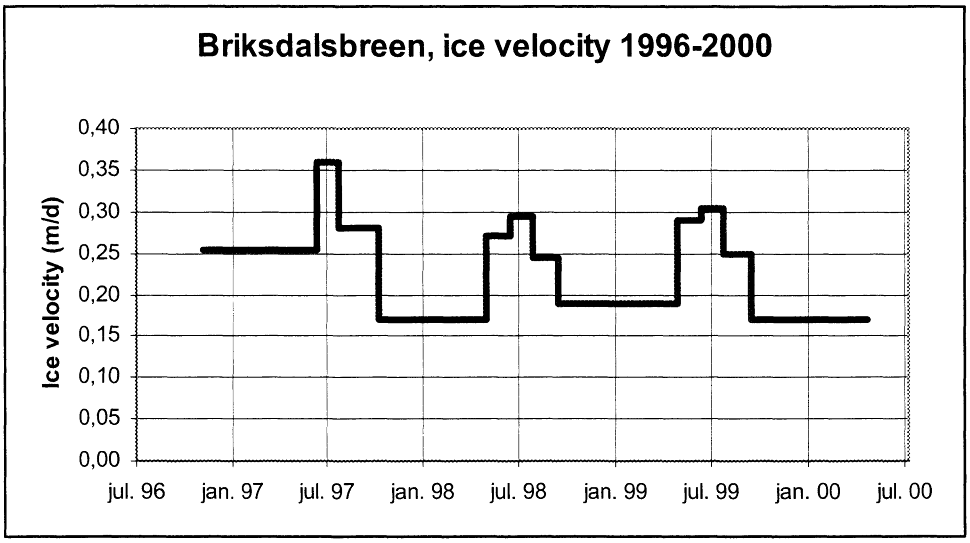


Figure 4-7

Glacier velocity at a fixed position 325 m from the glacier front (Fig. 4-2), interpolated between calculated velocities at stakes close to this position.

5 Nigardsbreen (Bjarne Kjøllmoen)

Nigardsbreen (61°42'N, 7°08'E) is one of the largest and most famous outlet glaciers (47.8 km^2) from Jostedalsbreen, flowing south-east from the centre of the ice cap (Fig. 5-1). Nigardsbreen accounts for approximately 10 % of the total area of Jostedalsbreen, and extends from 1960 m a.s.l. down to approximately 320 m a.s.l.

Glaciological investigations in 2000 include mass balance, front position change and various meteorological measurements. Some observations of the ice-dammed lake Brimkjelen at Tunsbergdalsbreen have also been performed (Fig. 5-10). Nigardsbreen has been the subject of mass balance investigation since 1962.

Figure 5-1

Oblique air photograph taken 26th July 2000 showing the lower parts of Nigardsbreen. It covers a total area of 48 km^2 (1984). 24 % of this area lies below the average equilibrium line altitude (1962-2000), which is at about 1490 m a.s.l.
Photo: Bjarne Kjøllmoen.

5.1 Mass balance 2000

Field work

Accumulation measurements were undertaken between 3rd and 5th May and the calculation of winter balance is based on (Fig. 5-2):

§ Direct measurements at the towers T95 (1685 m a.s.l.) and T56 (1805 moh.), which showed snow depths of 7.5 m and 7.6 m respectively.

§ Core samples at 1325 (5.2 m snow), 1610 (5.9 m), 1705 (6.9 m), 1760 (7.2 m) and 1960 m a.s.l. (6.1 m).

- 117 snow depth soundings along approximately 30 km of profiles between elevations of 1315 and 1940 m a.s.l., and some soundings at 600 and 1000 m a.s.l. Due to high snow density and an indistinct summer surface the probing conditions were difficult, especially in the higher areas (above 1700 m a.s.l.). Down at the glacier tongue the snow depth was ca. 2 m in 600 m altitude and about 4.5 m in 1000 m altitude. On the plateau snow depth varied between 6.5 and 8 m.
- Snow density was measured down to 4.3 m depth (SS at 5.5 m) at stake position 53 (1325 m a.s.l.) and down to 5.5 m depth (SS at 6.1 m) at position 57 (1960 m a.s.l.).

Location of stakes and towers, density pit, core samples and sounding profiles are shown in Figure 5-2.

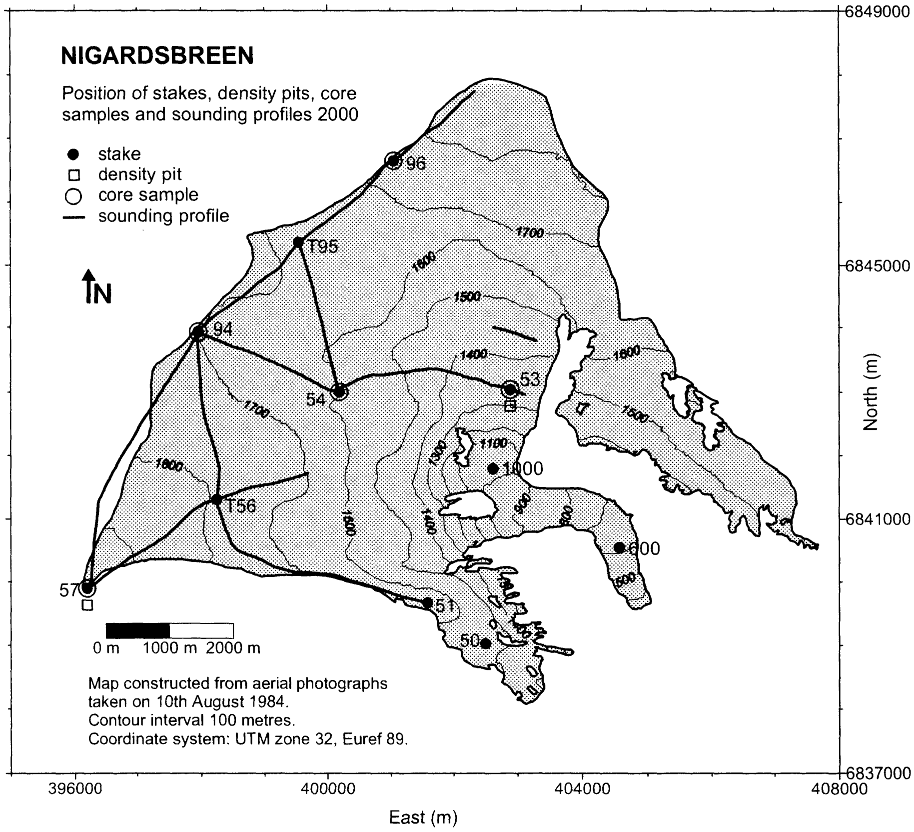


Figure 5-2

Location of towers and stakes, density pits, core samples and sounding profiles at Nigardsbreen in 2000.

Ablation measurements were carried out on 13th September. The net balance was measured directly at stakes in eleven different positions between 600 and 1960 m a.s.l. On the glacier tongue the net melting since autumn 1999 was about 7 m of ice at 600 m altitude and about 3 m of ice at 1000 m altitude. There was between 4 and 5 m of snow remaining on the plateau. Up to 60 cm of fresh snow had fallen in the upper parts of the glacier. A density measurement of the 4.2 m of remaining snow was performed at T95.

The second half of September and most of October was unusually warm in the Jostedalsbreen area, so there was further melting after the ablation measurements. Ablation after 13th September, amounting to 1.3 m w.eqv. at 600 m altitude, 0.8 m w.eqv. at 1000 m altitude and 0.2 m w.eqv. at 1325 m altitude, is not included in the calculations. Instead, it will be included in the winter balance in 2001.

Results

The mass balance is calculated using the traditional method, which means the balance between two successive "summer surfaces". The calculations are based on the glacier map from 1984.

Winter balance

The calculations of winter balance are based on point measurements of snow depth (towers, probings and core drillings) and on measurement of snow density at two locations.

Density profiles were modelled from the snow density measured at 1325 (5.2 m snow) and 1960 m altitude (6.1 m). Using these models mean snow density was 0.49 g/cm^3 (1325 m a.s.l.) and 0.51 g/cm^3 (1960 m a.s.l.). The model from 1325 m altitude is used in the areas below 1640 m a.s.l., whilst the model from 1960 m altitude is used in the areas above 1640 m a.s.l.

The winter balance calculations are performed using two different methods. In the first method, winter balance is performed by plotting measurements (water equivalents) in a diagram (Fig. 5-4). Based on visual evaluation a curve is drawn and a mean value for each 100 m height interval estimated. The areas above 1315 m a.s.l. are well represented with point measurements. Below this altitude the curve pattern is based on some probings at 1000 and 600 m altitude. The winter balance, hence, was 3.4 ±0.2 m w.eqv. corresponding to a water volume of 162 ±10 mill. m^3. The result is 141 % of the mean value for the period 1962-99. There is only three years (1967, 1989 and 1990) with a greater winter balance on Nigardsbreen.

The winter balance is also calculated using a gridding method based on the spatial distribution of the snow depth measurements (Fig. 5-3). In areas with insufficient measurements some (18) simulated points are extracted. These point values are modelled based on measurements from the period 1975-81 (years with extensive measurements). Water equivalents for each cell in a 100 x 100 m grid are calculated and summarized. The result based on this method, which is a control of the traditional method, shows a winter balance of 3.2 m w.eqv. (153 mill. m^3 water).

A map illustrating the snow distribution is shown in Figure 5-3.

Summer balance

The density of the 4.6 m of remaining snow (1685 m a.s.l.) was determined as 0.61 g/cm^3, whilst the density of melted ice is estimated to be 0.90 g/cm^3.

The summer balance was measured and calculated directly at nine stakes and towers, and increases from -0.5 m w.eqv. in the upper parts of the glacier to about -7 m down on the tongue. Based on measurements and estimates of stakes and snow density the summer balance was calculated to be -1.7 ±0.3 m w.eqv., which is -79 ±15 mill. m^3 of water. The result is 86 % of the average for 1962-99. Only 50 % of the snow accumulation had melted.

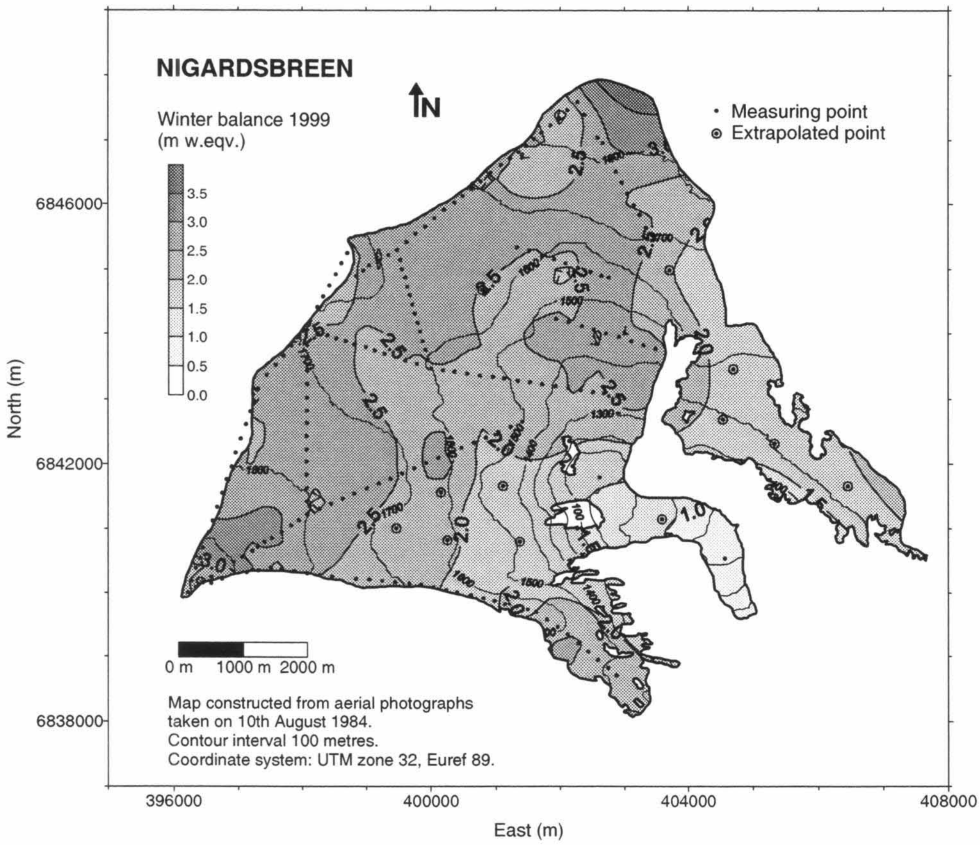


Figure 5-3

Winter balance at Nigardsbreen in 2000 interpolated from 129 snow depth measurings. In areas with few or none measurements 18 extrapolated points are added.

Net balance

The net balance at Nigardsbreen for 2000 was calculated as +1.7 m ±0.3 m w.eqv., which means a surplus of 82 ±15 mill.m^3 water. The mean value for the period 1962-99 is +0.50 m w.eqv. Since 1988, Nigardsbreen has had only one year with negative net balance (1996), and the average for 1989-2000 is +1.07 m w.eqv. The accumulated net balance for the entire period 1962-2000 is 19.6 m w.eqv. The diagram in Figure 5-4 indicates that the equilibrium line altitude (ELA) was 1250 m a.s.l., which is about 320 m lower than a year in balance. The Accumulation Area Ratio (AAR) was 93 %.

The mass balance results are shown in Table 5-1 and Figure 5-4. Historic mass balance results since 1962 are presented in Figure 5-5.

Mass balance Nigardsbreen 1999/00 – traditional method							
		Winter balance		Summer balance		Net balance	
		Measured 3rd May 2000		Measured 13th Sep 2000		Summer surfaces 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1900 - 1960	0,38	3,55	1,3	-0,60	-0,2	2,95	1,1
1800 - 1900	3,92	3,80	14,9	-0,80	-3,1	3,00	11,8
1700 - 1800	9,39	3,75	35,2	-1,05	-9,9	2,70	25,4
1600 - 1700	12,88	3,60	46,4	-1,30	-16,7	2,30	29,6
1500 - 1600	9,18	3,40	31,2	-1,55	-14,2	1,85	17,0
1400 - 1500	5,82	3,18	18,5	-1,85	-10,8	1,33	7,7
1300 - 1400	2,28	2,95	6,7	-2,20	-5,0	0,75	1,7
1200 - 1300	0,90	2,70	2,4	-2,70	-2,4	0,00	0,0
1100 - 1200	0,45	2,45	1,1	-3,35	-1,5	-0,90	-0,4
1000 - 1100	0,58	2,20	1,3	-4,05	-2,3	-1,85	-1,1
900 - 1000	0,47	1,93	0,9	-4,85	-2,3	-2,93	-1,4
800 - 900	0,44	1,65	0,7	-5,60	-2,5	-3,95	-1,7
700 - 800	0,33	1,35	0,4	-6,40	-2,1	-5,05	-1,7
600 - 700	0,39	1,05	0,4	-7,20	-2,8	-6,15	-2,4
500 - 600	0,24	0,75	0,2	-7,95	-1,9	-7,20	-1,7
400 - 500	0,12	0,45	0,1	-8,75	-1,1	-8,30	-1,0
320 - 400	0,05	0,20	0,0	-9,45	-0,5	-9,25	-0,5
320 - 1960	**47,82**	**3,38**	**161,8**	**-1,66**	**-79,4**	**1,72**	**82,4**

Table 5-1

Winter, summer and net balance for Nigardsbreen in 2000. Mean values for the period 1962-99 are b_w=2.39 m, b_s=-1.92 m and b_n=+0.47 m water equivalent.

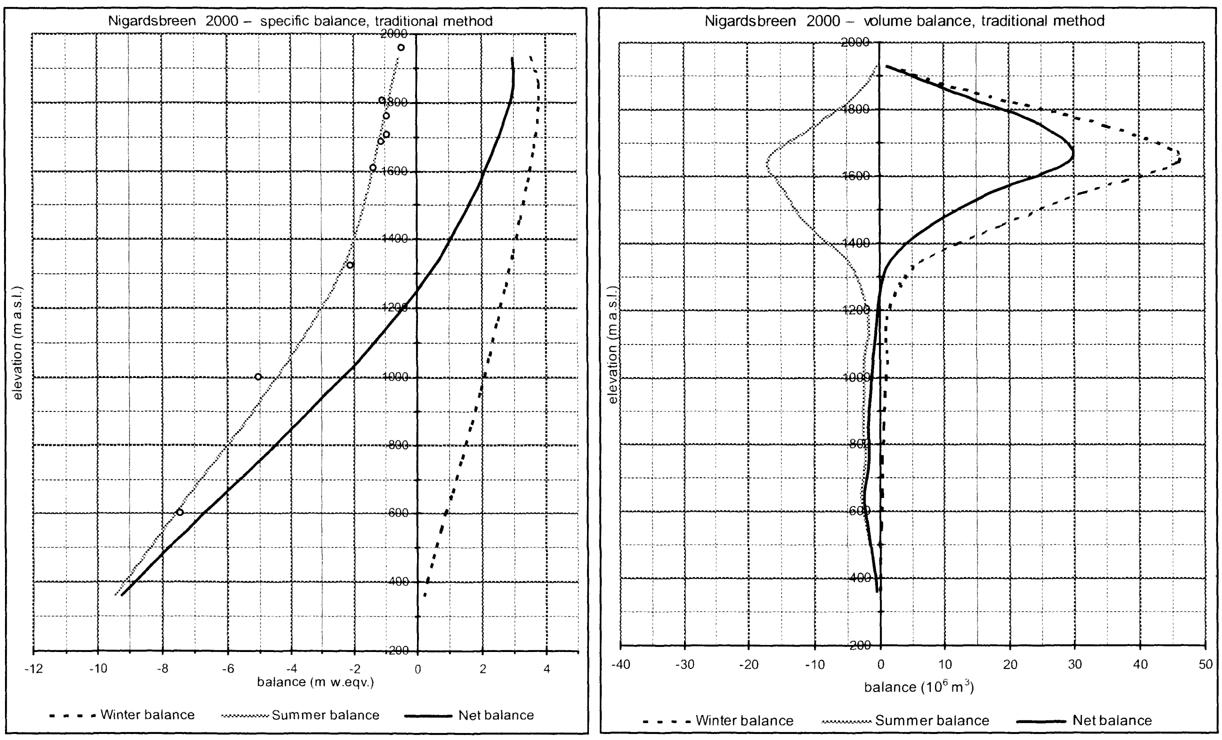


Figure 5-4

Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2000. Summer balance at nine stakes/towers is shown as dots (☛). The net balance curve intersects the y-axis and defines the ELA as 1250 m a.s.l. Thus the AAR was 93 %.

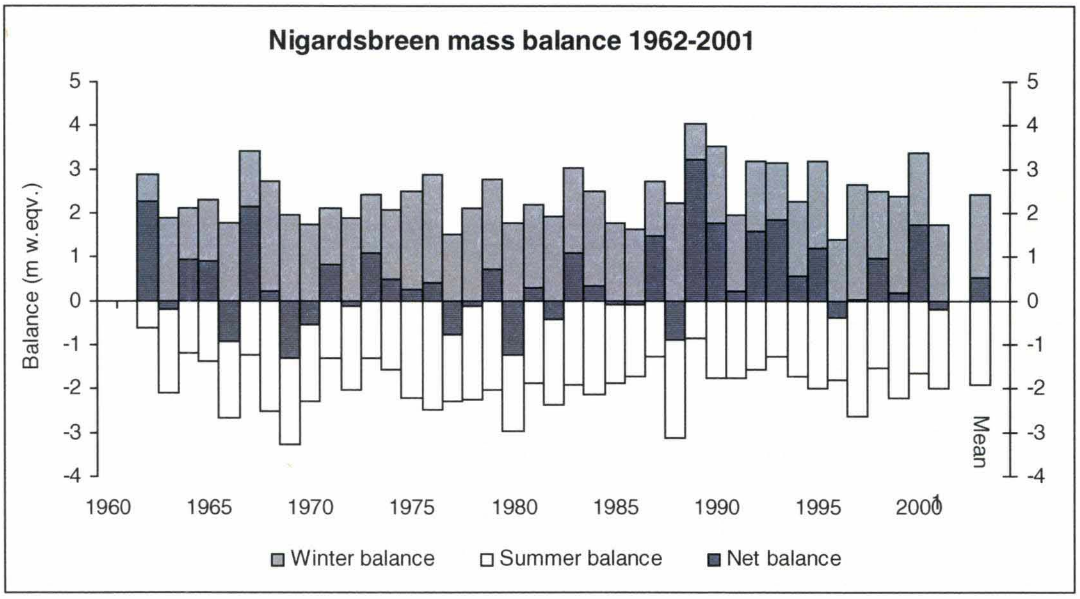


Figure 5-5

Mass balance at Nigardsbreen during the period 1962-2000. The accumulated surplus amounts to 19.6 m water equivalent.

5.2 Front position change

Due to the advance of the glacier front position over the last few years, the glacier stream changed channel pattern in 1999 from one main river to several smaller channels. This situation persisted over the last year (2000). The glacier front and stream pattern as photographed on 26th July 2000 is shown in Figure 5-6.

Figure 5-6

Since 1988 Nigardsbreen has advanced about 260 metres. The glacial stream pattern has changed because of the advance. The photograph was taken on 26th July 2000.
Photo: Bjarne Kjøllmoen.

Changes in front position are annually measured from fixed points along a straight line drawn from the original stream outlet. The measurement in October 2000 shows that Nigardsbreen has advanced 23 m since autumn 1999. After a long period with recession that stopped in 1988, the total advance amounts to about 260 m. The annual and cumulative advance since 1988 is shown in Figure 5-7.

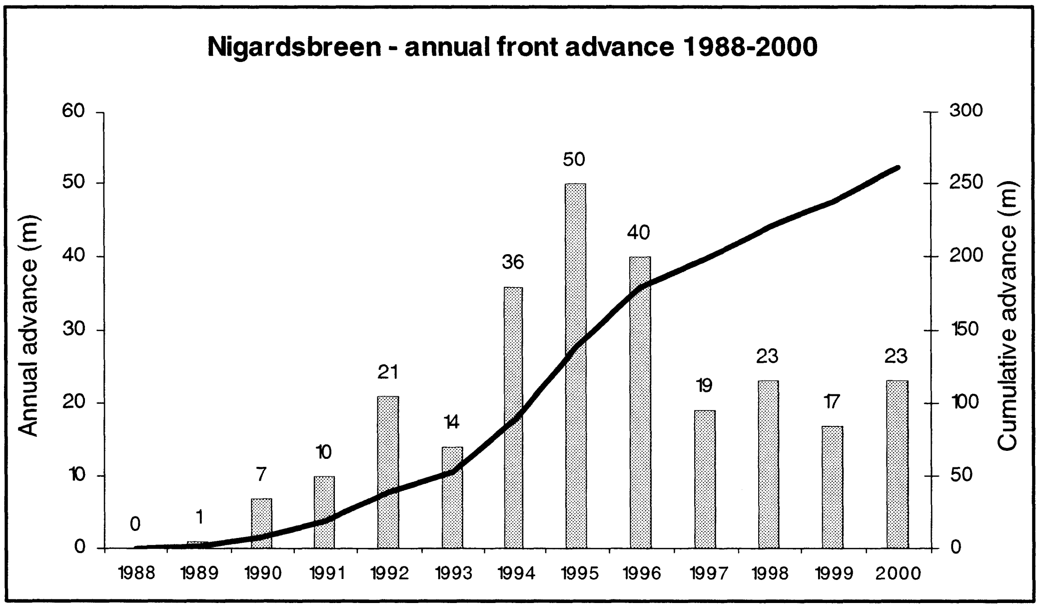


Figure 5-7

Annual and cumulative front advance at Nigardsbreen during the period 1988-2000. Since 1989 the glacier has advanced about 260 metres.

5.3 Meteorological measurements

Meteorological observations, such as air temperature, wind speed and wind direction are recorded automatically at the field station Steinmann (position 51 in Fig. 5-2). Down in the Jostedalen valley, there is another meteorological station, Bjørkehaug, run by the Norwegian Meteorological Institute.

Results of the air temperature measurements at Steinmann (1630 m a.s.l.) and Bjørkehaug (324 m a.s.l.) during the period 1989-2000 are presented in Table 5-2. The values indicate the daily mean air temperature for the "summer season" (defined as 1st June to 30th September).

The summer 2000 temperature at Steinmann was 2.0 °C, whilst the mean temperature for the period 1989-99 is 2.7 °C. The corresponding values at Bjørkehaug were 11.8 and 11.6 °C. The lapse rate between the two stations was 0.75 °C in 2000.

Daily mean values 1st June - 30th September ("Summer season")			
Year	Steinmann (°C)	Bjørkehaug (°C)	Lapse rate Bj./St. (°C/100 m)
1989	1,7	11,2	0,73
1991	2,6	11,7	0,70
1992	2,5	11,4	0,68
1993	1,2	10,2	0,69
1994	2,9	11,2	0,64
1996	2,9	11,6	0,66
1997	5,0	13,5	0,65
1998	2,6	11,5	0,68
1999	3,1	12,4	0,71
2000	[1)]2,0	11,8	0,75
[2)]Mean 1989-2000	2,7	11,6	0,68

1) Data is extrapolated from 13th to 30th September 2000.

2) Mean values for the period 1989-99 except the years 1990 and 1995.

Table 5-2

Mean temperature at Steinmann (1630 m a.s.l.) and Bjørkehaug (324 m a.s.l.) and temperature gradient between the two locations during the "Summer season" (1st June- 30th September) for the period 1989-2000.

5.4 Tunsbergdalsbreen

Mass balance

From 1966 to 1972 mass balance measurements were made simultaneously at both Tunsbergdalsbreen (47.7 km^2) and Nigardsbreen. A linear regression analysis of the results from these seven years gives an equation that can be used to calculate the annual net balance of Tunsbergdalsbreen.

$$T = 0.987 \cdot N - 0.283$$

T = Net balance at Tunsbergdalsbreen, and N = Net balance at Nigardsbreen.

For 2000 the net balance at Tunsbergdalsbreen was estimated as +1.41 ±0.45 m w.eqv., corresponding to a surplus of about 67 mill. m^3 of water.

Since 1962 the estimated accumulated net balance is about 8 m w.eqv. (Fig. 5-8). The entire surplus has occured since 1988.

Based on the measurements during 1966-72 a correlation between the equilibrium line altitude (ELA) for Nigardsbreen and Tunsbergdalsbreen was established. The analysis indicates that the ELA at Tunsbergdalsbreen in autumn 2000 was about 1100 m a.s.l.

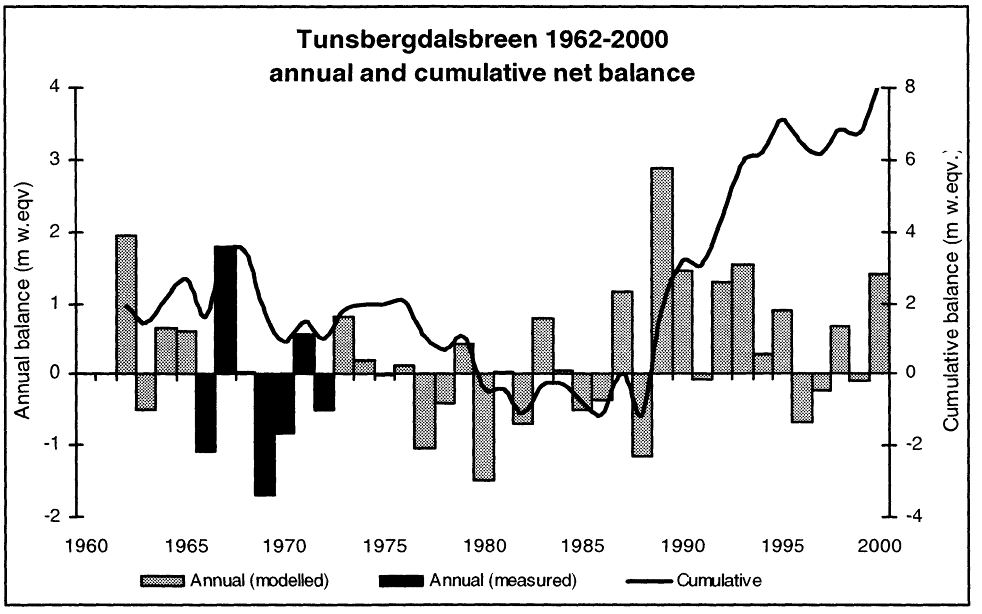


Figure 5-8

Annual and cumulative net balance for Tunsbergdalsbreen for the period 1962-2000. The values are measured for the period 1966-72. The calculations indicate a surplus of ca. 8 m since 1962.

Brimkjelen

About 3 km above the western side of the glacier snout lies Brimkjelen, which is an ice-dammed lake. Due to the glacier recession during the last century, the area and volume of the lake has decreased considerably. The last estimate of the volume was about 2 million m^3 in 1982.

From 1984 to 1997 no systematic observations were made of the lake. Observations was resumed in the autumn of 1997 and continued in 2000 by photographing on 27th July and 13th September. The lake was empty on both occasions. The circular pattern of crevasses and some subsidence of the ice towards the lake, however, may indicate that a small part of the glacier has been afloat.

6 Austdalsbreen (Hallgeir Elvehøy)

Austdalsbreen (61°45'N, 7°20'E) is an eastern outlet from the northern part of Jostedalsbreen and covers the altitudinal range between 1200 and 1760 m a.s.l. The glacier calves into the regulated lake Austdalsvatnet. Glaciological investigations started at Austdalsbreen in 1986 in connection with the construction of a hydroelectric power plant for which lake Austdalsvatnet is a reservoir.

The glaciological investigations in 2000 included mass balance front position change and glacier velocity. Mass balance at Austdalsbreen has been measured since 1988.

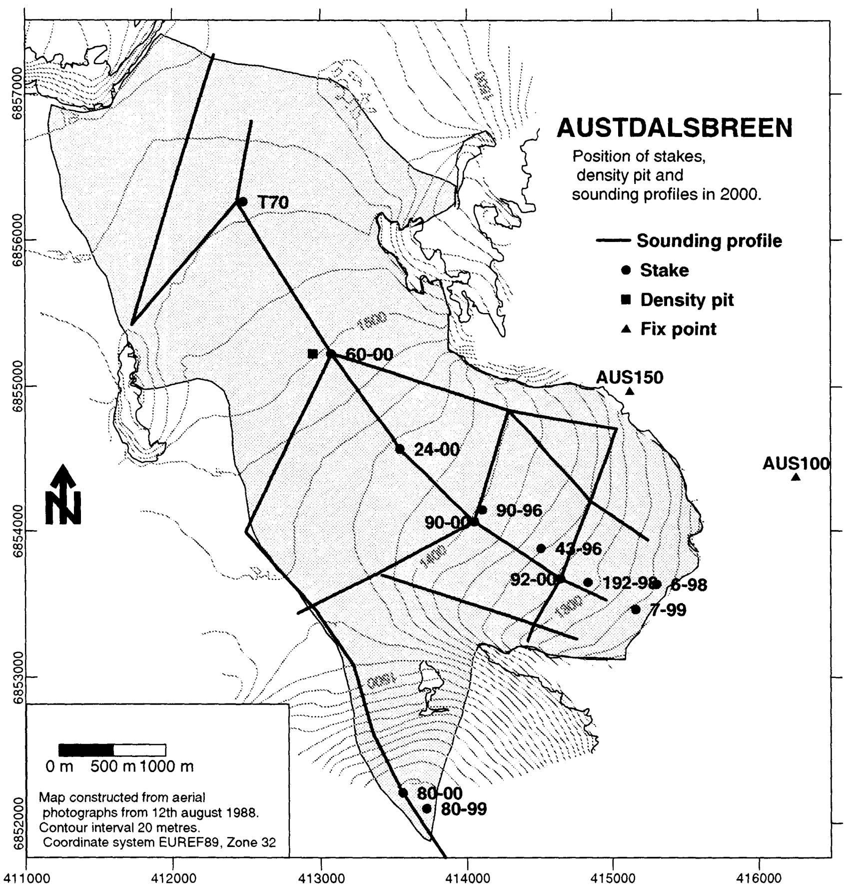


Figure 6-1

Location of stakes, density pits and sounding profiles at Austdalsbreen in 2000.

6.1 Mass balance 2000

Field work

Winter accumulation was measured 30th April and 1st May. Calculation of winter balance is based on the following data (Fig. 6-1):

- Snow depth measurements at stake 6.98 (1240 m a.s.l.), 7.99 (1240 m a.s.l.) and T70 (1545 m a.s.l.) showing snow depth of 2.2, 2.8 and 7.1 m respectively.

- Snow depth measurements by coring at 1320 m a.s.l. (stake 92.00), 1400 m a.s.l.(stake 90.00), 1440 m a.s.l.(stake 24.00), 1505 m a.s.l.(stake 60.00) and 1730 m a.s.l. (stake 80.00) showing snow depth of 5.5, 5.2, 6.3, 6.8 and 5.2 m respectively.
- Snow depth measured by sounding at 86 locations along 18 km of profiles. At Austdalsnuten above 1700 m a.s.l. the snow depth was 5 meter. Between 1450 and 1600 m a.s.l. the snow depth was between 6 and 7 meter. Between 1300 and 1450 m a.s.l. the snow depth vas between 5 and 6 meter. Below 1300 m a.s.l. the snow depth varied between 2 and 5 meter. The summer surface from 1999 (SS) was easy to detect in all areas except close to the northern drainage divide.
- Snow density measured down to 5.4 m depth at stake 60.00 (1505 m a.s.l.). Snow depth to SS was 6.8 metres. Mean snow density was 0.47 g/cm^3.

Summer ablation and net balance was measured 14th September. The net balance was measured at eight locations between 1240 and 1730 m a.s.l. At stake 80 (1730 m a.s.l.) 2 meter of snow remained. At stakes between 1440 and 1600 m a.s.l. (24.00, 60.00 and T70) between 2½ and 3½ meter remained. At stakes between 1300 and 1400 m a.s.l. (192.98, 43.96 and 90.96) between ½ and 1½ meter snow remained. Close to the glacier front (1240 m a.s.l.) ca. 2 ¼ m ice and all the snow from last winter had melted away. The transient snow line altitude (TSL) was approximately 1300 m a.s.l.

The second half of September and most of October was unusual warm in the Jostedalsbreen area, and subsequent the melting continued after the ablation measurement. The ablation after 14th September, amounting to between 0,8 m w.eqv. 1240 m a.s.l. and 0.1 m w.eqv. 1550 m a.s.l., is not included in the calculations. It will be included in the winter balance of 2001.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between to successive summer surfaces excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements. The calculations are based on a map from 1988 adjusted for glacier retreat between 1988 and 2000.

Winter balance

A snow depth - water equivalent profile was calculated based on snow density measurements 1505 m a.s.l. The mean density of 5 meters of snow in this profile was 0.47 g/cm^3. Snow depth measurements are reduced to water equivalents using this profile.

Snow depth water equivalent values are plotted against altitude in a diagram. Based on averaging of values within 50 meter altitudinal intervals and a visual evaluation, an altitudinal winter balance curve was drawn. From this curve a mean value for each 50 m height interval is determined. Below 1300 m a.s.l. the snow depth is varying a lot due to irregular topography and many crevasses which trap a large portion of the drifting snow. In this area the higher values are thought to be more representative. The winter balance was 33 ±2 mill. m^3 water equivalents or 2.8 ±0.2 meter. This is 117 % of the 1988 – 99 average which is 2.37 meter water equivalents

Summer balance

The summer balance was calculated for eight stake positions between 1240 and 1730 m a.s.l., and increases from –1.0 m w.eqv. above 1550 m a.s.l to approximately –3.5 m w.eqv. close to the terminus. From these values a summer balance curve was drawn (Fig. 6-3).

Calving from the glacier terminus is calculated as the annual volume of ice (in water equivalents) that is transported through a cross section close to the terminus, and adjusted for the volume change related to the annual front position change. This volume is calculated as:

$$Q_k = \rho_{ice} * (u_{ice} - u_f) * W * H$$

where $\rho_{ice} = 0.9$ g/cm^3, u_{ice} and u_f is annual glacier velocity and front position change averaged across the terminus (m/a), W is terminus width (m), and H is mean ice thickness along the terminus (m). The glacier velocity, u_{ice}, was 60 ±10 m/a (chapter 6.3), and u_f was +2 ±5 m/a (chapter 6.2). The ice thickness H was 43 ±5 meter based on surface altitude surveyed 14th September 2000 and a bottom topography map compiled from radar ice thickness measurements (1986), hot water drilling (1987) and lake depth surveying (1988 and 1989), and W was 1050 ±50 meter. The calving volume was 2.4 ±0.5 mill. m^3 or 0.20 ±0.04 meter w.eqv. averaged across the glacier area (11.8 km^2).

The summer balance (calving included) was calculated to -1.7 ±0.2 m w.eqv., which corresponds to -20 ±2 mill. m^3 of water. The result is 75 % of the 1988-99 average of -2.22 m w.eqv.

Net balance

The net balance at Austdalsbreen was calculated to 13 ±3 mill. m^3 water or +1.1 ±0.3 m w.eqv. The 1988-99 average is +0,16 meter. The ELA for 2000 determined from the net balance curve in Figure 6-2 is 1315 m a.s.l. which is close to the observed TSL at approximately 1300 m a.s.l. The accumulation area ratio (AAR) was 87 %. The altitudinal distribution of winter-, summer- and net balances are shown in Figure 6-2 and Table 6-1. Results from 1988-2000 are shown in Figure 6-3.

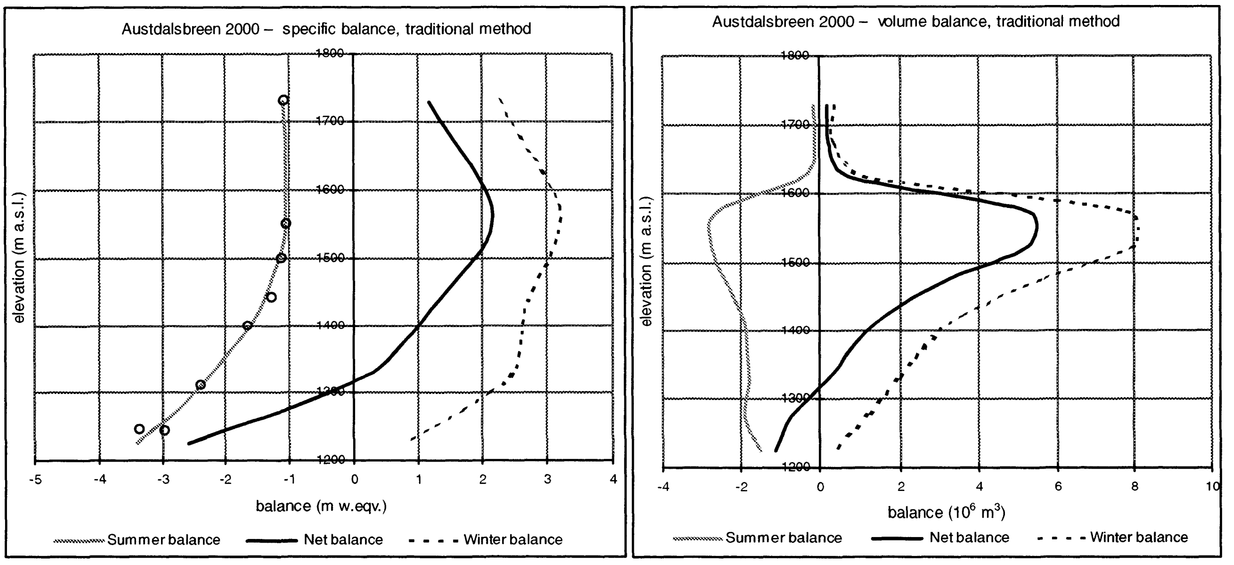


Figure 6-2

Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2000. Specific summer balance at eight locations is shown (o).

Mass balance Austdalsbreen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 30th Apr 2000 Specific (m w.eq.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 14th Sep 2000 Specific (m w.eq.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 1999 - 2000 Specific (m w.eq.)	Net balance Volume (10^6 m^3)
1700 - 1757	0,16	2,28	0,36	-1,10	-0,17	1,18	0,19
1650 - 1700	0,13	2,59	0,33	-1,05	-0,13	1,54	0,20
1600 - 1650	0,38	2,94	1,11	-1,05	-0,39	1,89	0,71
1550 - 1600	2,45	3,20	7,83	-1,05	-2,57	2,15	5,26
1500 - 1550	2,54	3,15	8,00	-1,08	-2,74	2,07	5,26
1450 - 1500	1,92	2,90	5,57	-1,25	-2,40	1,65	3,17
1400 - 1450	1,36	2,65	3,59	-1,45	-1,96	1,20	1,63
1350 - 1400	1,01	2,60	2,63	-1,80	-1,82	0,80	0,81
1300 - 1350	0,79	2,45	1,93	-2,25	-1,77	0,20	0,16
1250 - 1300	0,69	1,70	1,17	-2,75	-1,89	-1,05	-0,72
1200 - 1250	0,44	0,80	0,35	-3,40	-1,48	-2,60	-1,13
Calving					-2,4		-2,4
1200 - 1757	**11,84**	**2,77**	**32,9**	**-1,66**	**-19,7**	**1,11**	**13,2**

Table 6-1

Altitudinal distribution of winter-, summer- and net balances at Austdalsbreen in 2000.

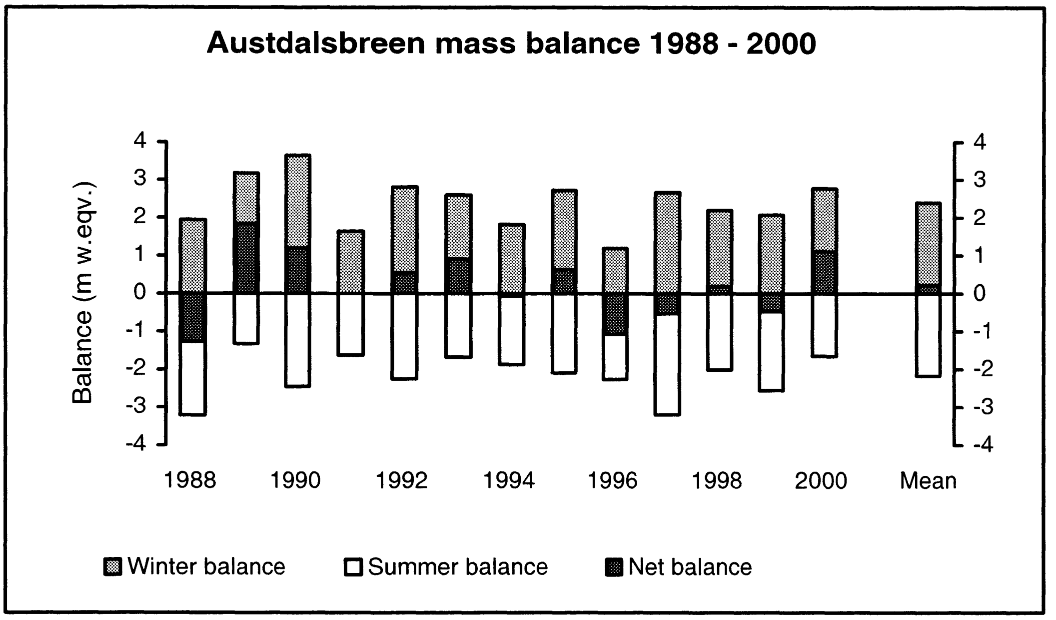


Figure 6-3

Winter-, summer and net balances at Austdalsbreen during the period 1988-2000. The cumulative net balance was +3,0 m w.eqv. Mean values for the period 1988-2000 are b_w=2.37 m, b_s=-2.22 m and b_n=+0.15 m w.eqv.

6.2 Front position change

Seven points along the terminus was surveyed on the 14th September 2000. Between 30th September 1999 and 14th September 2000 the mean front position change was +2 ±5 meter (Fig. 6-4). That means the front position is unchanged since September 1999. The front position retreat since 1988 is approximately 340 meter.

Due to large variations in calving during the year, the annual variations in front position is large compared to the year-to-year front position change. Figure 6-5 illustrates how the front position at a central flow line has varied during the last 13 years. As a consequence of the lake regulation it was expected that the glacier terminus would retreat. A modelling effort resulted in a prediction for future front position change shown as a broken line in Figure 6-5.

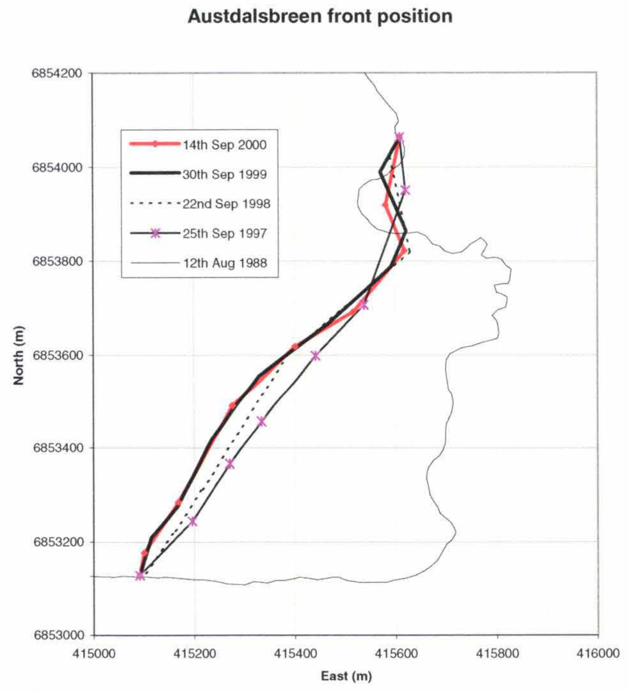


Figure 6-4

Surveyed front positions at Austdalsbreen in 1988, 1997, 1998, 1999 and 2000. Mean front position advance between 30th September 1999 and 14th September 2000 was 2 meter.

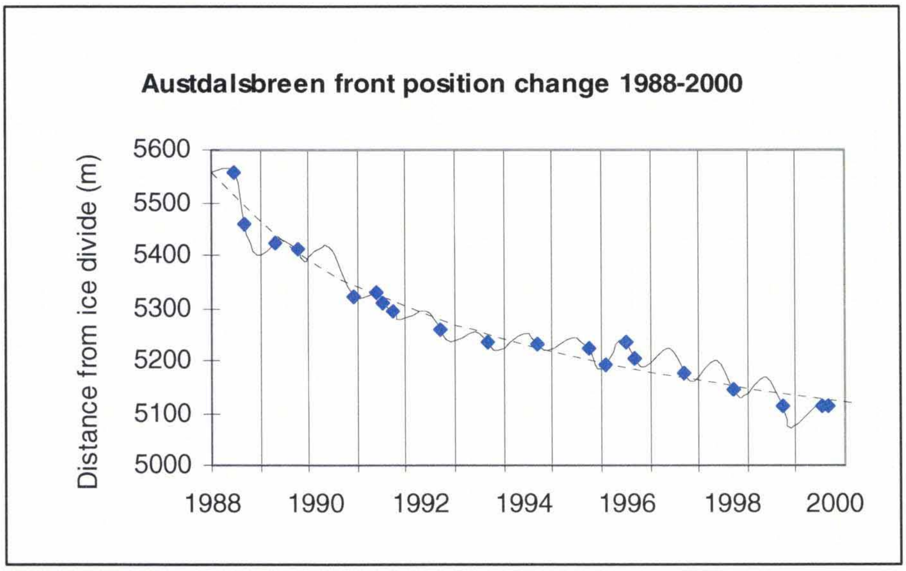


Figure 6-5

Surveyed front position change along a central flow line shown as change in glacier length along this flow line (dots). The solid line indicates annual variations in front position. The glacier advances from December to July when the lake is frozen, and retreats during July-December due to calving. In 1988 the level of lake Austdalsvatnet was regulated as a reservoir for the first time. The broken line shows predicted front position change based on expected annual lake level variations due to regulations and an annual net balance of -0.47 m w.eqv. (Laumann & Wold, 1992).

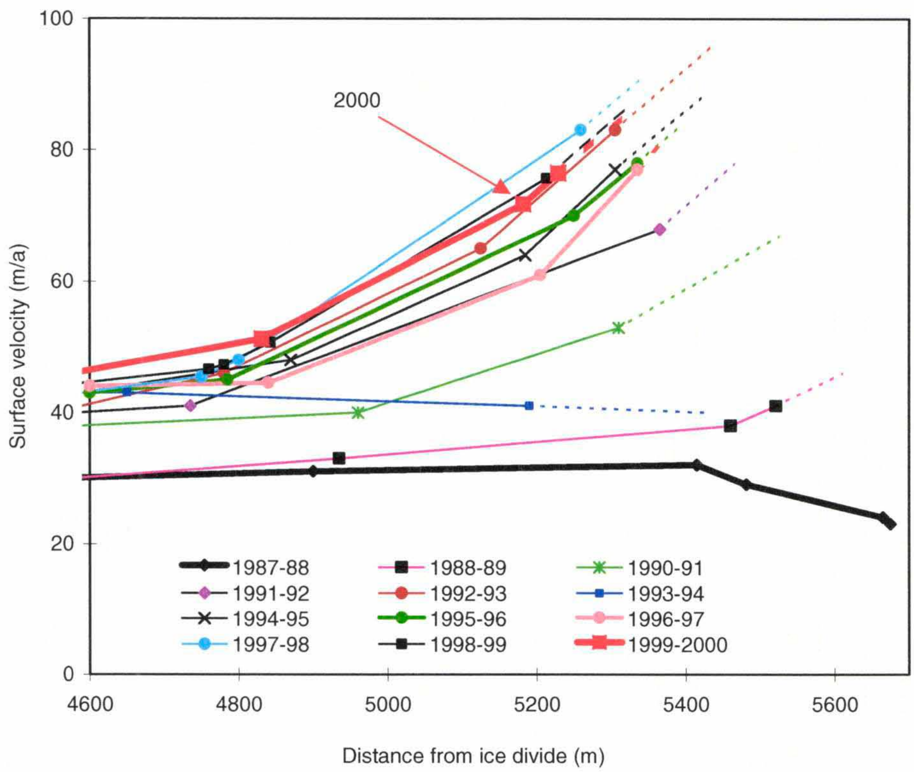


Figure 6-6

Glacier velocity (m/a, September-September) along a central flow line interpolated between averaged stake positions at the lower part of the glacier. Between the lowest stake and the terminus the velocity is extrapolated (broken line). The distance 4600 meter from ice divide corresponds approximately to stake 192 (Fig. 6-1). Between 1988 and 2000 the terminus has retreated 340 meters.

6.3 Glacier velocity

Glacier velocities are calculated from repeated surveys of stakes on the lower part of the glacier. The results are compared with results from 1988-1999 (Fig. 6-6). Estimated glacier velocity at the terminus is similar to 1995 and 1999 but less than 1993 and 1998. Further upstream the year-to-year variations are minor.

The glacier velocity close to the terminus seems to be varying around 85 m/a with inter-annual variations due to differences in annual lake level variations in the reservoir.

To calculate the calving volume (chapter 6.1) we estimate the glacier velocity averaged across the front width and depth. Surface, centre line velocity is calculated from measurements at stake 6.98 and 7.99 (76.5 m/a and 71.8 m/a), the average distance from stake to terminus, and estimated strain rate close to the terminus based on earlier measurements (0.1 a^{-1}). The cross-sectional averaged glacier velocity is estimated to be 70% of the centre line surface velocity based on earlier measurements and estimates of the amount of glacier sliding at the bed, resulting in an terminus cross-sectional averaged glacier velocity of 60 ±10 m/a.

7 Hardangerjøkulen (Hallgeir Elvehøy and Karin Krantz)

Hardangerjøkulen (61°30'N, 7°30'E) is the sixth largest (73 km^2) glacier in Norway. The glacier is situated on the main water divide between Hardangerfjorden and Hallingdalen. In 1963, the Norwegian Polar Institute started mass balance measurements on the south-western outlet glacier Rembesdalskåka (17 km^2), which drains to the valley Simadalen and Hardangerfjorden. This valley has been ravaged by jøkulhlaups from the glacier-dammed Lake Demmevatnet, the latest occurring in 1937 and 1938. Since 1985, the Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations at Rembesdalskåka. The investigated basin covers the altitudinal range between 1020 and 1865 m a.s.l.

In 2000, the University of Oslo started mass balance measurements on the northern outlet glacier Midtdalsbreen (7 km^2), which drains towards Hallingdalen. Midtdalsbreen covers the altitudinal range from 1380 to 1865 m a.s.l.

At Midtdalsbreen, the University of Bergen started front position measurements in 1982. Statkraft initiated front position measurements at Rembesdalskåka in 1995. These measurements are described in chapter 17.

Hardangerjøkulen has been mapped twice, in 1961 and 1995. An analysis of volume changes between 1961 and 1995 is described in chapter 16.

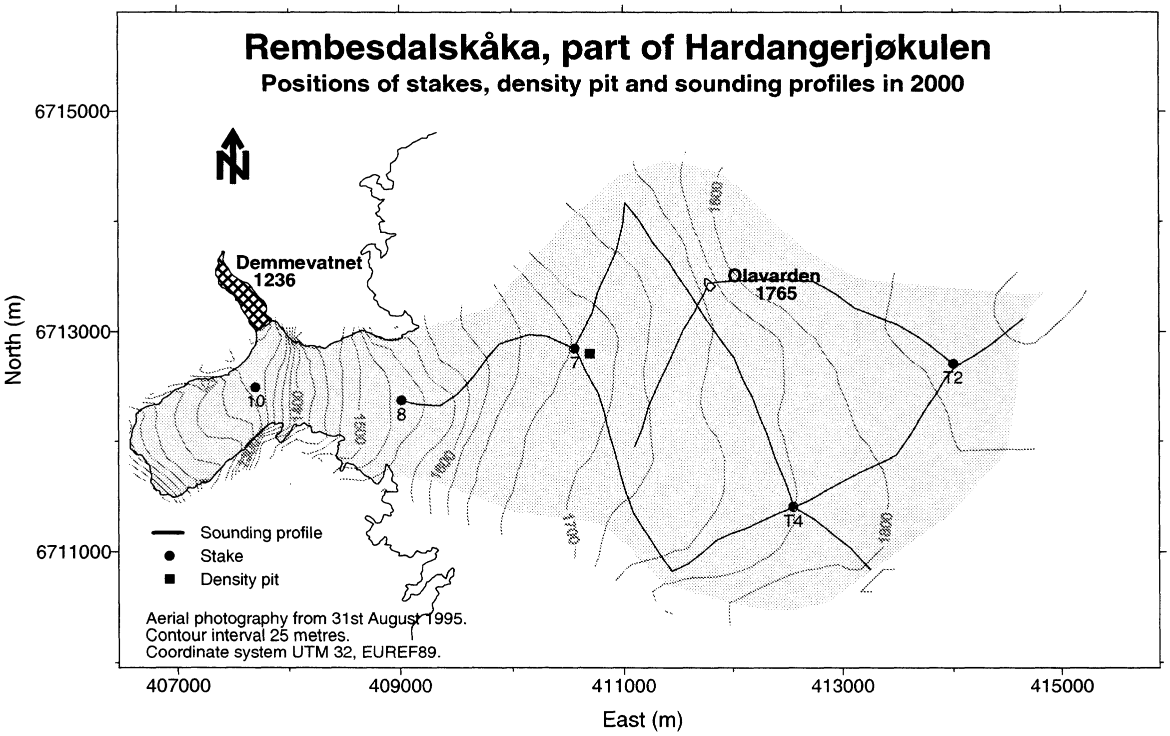


Figure 7-1

Location of stakes, density pits and sounding profiles at Rembesdalskåka, the south-western part of Hardangerjøkulen, in 2000.

7.1 Mass balance at Rembesdalskåka in 2000

Field work

Winter accumulation was measured 11th May. Calculation of winter balance is based on the following data (Fig. 7-1):

- Snow depth measurements at stake 10 (1285 m a.s.l.), 8 (1530 m a.s.l.), T4 (1770 m a.s.l.) and T2 (1830 m a.s.l.) showing snow depth of 3.9, 4.9, 6.1 and 5.5 m respectively.
- Snow depth measurements by coring at 1675 m a.s.l. (stake 7) showing snow depth of 6.0 metres.
- Snow density measured down to 5.85 m depth at stake 7 (1675 m a.s.l.). Mean snow density was 0.52 g/cm^3. Below the SS at 6.0 m depth there was firn.
- Snow depth measured by sounding at 81 locations along 18 km of profiles on the glacier plateau above 1500 m a.s.l. Between 1500 and 1700 m a.s.l. the snow depth was 4½ to 6 meters. Above 1700 m a.s.l. the snow depth was 5 to 6½ meter. The SS was fairly easy to detect.

Summer ablation and net balance was measured 13th September. There was fresh snow on the glacier above 1300-1400 m a.s.l. At the stakes the depth of new snow was 0.15 – 0.55 metres. The transient snow line (TSL) could not be detected, but the TSL altitude was probably approximately 1400 m a.s.l. The net balance was measured at five locations between 1285 and 1830 m a.s.l. At stakes 7, T4 and T2, 3.2, 3.1 and 3.2 meter of snow, respectively, remained. At stake 8 the remaining snow depth was 1.2 m. At stake 10 on the glacier tongue (1285 m a.s.l.) ca. 1½ m ice and all the snow from last winter had melted away.

The second half of September and most of October was unusual warm in West-Norway, and subsequent the melting continued after the ablation measurement. The ablation after 13th September, amounting to 1.1 m w.eqv. at stake 10, is not included in the calculations. It will be included in the winter balance of 2001.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive "summer surfaces" excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements. The calculations are based on a map from 1995.

Winter balance

A snow depth - water equivalent profile was calculated based on snow density measurements 1675 m a.s.l.. The mean density of 5 meters of snow in this profile was 0.53 g/cm^3. Snow depth measurements are reduced to water equivalents using this profile.

Snow depth water equivalent values are plotted against altitude in a diagram. Based on averaging of values within 50 meter altitudinal intervals and a visual evaluation, an altitudinal winter balance curve was drawn. Below 1500 m a.s.l. the only snow depth measurement was at stake 10. Therefore, the winter balance curve had to be extrapolated from measurements at stake 10 and 8. From this curve a mean value for each 50 m height interval is determined. The winter balance was 50 ±3 mill. m^3 water equivalents or 2.9 ±0.2 meter. This is 138 % of the 1963 – 99 average which is 2.12 m w.eqv., and 134 % of the 1995-99 average of 2.19 m w.eqv.

Summer balance

The summer balance was calculated for five stake positions between 1285 and 1830 m a.s.l. From these values a summer balance curve was drawn (Fig. 7-2).

The summer balance was calculated to -1.5 ±0.2 m w.eqv., which is -26 ±3 mill. m^3 of water. This is 77 % of the 1963-99 average which is –1.95 m w.eqv. and 66 % of the 1995-99 average of –2.27m w.eqv. Only six times in the 37 years of measurements the summer balance was smaller than in 2000.

Net balance

The net balance at Rembesdalskåka was calculated to 24 ±5 mill. m^3 water or +1.4 ±0.3 m w.eqv. The 1963-99 average is +0.21 meter, and the 1995-99 average is –0.11 meter. Only five years in the period 1963-99 the net balance at Rembesdalskåka has been more positive than in 2000. The ELA for 2000 determined from the net balance curve in Figure 7-2 is 1425 m a.s.l. The accumulation area ratio (AAR) was 92 %. The altitudinal distribution of winter-, summer- and net balances are shown in Figure 7-2 and Table 7-1. Results from 1963-2000 are shown in Figure 7-3 and 7-4.

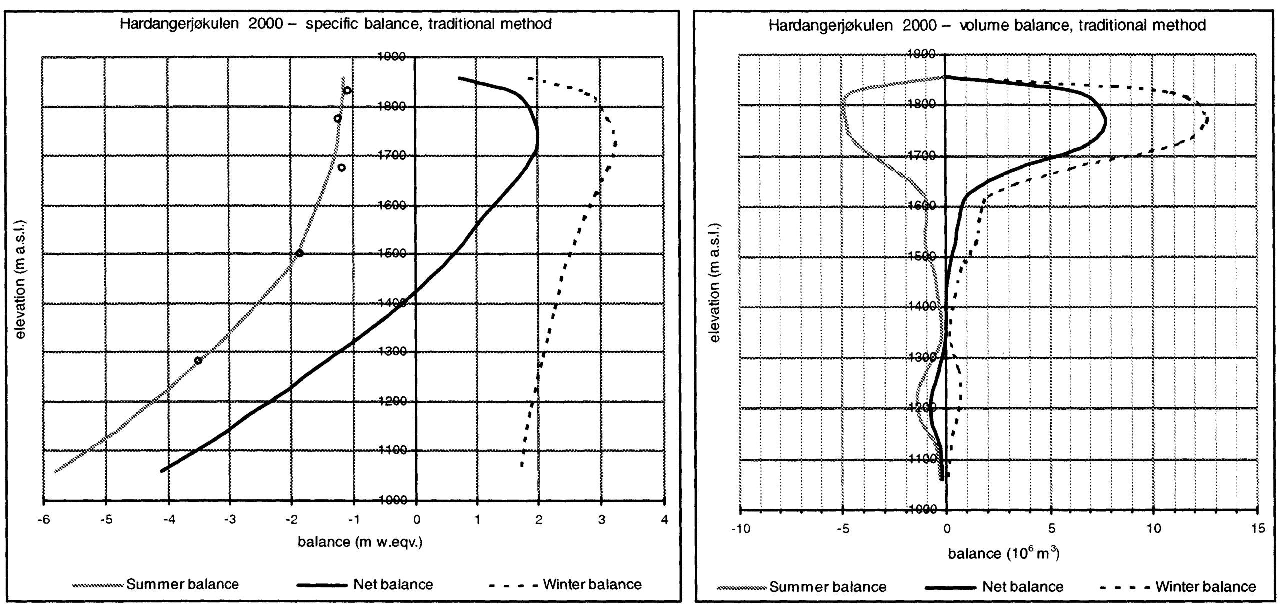


Figure 7-2

Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalskåka, Hardangerjøkulen in 2000. Specific summer balance at five locations is shown (o).

Mass balance Hardangerjøkulen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km²)	Winter balance Measured 11th May 2000 Specific (m w.eqv.)	Winter balance Volume (10^6 m³)	Summer balance Measured 13th Sep 2000 Specific (m w.eqv.)	Summer balance Volume (10^6 m³)	Net balance Summer surfaces 1999 - 2000 Specific (m w.eqv.)	Net balance Volume (10^6 m³)
1850 - 1865	0,09	1,87	0,2	-1,15	-0,1	0,72	0,1
1800 - 1850	3,93	2,79	11,0	-1,15	-4,5	1,64	6,5
1750 - 1800	4,03	3,13	12,6	-1,20	-4,8	1,93	7,8
1700 - 1750	3,46	3,25	11,2	-1,25	-4,3	2,00	6,9
1650 - 1700	1,94	3,15	6,1	-1,35	-2,6	1,80	3,5
1600 - 1650	0,75	2,95	2,2	-1,50	-1,1	1,45	1,1
1550 - 1600	0,59	2,75	1,6	-1,65	-1,0	1,10	0,7
1500 - 1550	0,57	2,60	1,5	-1,80	-1,0	0,80	0,5
1450 - 1500	0,29	2,45	0,7	-2,00	-0,6	0,45	0,1
1400 - 1450	0,19	2,35	0,4	-2,35	-0,4	0,00	0,0
1350 - 1400	0,10	2,25	0,2	-2,70	-0,3	-0,45	0,0
1300 - 1350	0,10	2,15	0,2	-3,10	-0,3	-0,95	-0,1
1250 - 1300	0,27	2,05	0,6	-3,55	-1,0	-1,50	-0,4
1200 - 1250	0,36	1,95	0,7	-4,00	-1,5	-2,05	-0,7
1150 - 1200	0,28	1,86	0,5	-4,50	-1,3	-2,64	-0,7
1100 - 1150	0,11	1,78	0,2	-5,00	-0,5	-3,22	-0,3
1020 - 1100	0,05	1,70	0,1	-5,80	-0,3	-4,10	-0,2
1020 - 1865	17,1	2,93	50,1	-1,50	-25,7	1,43	24,4

Table 7-1

Altitudinal distribution of winter-, summer- and net balances at Rembesdalskåka, Hardangerjøkulen in 2000.

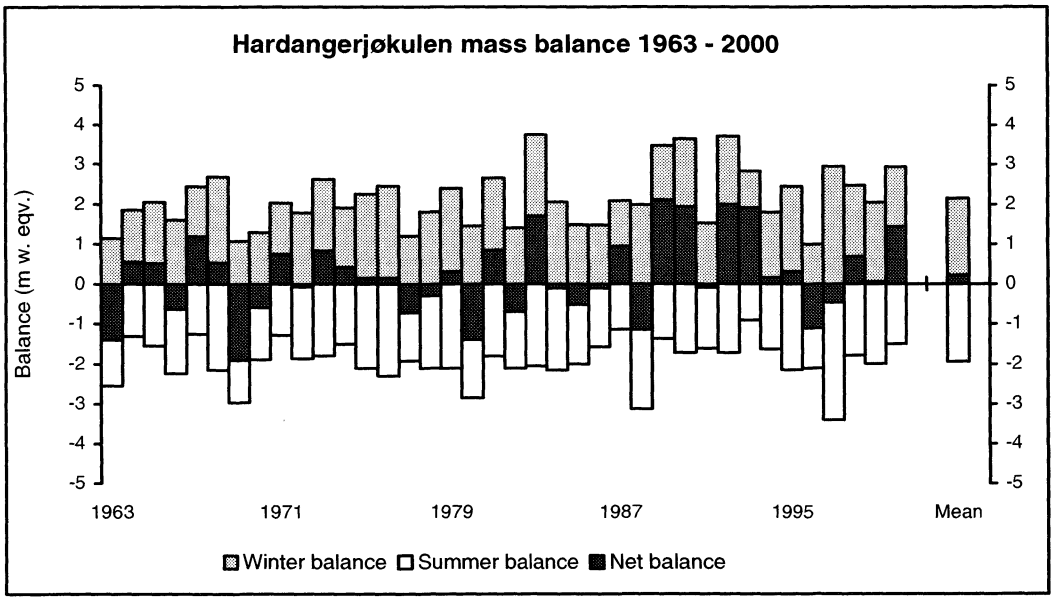


Figure 7-3

Winter-, summer and net balance at Hardangerjøkulen during the period 1963-2000. Mean values for the period 1988-2000 are b_w=2.37 m, b_s=-2.22 m and b_n=+0.15 m water equivalents.

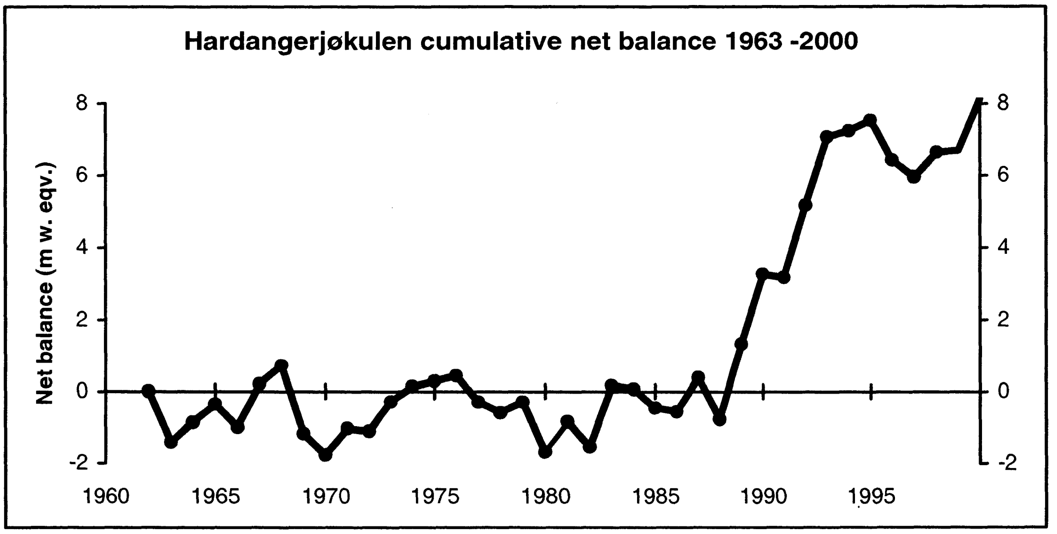


Figure 7-4

Cumulative net balance at Hardangerjøkulen. The cumulative net balance was 8 m w.eqv.

7.2 Mass balance at Midtdalsbreen in 2000

Field work

The winter accumulation was measured on 5th May 2000. The accumulation was estimated from snow depth soundings as shown in Figure 7-5. Since there were only a few measurements in the upper part of Midtdalsbreen, measurements from Rembesdalskåka were used to support the estimation of the winter balance in the upper part of Midtdalsbreen. The sounding conditions were difficult due to several layer of ice in the snow pack.

Snow density measurements at two locations were used to convert snow depth to water equivalents. The first site was at the lower part of Midtdalsbreen, at about 1490 m a.s.l. The mean density was 0.50 g/cm^3. This measurement was used from about 1550 m a.s.l and down to the front.

For calculation of water equivalent in the upper part of Midtdalsbreen the density measurements made at stake 7 (1675 m a.s.l) on Rembesdalskåka were used (Fig. 7-1). The mean density was 0.53 g/cm^3. Midtdalsbreen is divided into 50 meter intervals and the points in each interval are interpolated with an inverse distance weighing interpolation using the software ARC/INFO.

Midtdalsbreen

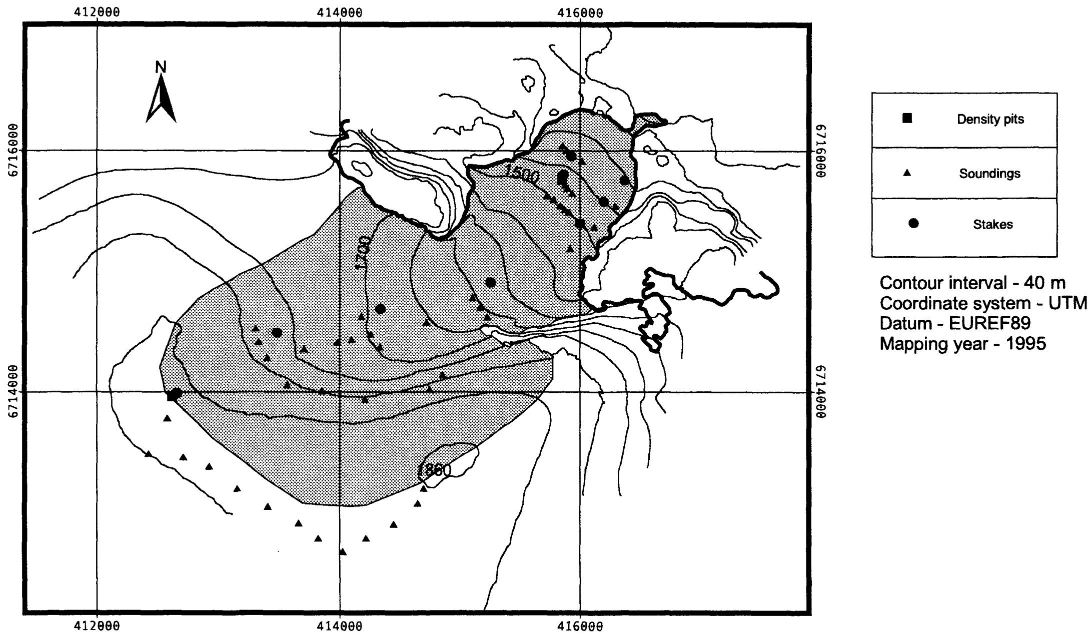


Figure 7-5

Stakes (open circles), put out in May 2000, and soundings (closed circles) on Midtdalsbreen. The soundings were done the 5th of May 2000. The soundings outside Midtdalsbreen drainage area were done by NVE at Rembesdalskåka on the 11th of May 2000 (Fig. 7-1). Contour interval 100 metres.

In May 2000 ten stakes were drilled at Midtdalsbreen (Fig. 7-5). Nine of those were used in the minimum measurements. The method is a stratigraphic method, which is based on measuring the summer surfaces from one year to the next. The minimum measurements of year 2000 were performed in the beginning of January 2001. The snow depth of this year snow was measured and together with the height of the stakes it was possible to estimate the summer surface. The difference between the snow depth in May and the summer surface, multiplied with the density of snow/ice is the specific net balance. The density of remaining snow from last winter was measured in September to 0.59 g/cm^3 and ice is about 0.9 g/cm^3. The summer balance is calculated from the winter and net balances.

Results

The calculations are based on a map from 1995.

The specific mass balance per altitude is shown in Figure 7-6 and Table 7-2.
The mean specific winter balance was 2.9 m w.eqv. and the summer balance was -1.6 m w.eqv. The net balance was then very positive and estimated to 1.3 m w.eqv. The ELA was determined from Figure 7-6 to 1500 m a.s.l.

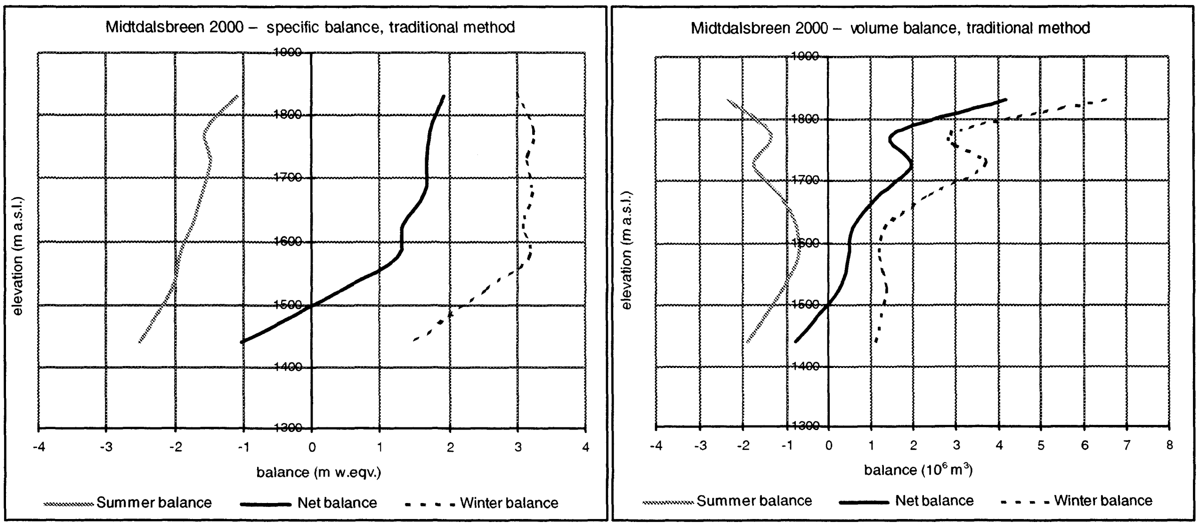


Figure 7-6

The winter, summer and net balance at Midtdalsbreen in 2000. The net balance curve intersects the y-axis and defines the ELA to 1500 m a.s.l. Accordingly the AAR was 89 %.

Mass balance Midtdalsbreen1999/00 – traditional method

		Winter balance Measured 5th May 2000		Summer balance Measured 5th Jan 2001		Net balance Summer surface 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1800 - 1862	2,17	3,00	6,5	-1,08	-2,3	1,92	4,2
1750 - 1800	0,89	3,26	2,9	-1,54	-1,4	1,72	1,5
1700 - 1750	1,18	3,15	3,7	-1,48	-1,7	1,67	2,0
1650 - 1700	0,71	3,24	2,3	-1,60	-1,1	1,64	1,2
1600 - 1650	0,44	3,09	1,4	-1,75	-0,8	1,34	0,6
1550 - 1600	0,38	3,18	1,2	-1,94	-0,7	1,24	0,5
1500 - 1550	0,54	2,52	1,4	-2,05	-1,1	0,47	0,3
1380 - 1500	0,76	1,46	1,1	-2,50	-1,9	-1,04	-0,8
1380 - 1862	**7,07**	**2,89**	**20,5**	**-1,57**	**-11,1**	**1,32**	**9,4**

Table 7-2

The specific and volume mass balance at Midtdalsbreen in 2000. The specific mass balance is expressed in m w.eqv. and the volume mass balance in 10^6 m^3.

8 Harbardsbreen (Bjarne Kjøllmoen)

Harbardsbreen (61°40'N, 7°35'E) is a plateau glacier situated approximately 25 km east of Jostedalsbreen in the Breheimen area. Its area is about 25 km^2, and of this about 13 km^2 drains eastward to Steindalselvi and Fivlemyrane reservoir (Fig. 8-1). The range in elevation is between 1250 and 1960 m a.s.l.

The glaciological investigations performed in 2000 include mass balance, air temperature measurements and observations of an ice-dammed lake. The investigations at Harbardsbreen started with aerial photography and mapping in 1996, whilst the glacier has been subject to mass balance measurements since 1997.

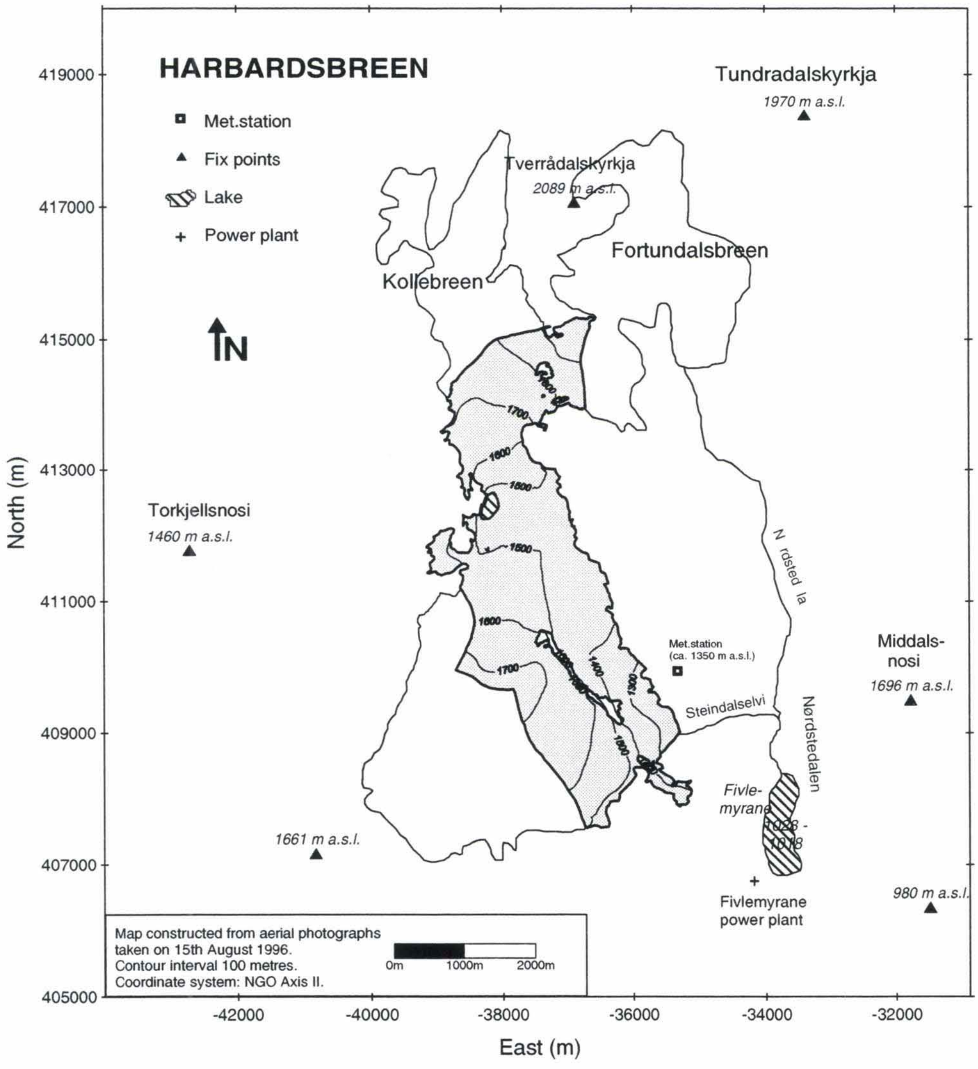


Figure 8-1

The total area of Harbardsbreen is about 25 km^2 of which approximately 13 km^2 drains eastward to Steindalselvi and Fivlemyrane reservoir. The investigations are performed on this east-facing part of the glacier.

8.1 Mass balance 2000

Field work

Accumulation was measured on 29th April and the winter balance calculation is based on (Fig. 8-2):

- Direct measurement of stake 70 (1940 m a.s.l.) showing a snow depth of 2.9 m. It was also possible to make connections between substitute stakes at positions 10 (1285 m a.s.l.), 20 (1415 m a.s.l.), 30 (1490 m a.s.l.), 40 (1620 m a.s.l.), 50 (1700 m a.s.l.), 45 (1720 m a.s.l.) and 60 (1790 m a.s.l.) and stakes that emerged by melting during the summer. The corresponding snow depths were 4.8, 5.1, 5.0, 5.9, 4.5, 5.2 and 4.6 m.
- Core samples at 1285, 1415, 1490, 1620, 1700, 1720 and 1790 m a.s.l. showing snow depths of 4.2, 5.0, 5.1, 6.3, 4.3, 5.6 and 4.6 m.
- 147 snow depth soundings along about 20 km of profiles between 1290 and 1940 m a.s.l. The probing conditions were fairly difficult at heights above 1500 m altitude. The snow depth varied between 3.5 and 6.5 m.
- Snow density was measured down to 1.5 m depth (SS at 5.0 m) at altitude 1490 m a.s.l. This density measurement was not sufficient for estimation of the snow density for the entire snow pack. Thus a snow density measurement carried out at 1500 m altitude (SS at 6.8 m) at Austdalsbreen (Chap. 6) is used.

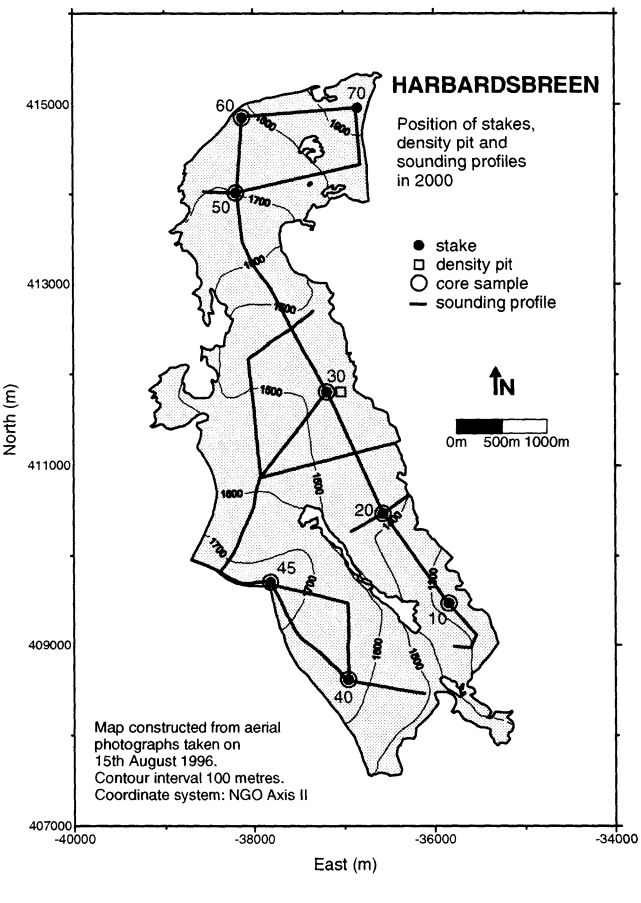


Figure 8-2

Location of stakes, density pit and sounding profiles at Harbardsbreen in 2000.

Ablation was measured on 13th September. The net balance was measured directly at stakes in eight different locations between 1285 and 1940 m a.s.l. There was snow remaining over the entire glacier surface - from 0.2 m at the lower areas to more than 2 m on the southwestern part of the glacier. Thus the snow line can be considered to lie below the altitude range of the glacier (i.e. below 1250 m a.s.l.). Between 5 and 45 cm fresh snow had fallen.

The second half of September and most of October was unusual warm in the Breheimen area, and subsequently melting continued after the ablation measurement. Ablation after 13th September, amounting to about 0.5 m w.eqv. between 1300 and 1400 m altitude, and to ca. 0.1 m w.eqv. between 1400 and 1500 m altitude, is not included in the calculations. Instead it will be included in the winter balance 2001 calculation.

Results

The mass balance is calculated using the traditional method, which means the balance between two successive "summer surfaces". The calculations are based on a glacier map from 1996.

Winter balance

The winter balance calculations are based on point measurements of snow depth (stakes, probings and core drillings) and a measurement of snow density at Austdalsbreen.

The winter balance calculations are performed using two different methods. First, winter balance is estimated by plotting measurements (water equivalents) on a diagram (Fig. 8-4). Based on a visual evaluation a curve was drawn and a mean value for each 50 m height interval calculated. The entire glacier surface is well represented with point measurements (Fig. 8-3). The winter balance was calculated as 2.3 ±0.2 m w.eqv., corresponding to a water volume of 30 ±3 mill. m^3. Previous results are 2.2 m (1997), 1.7 m (1998) and 1.8 m w.eqv. (1999).

The winter balance is also calculated using a gridding method based on the spatial distribution of the snow depths (Fig. 8-3). Water equivalents for each cell in a 100 x 100 m grid are calculated and summarised. The result based on this method, which is a control of the traditional method, was also 2.3 m w.eqv.

Figure 8-3 shows snow distribution over Harbardsbreen.

Summer balance

The summer balance was directly measured and calculated at eight stakes, and increases from -1.1 m w.eqv. at stake 45 (1720 m a.s.l.) to -2.0 m w.eqv. at stake 20 (1415 m a.s.l.). The density of the remaining snow is estimated as 0.60 g/cm^3, whilst the density of melted firn is estimated as 0.70 g/cm^3. Based on estimated density and stake measurements the summer balance was calculated to be -1.5 ±0.3 m w.eqv., which is -20 ±4 mill. m^3 of water. The result was -2.2 m in 1999, -1.6 m in 1998 and -2.7 m w.eqv. in 1997.

Net balance

The net balance for 2000 was +0.8 ±0.4 m w.eqv., corresponding a surplus of 10 ±4 mill.m^3 of water. This is the first year with a significant positive net balance at Harbardsbreen since measurements started in 1997. According to Figure 8-4 the equilibrium line altitude is below the elevation range of the glacier, and thus the AAR is 100 %.

The mass balance results are shown in Table 8-1 and Figure 8-4. Historic mass balance results since 1997 are presented in Figure 8-5.

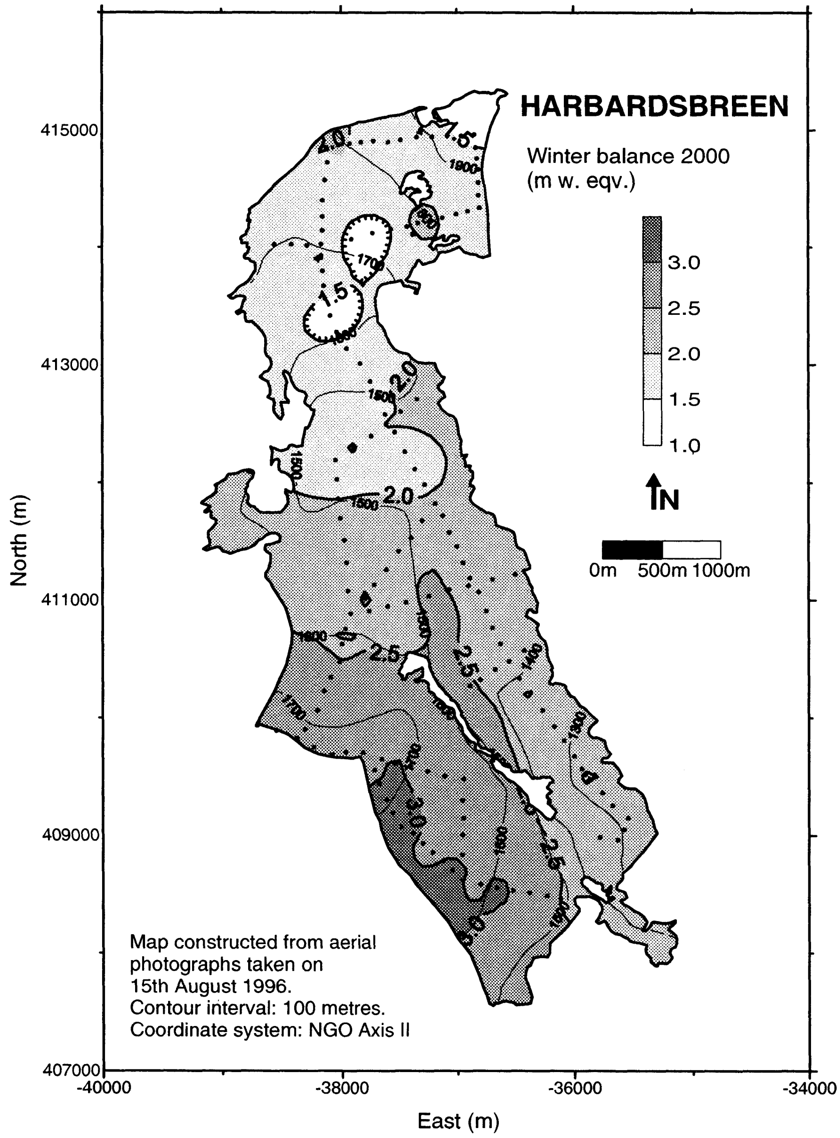


Figure 8-3

Winter balance at Harbardsbreen in 2000 interpolated from 148 snow depth measurings (•).

Mass balance Harbardsbreen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 29th Apr 2000: Specific (m w.eq.)	Winter balance, Measured 29th Apr 2000: Volume (10^6 m^3)	Summer balance, Measured 13th Sep 2000: Specific (m w.eq.)	Summer balance, Measured 13th Sep 2000: Volume (10^6 m^3)	Net balance, Summer surfaces 1999 - 2000: Specific (m w.eq.)	Net balance, Summer surfaces 1999 - 2000: Volume (10^6 m^3)
1900 - 1960	0,28	1,50	0,4	-1,15	-0,3	0,35	0,1
1850 - 1900	0,35	1,70	0,6	-1,15	-0,4	0,55	0,2
1800 - 1850	0,32	1,90	0,6	-1,18	-0,4	0,73	0,2
1750 - 1800	0,58	2,10	1,2	-1,20	-0,7	0,90	0,5
1700 - 1750	1,12	2,35	2,6	-1,25	-1,4	1,10	1,2
1650 - 1700	1,89	2,50	4,7	-1,33	-2,5	1,17	2,2
1600 - 1650	1,27	2,55	3,2	-1,40	-1,8	1,15	1,5
1550 - 1600	1,16	2,40	2,8	-1,50	-1,7	0,90	1,0
1500 - 1550	1,57	2,30	3,6	-1,60	-2,5	0,70	1,1
1450 - 1500	2,56	2,25	5,8	-1,70	-4,4	0,55	1,4
1400 - 1450	0,82	2,25	1,8	-1,80	-1,5	0,45	0,4
1350 - 1400	0,43	2,25	1,0	-1,90	-0,8	0,35	0,2
1300 - 1350	0,42	2,25	0,9	-2,00	-0,8	0,25	0,1
1250 - 1300	0,39	2,25	0,9	-2,10	-0,8	0,15	0,1
1250 - 1960	**13,16**	**2,30**	**30,2**	**-1,52**	**-20,0**	**0,77**	**10,2**

Table 8-1

Winter, summer and net balance for Harbardsbreen in 2000. Mean values for the previous three years are b_w=1.88 m, b_s=-2.16 m and b_n=-0.28 m water equivalents.

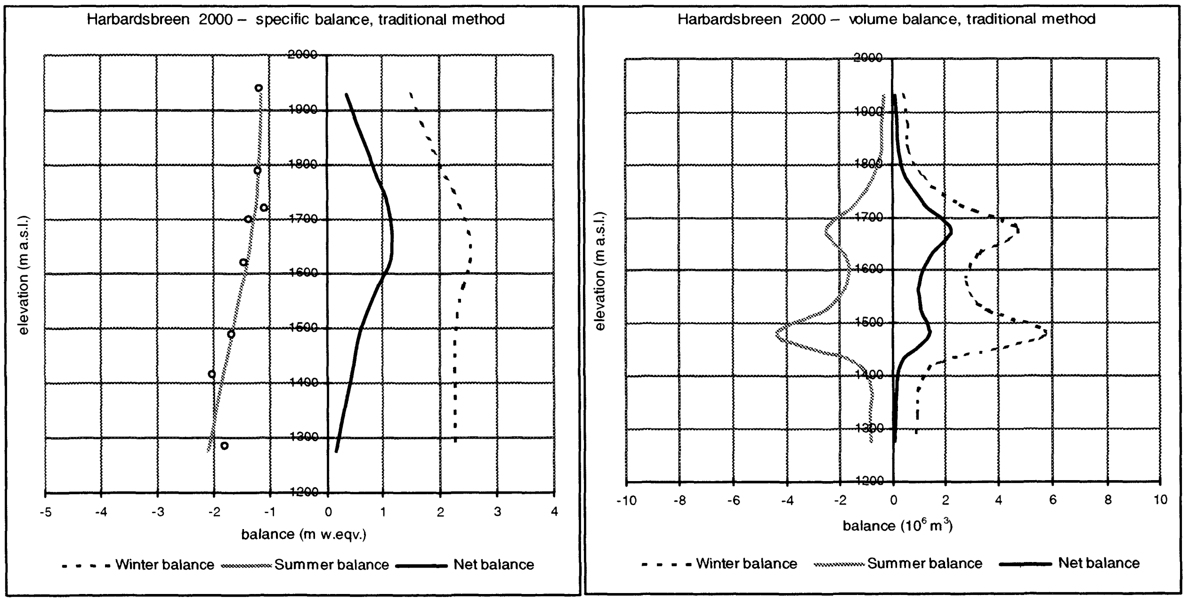


Figure 8-4

Mass balance diagram showing specific balance (left) and volume balance (right) for Harbardsbreen in 2000. Summer balance at eight stakes is shown (○). There was no exposed ice, and thus the ELA was lower than 1250 m a.s.l.

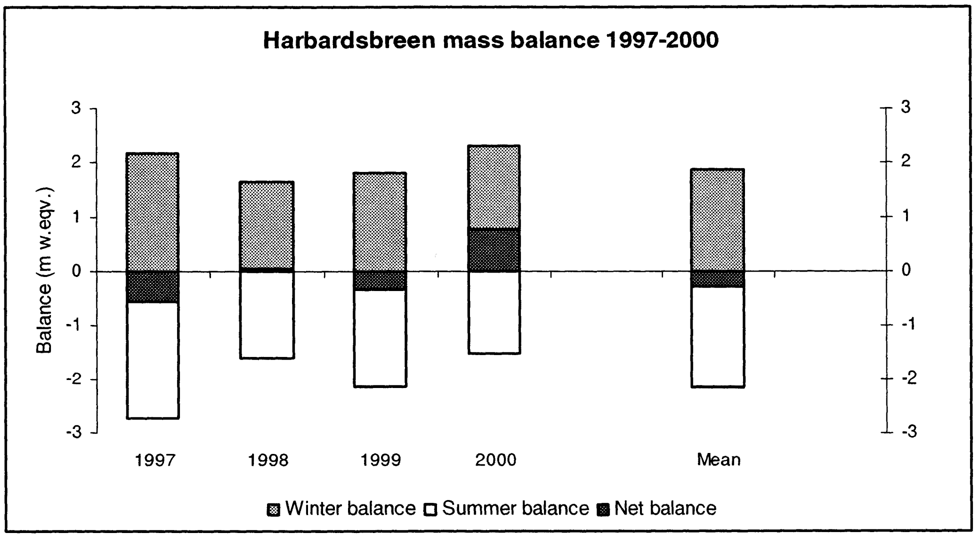


Figure 8-5

Mass balance at Harbardsbreen in the period 1997-2000.

8.2 Air temperature

A station for automatically recording air temperature was set-up on the eastern side of Harbardsbreen (Fig. 8-1) in May 1997. Data is stored at the site and was transferred during field visits in February, April and September 2000.

Air temperature results from Harbardsbreen (1320 m a.s.l.) for the period 1997-2000 are presented in Table 8-2, and compared with corresponding measurements from Sognefjell station (1413 m a.s.l.), run by the Norwegian Meteorological Institute. The values in the table indicate the daily mean air temperature for the "summer season" (defined as 1st June to 30th September).

Daily mean values 1st June - 30th September ("Summer season")			
Year	Harbardsbreen (°C)	Sognefjell (°C)	Lapse rate Ha./So. (°C/100 m)
1997	6,1	6,3	-0,26
1998	4,2	4,1	0,09
1999	[1)]3,5	5,5	-2,20
2000	4,7	4,4	0,35
Mean 1997-2000	4,6	5,1	-0,51
Mean 1980-1988	-	4,2	-

1) This value is probably erroneous.

Table 8-2

Mean air temperature at Harbardsbreen (1320 m a.s.l.) and Sognefjell (1413 m a.s.l.) in the "Summer season" (1st June - 30th September) for the period 1997-2000. Average values for 1997-2000 and 1980-1988 (Sognefjell only) are also shown.

The mean summer temperature in 2000 was 4.7 °C at Harbardsbreen and approximately the same at Sognefjell (4.4 °C). The results from 1997 and 1998 are also approximately equal for the two stations. The results for 1999, however, differ by 2.0 °C. This difference probably indicate an erroneous value at Harbardsbreen in 1999.

8.3 Ice-dammed lake

Observations (Tab. 8-3) of the ice-dammed lake at the western side of the glacier (altitude 1480 m a.s.l.) have been performed since 1992. The observations suggest frequent jøkulhlaups (Kjøllmoen (ed.) 2000).

During the past year (2000) the lake was photographed on 29th April, 27th July and 13th September (Fig. 8-6). The observations showed water in the lake in July and September, whilst it was empty in April. During field visits in May, July and September 1999 the lake was empty. Hence, since the jøkulhlaup in winter 1998/99, the drainage channel was open for the rest of 1999. The time of channel closing is difficult to estimate, but it probably occured at the end of winter 2000 and before the melting season started.

Date	Observation
19 09 1992	Water in the lake
23 09 1993	Water in the lake (uncertain observation)
28 07 1994	Water in the lake
20 07 1996	Water in the lake
14 09 1996	Water in the lake
01 02 1997	Empty
19 05 1997	Much snow, but no visible water- or ice surface in the lake
25 07 1997	Water in the lake
24 09 1997	Water in the lake
15 05 1998	Much snow, probably some water in the lake
12 08 1998	Water in the lake
23 09 1998	Water in the lake
08 05 1999	Empty
30 07 1999	Empty
30 09 1999	Empty
29 04 2000	Empty
27 07 2000	Water in the lake
13 09 2000	Water in the lake

Table 8-3

Observations of the glacier-dammed lake at Harbardsbreen in the period 1992-2000.

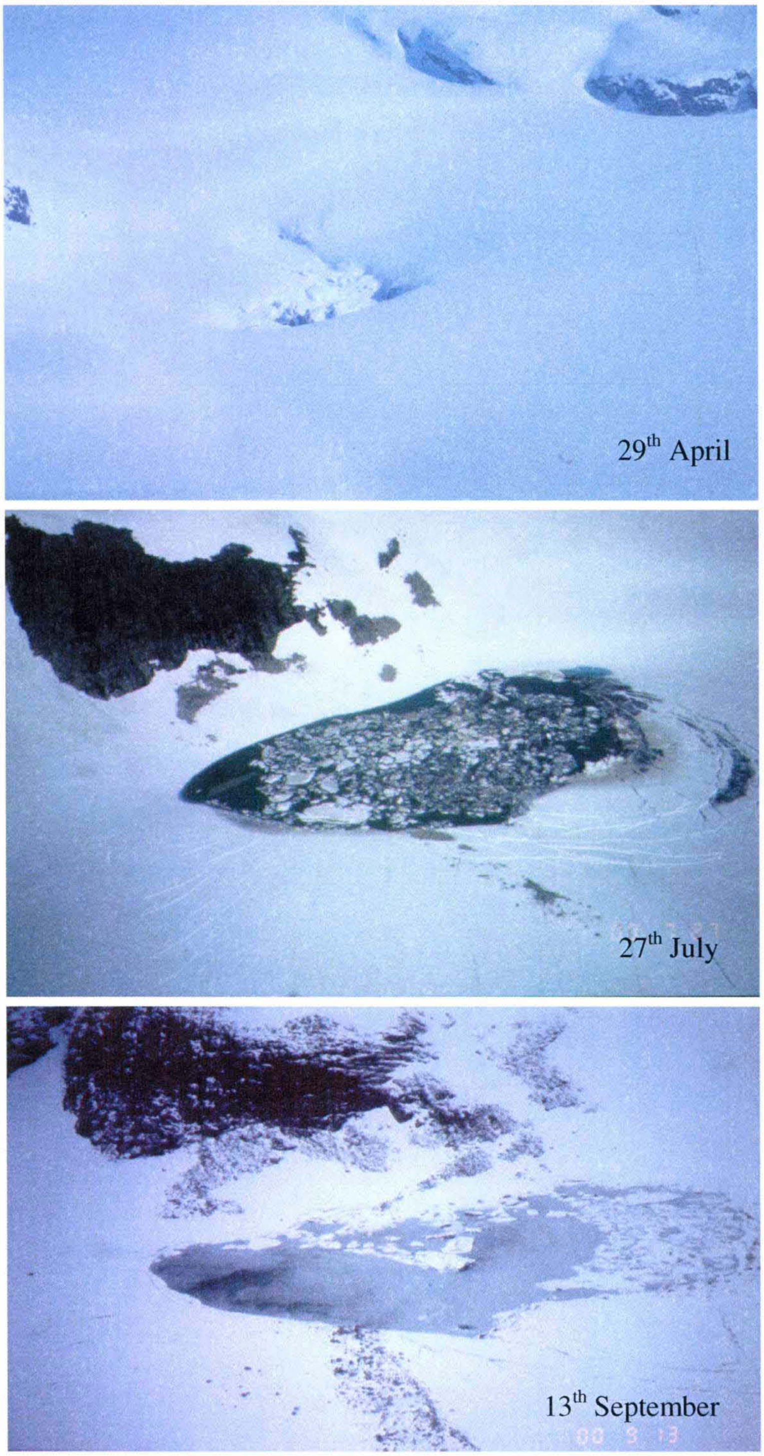


Figure 8-6

The glacier-dammed lake photographed on 29th April, 27th July and 13th September 2000. The lake was empty in April, whilst water was observed there in July and September. Photo: Hallgeir Elvehøy (April) and Bjarne Kjøllmoen (July and September).

9 Storbreen (Liss M. Andreasen)

Storbreen (61°34' N, 8°8' E) is situated in the Leirdalen valley in the central part of Jotunheimen, a mountain area in central southern Norway (Fig. 9-1). The glacier has a total area of 5.4 km^2 and ranges in altitude from 1390 to 2090 m a.s.l. (Fig. 9-2). Mass balance measurements were initiated in 1949 and have been carried out continuously since then.

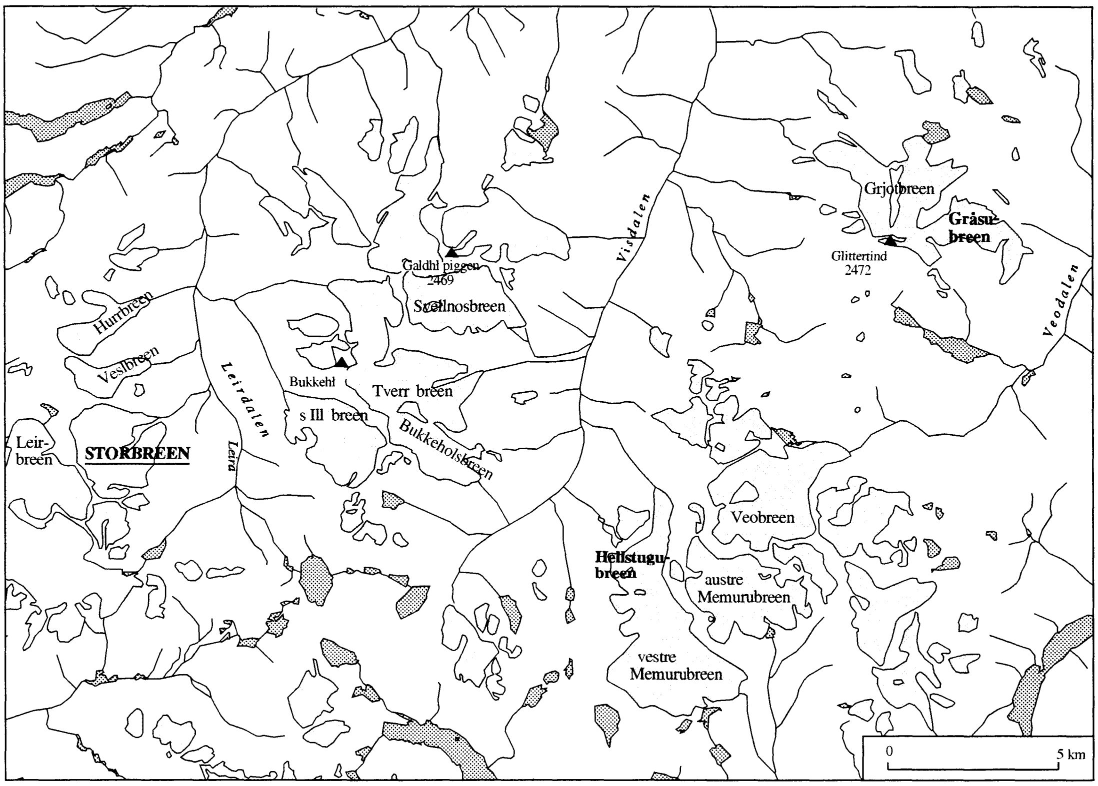


Figure 9-1

Location map showing Storbreen and other glaciers in Jotunheimen. Mass balance measurements are carried out on Storbreen and Hellstugubreen in the central part and on Gråsubreen in the eastern part of Jotunheimen.

9.1 Mass balance 2000

Field work

Accumulation measurements were performed on 10th May. Five stakes at five different locations were visible. Snow depth was measured at 200 points along 19 km of profiles, covering almost all height intervals of the glacier (Figs. 9-2 and 9-3). The probing conditions were good, and last years summer surface was easy to identify. Snow depth varied between 1.8 and 7.1 m. Nearly 70 % of the soundings were between 3 and 5 meters (Fig. 9-3). Snow density was measured at stake 4 (1730 m a.s.l., Fig. 9.2) by sampling in a pit through the snow pack (3.8 m snow). Ablation measurements were carried out on 21st September. Summer balance was calculated from stakes at 5 locations, net balance was calculated from stakes at 7 locations.

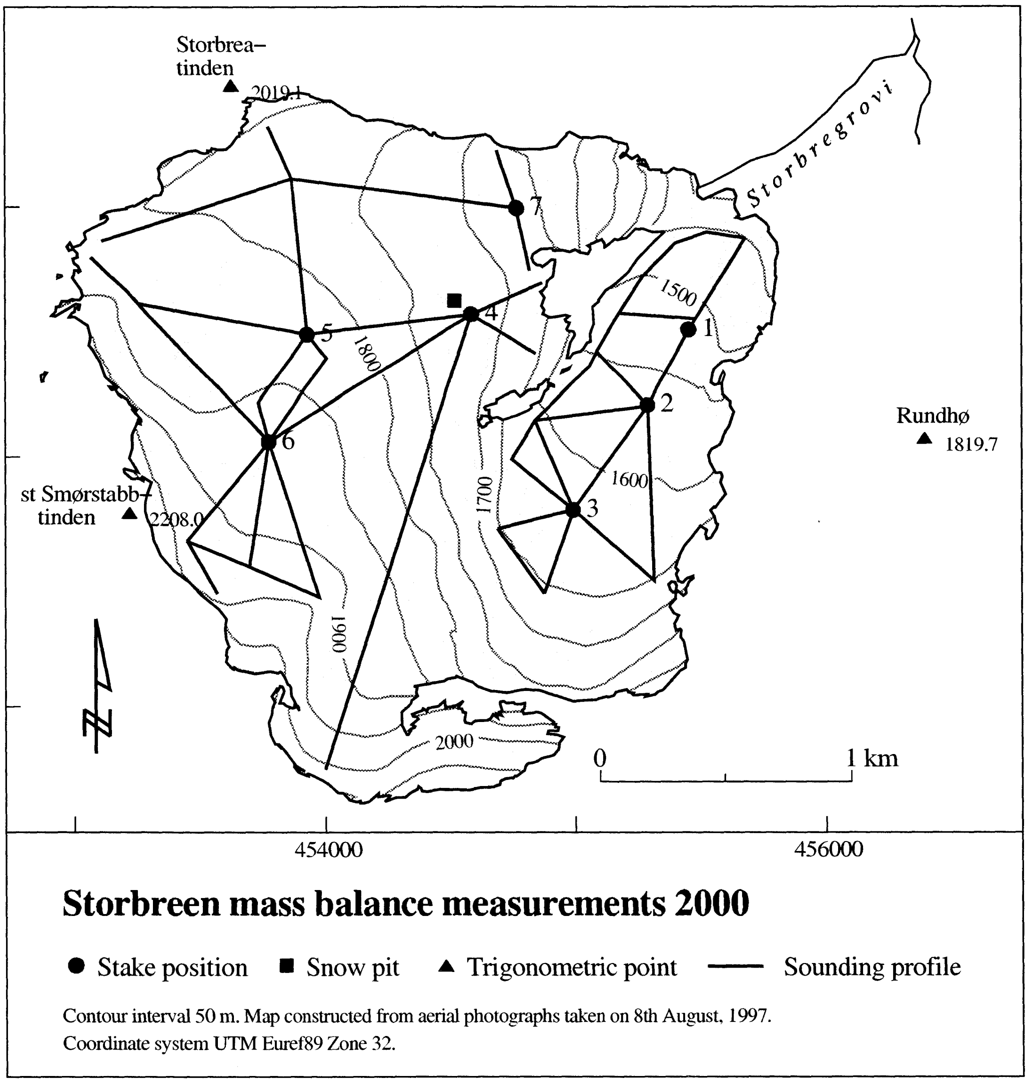


Figure 9-2

Map of Storbreen showing the mass balance programme in 2000.

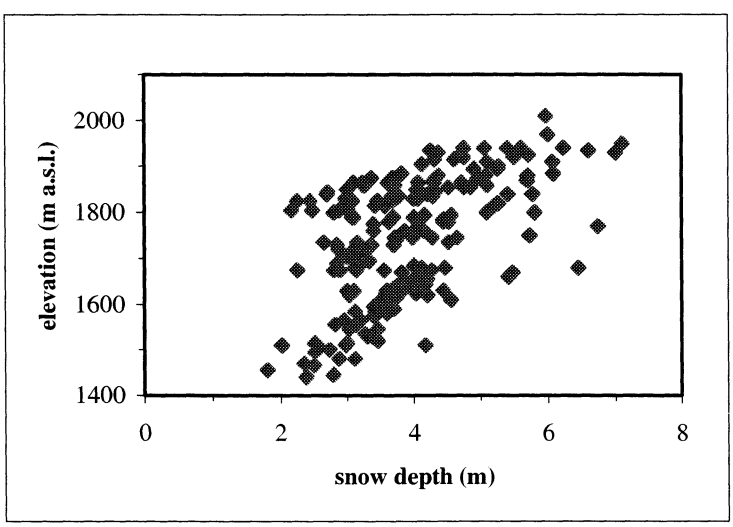


Figure 9-3

Snow depth measured at Storbreen on 10th May 2000. Each point represents one sounding.

Results

Mass balance was calculated by using the stratigraphic method, also known as the traditional method. The results are shown in Table 9-1 and Figure 9-4.

Winter balance

Winter balance was calculated from the soundings and the density measurement. The density was higher than normal at 0.48 g/cm^3. The density profile was considered representative for the rest of the glacier. The winter balance was computed as the mean of the soundings within each 50-meter interval. The specific winter balance was 2.0 ±0.2 m w.eqv. This is 141% of the mean for the period 1949-99.

Summer balance

Summer balance was calculated directly from stakes in five locations and indirectly by net balance at stakes in two other locations. The density of the remaining snow was assumed to be 0.65 g/cm^3, based on measurements from previous years. The density of the melted ice was estimated to be 0.90 g/cm^3. The summer balance was calculated to −1.5 ±0.2 m w.eqv. This is 90 % of the mean for the period 1949-99.

Net balance

The net balance of Storbreen in 2000 was positive, 0.55 ± 0.3 m w.eqv. The equilibrium line altitude (ELA) was 1650 m a.s.l., which corresponds to an accumulation area ratio (AAR) of 76 % (Fig. 9-4). Out of the total 52 years of measurements, 20 of the years have had a positive net balance, while the rest have been negative (Fig. 9-5). Storbreen has experienced a cumulative mass loss of −10.5 m w.eqv. between 1949 and 2000, or −0.20 m w.eqv. per year. Most of this mass loss occurred before 1980.

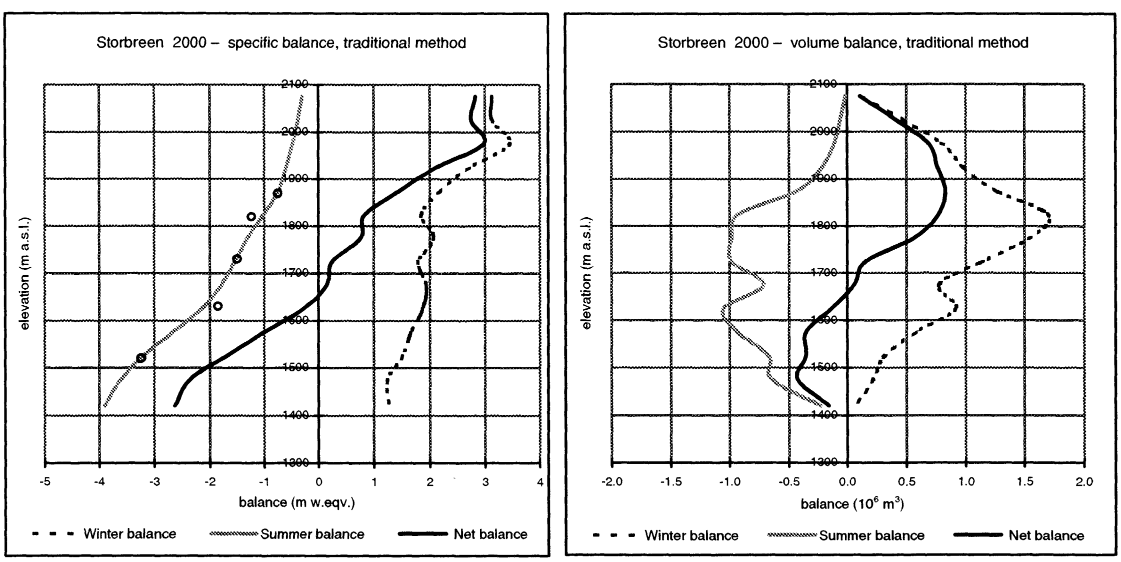


Figure 9-4

Mass balance diagram for Storbreen 2000 showing specific balance to the left and volume balance to the right.

Mass balance Storbreen 1999/00 – traditional method							
		Winter balance Measured 10th May 2000		Summer balance Measured 21st Sep 2000		Net balance Summer surfaces 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2050 - 2100	0.04	3.13	0.13	-0.30	-0.01	2.83	0.11
2000 - 2050	0.15	3.13	0.47	-0.38	-0.06	2.75	0.41
1950 - 2000	0.23	3.46	0.80	-0.48	-0.11	2.98	0.69
1900 - 1950	0.36	2.72	0.98	-0.60	-0.22	2.12	0.76
1850 - 1900	0.57	2.19	1.25	-0.74	-0.42	1.45	0.83
1800 - 1850	0.92	1.85	1.70	-1.01	-0.93	0.84	0.77
1750 - 1800	0.75	2.07	1.56	-1.31	-0.98	0.76	0.57
1700 - 1750	0.64	1.79	1.15	-1.54	-0.99	0.25	0.16
1650 - 1700	0.40	1.94	0.77	-1.79	-0.72	0.15	0.06
1600 - 1650	0.49	1.87	0.92	-2.15	-1.05	-0.28	-0.14
1550 - 1600	0.35	1.66	0.58	-2.67	-0.93	-1.01	-0.35
1500 - 1550	0.21	1.51	0.32	-3.20	-0.67	-1.69	-0.36
1450 - 1500	0.18	1.23	0.22	-3.60	-0.65	-2.37	-0.43
1390 - 1450	0.06	1.27	0.08	-3.90	-0.23	-2.63	-0.16
1390 - 2100	**5.35**	**2.04**	**10.91**	**-1.49**	**-7.97**	**0.55**	**2.94**

Table 9-1

The distribution of winter, summer and net balance for 50 m altitude intervals for Storbreen in 2000.

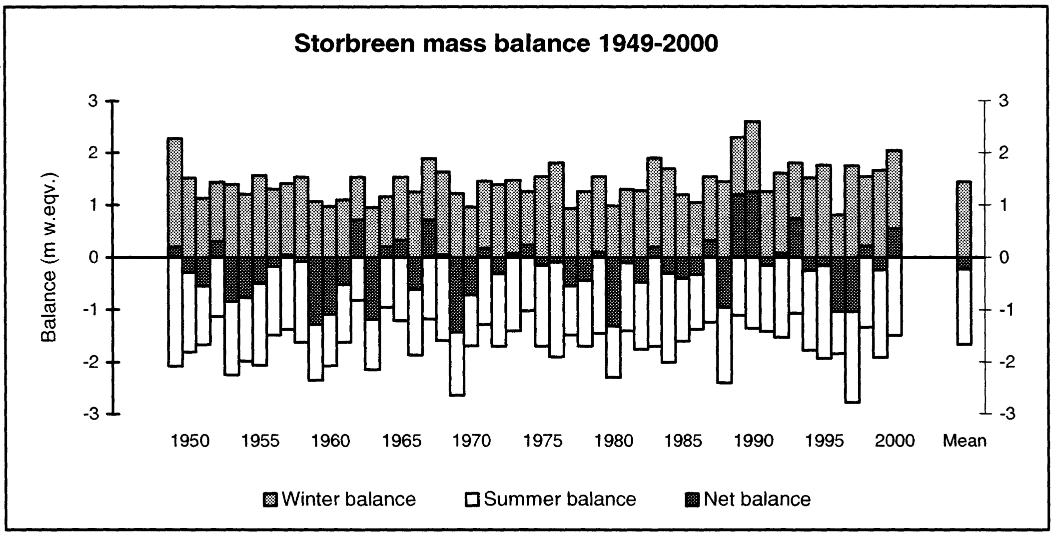


Figure 9-5

Bar graph showing winter, summer and net balance at Storbreen for the period 1949-2000.

9.2 Front position change

The front of Storbreen was covered by snow in September 2000. Therefore, it was not possible to measure the actual front position. The glacier had about the same position in 1999 as it had in 1988. Between 1900 and 1988 the glacier retreated more than 1 km.

10 Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61°34`N, 8° 26`E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 9-1). It ranges in elevation between 1480 and 2210 m a.s.l. and has an area of 3.0 km^2 (Fig. 10-1). Mass balance investigations have been performed since 1962.

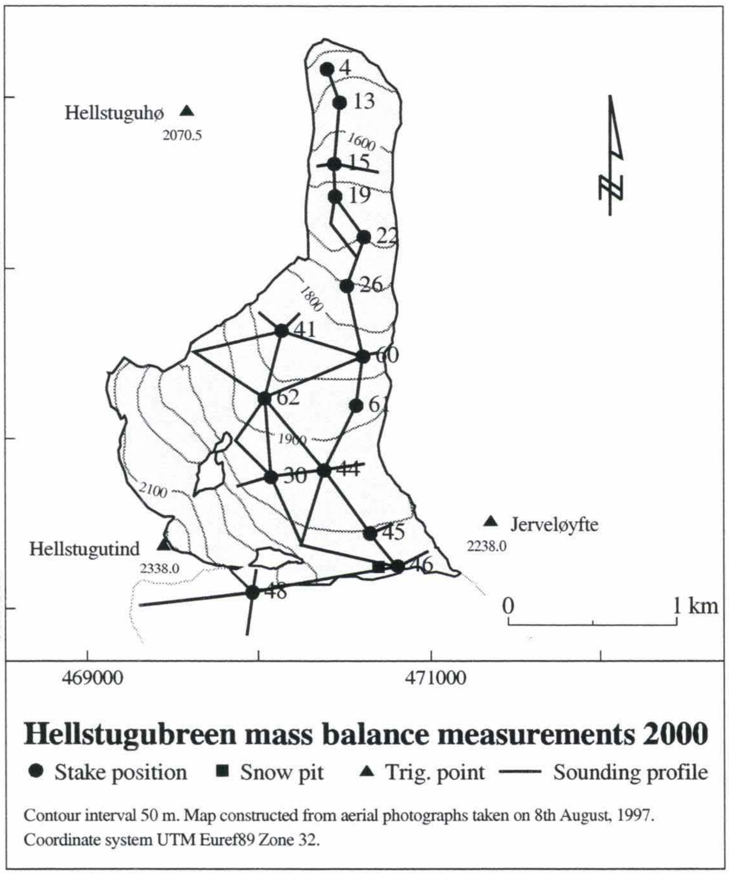


Figure 10-3

Map of Hellstugubreen showing the mass balance programme in 2000. Figure 9-1 shows a location map of the study glaciers in Jotunheimen.

A new map of the glacier has been produced from aerial photographs taken in 1997. It replaces the old map from 1980 in the mass balance calculations. The 1997-map has been compared with older maps in order to quantify the glacier changes. The map itself and results are presented in chapter 16.4.

10.1 Mass balance 2000

Field work

Accumulation measurements were carried out on 13th May. Fifteen stakes had survived the winter. Snow depth was measured at 139 points along 13 km of profiles covering most of the glacier. The probing conditions were good, and last years summer surface was easy to identify over the whole glacier. The snow depth varied between 0.2 and 4.2 meters. 75 % of the measurements were between 2.0 and 3.5 meters (Fig. 10-2). The snow density was measured by sampling in a pit through the total snow pack (3.2 m) at 1950 m a.s.l. Ablation measurements were made on 21st September. Stakes in fourteen locations were measured. The location of stakes, density pit and sounding profiles are shown in Figure 10.1.

Results

The mass balance was calculated using the stratigraphic method, also known as the traditional method. The results are presented in Table 10-1 and Figure 10-3.

Winter balance

The calculation of winter balance was based on the soundings and the density measurement that is considered to be representative for the rest of the glacier. The mean snow density was higher than usual at 0.49 g cm^3. The winter balance was computed as the mean of the soundings within each 50-meter interval. Winter balance was calculated to 1.3 ±0.2 m w.eqv., which was 112 % of the mean for the period 1962-99.

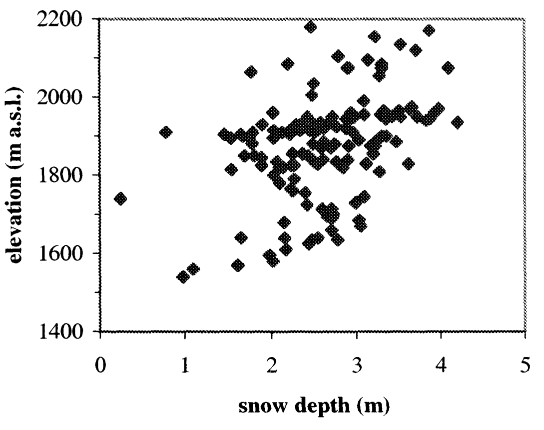


Figure 10-2

Snow measured at Hellstugubreen 13th May 2000. Each point represents one sounding.

Summer balance

The summer balance was calculated from 14 stakes. The density of the remaining snow was assumed to be 0.65 g/cm^3 based on the measurement in May and on previous years experience. The density of the melting ice was estimated to be 0.9 g/cm^3. The summer balance was calculated as -1.1 ±0.2 m w.eqv., which is 86 % of the mean value for the entire observation period.

Net balance

The net balance of Hellstugubreen 2000 was positive, 0.2 ± 0.3 m w.eqv. This is the twelfth year with a positive mass balance in the total 39 years of measurements. The equilibrium line altitude (ELA) was 1840 m a.s.l. and the AAR was 63 % (Fig. 10-3). Since 1962 the glacier has had a deficit amounting to 10.3 m w.eqv. and the mean annual net balance has been -0.26 m w.eqv. (Fig. 10-4).

Mass balance Hellstugubreen 1999/00 – traditional method							
		Winter balance Measured 13th May 00		Summer balance Measured 21st Sep 00		Net balance Summer surfaces 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2100 - 2210	0.11	1.66	0.19	-0.18	-0.02	1.48	0.16
2050 - 2100	0.28	1.51	0.42	-0.27	-0.08	1.24	0.35
2000 - 2050	0.18	1.25	0.23	-0.40	-0.07	0.85	0.16
1950 - 2000	0.38	1.49	0.56	-0.61	-0.23	0.88	0.33
1900 - 1950	0.61	1.33	0.81	-0.89	-0.54	0.44	0.27
1850 - 1900	0.35	1.33	0.46	-1.13	-0.39	0.20	0.07
1800 - 1850	0.33	1.21	0.40	-1.32	-0.43	-0.11	-0.04
1750 - 1800	0.13	1.10	0.15	-1.52	-0.20	-0.42	-0.06
1700 - 1750	0.10	1.17	0.12	-1.67	-0.17	-0.50	-0.05
1650 - 1700	0.17	1.37	0.23	-1.79	-0.30	-0.42	-0.07
1600 - 1650	0.13	1.16	0.15	-1.94	-0.25	-0.78	-0.10
1550 - 1600	0.16	0.82	0.13	-2.25	-0.36	-1.43	-0.23
1500 - 1550	0.08	0.50	0.04	-2.72	-0.21	-2.22	-0.17
1480 - 1500	0.02	0.47	0.01	-3.01	-0.05	-2.54	-0.04
1480 - 2210	**3.03**	**1.29**	**3.89**	**-1.10**	**-3.32**	**0.19**	**0.58**

Table 10-2

The distribution of winter, summer and net balance for 50 m altitude intervals for Hellstugubreen in 2000.

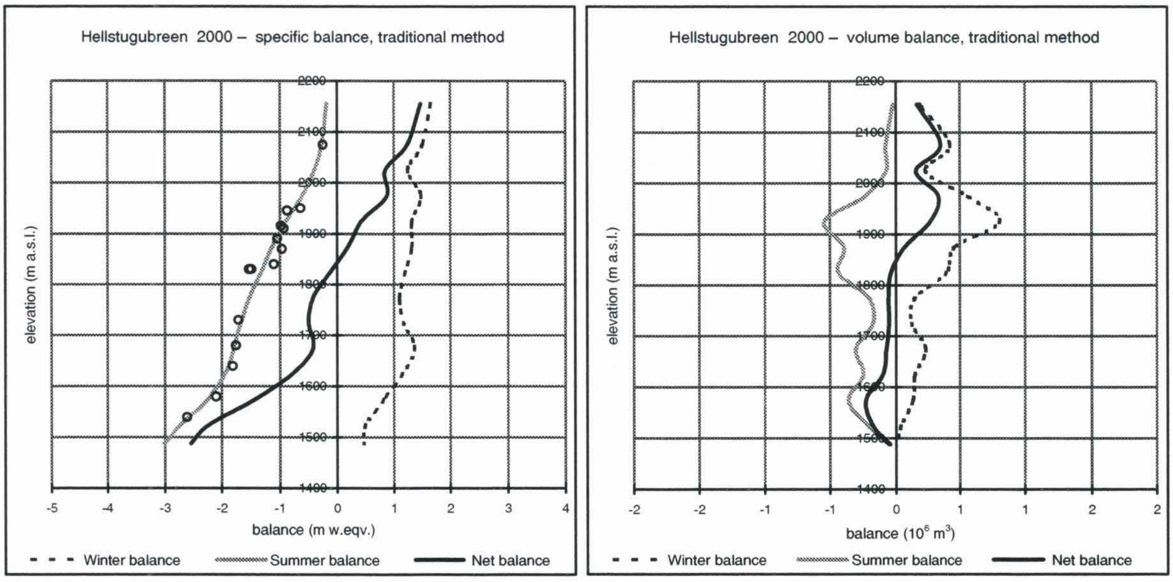


Figure 10-3

Mass balance diagram for Hellstugubreen 2000 showing specific balance to the left and volume balance to the right.

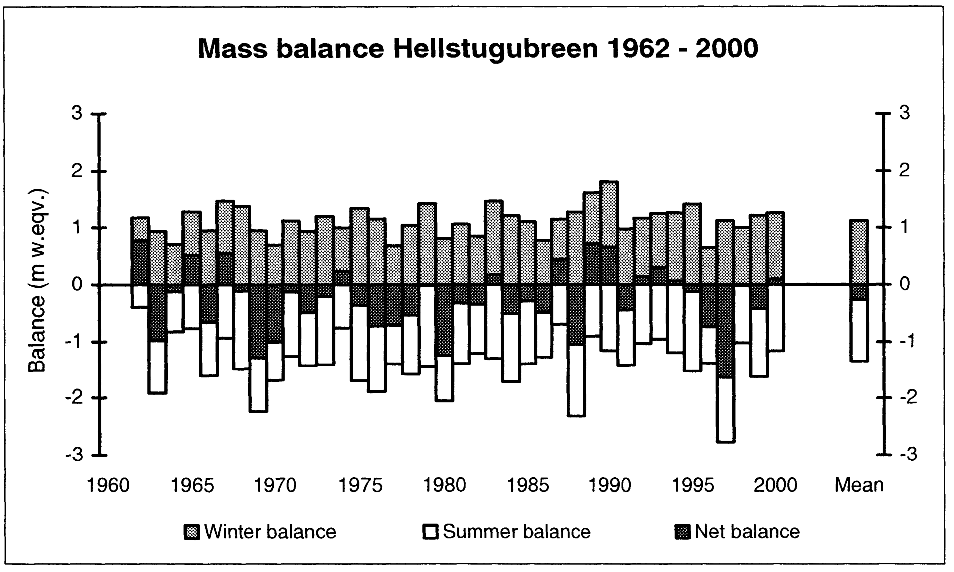


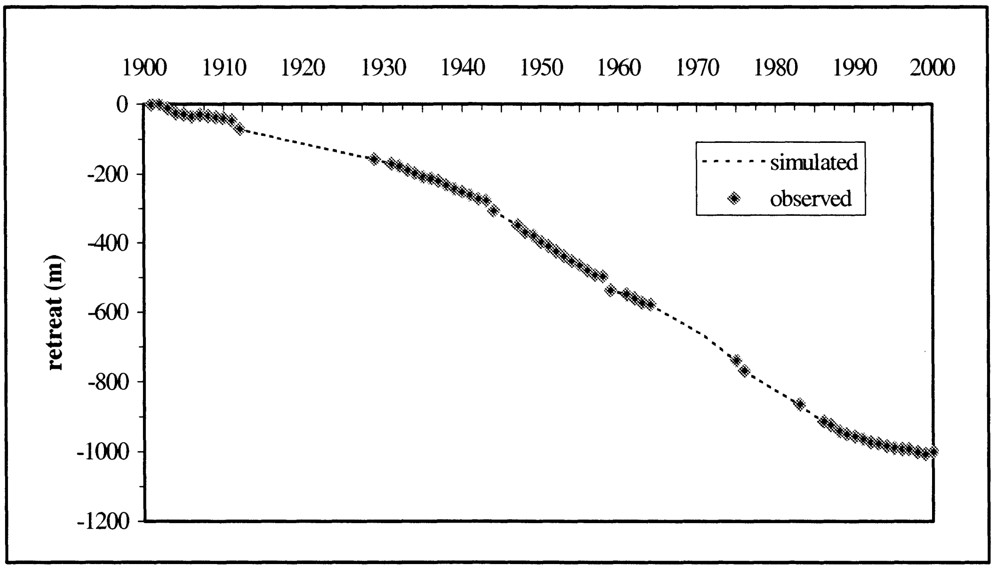
Figure 10-4

Bar graph showing winter, summer and net balance at Hellstugubreen during the period 1962-2000.

10.2 Front position change

Hellstugubreen had no net change in front position between September 1999 and September 2000.

The front position measurements started in 1901 when Øyen erected a cairn in front of the glacier. The glacier has retreated a total of 1000 m since then or, in other words, the average annual retreat has been 10 m (Fig. 10-5). Since 1990 the retreat has been about 60 meters.



Figur 10-5

Diagram showing the cumulative front position of Hellstugubreen from 1901 to 2000. The observations were discontinued in 1912 due to lack of funds, but were later resumed. Observations were sparse during the 1970s and 1980s.

11 Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37'E) is located in the eastern part of the Jotunheimen mountain area in southern Norway (Fig. 9-1). The glacier covers an area of 2.2 km^2 and ranges in elevation from 1830 to 2290 m a.s.l. (Fig. 11-1). Annual mass balance measurements began in 1962 and have continued annually since then. Gråsubreen is a polythermal glacier. Superimposed ice occurs in the central parts of the glacier where snowdrift causes a relatively thin snow pack, and superimposed ice may be responsible for up to 8 % of the total accumulation in these areas.

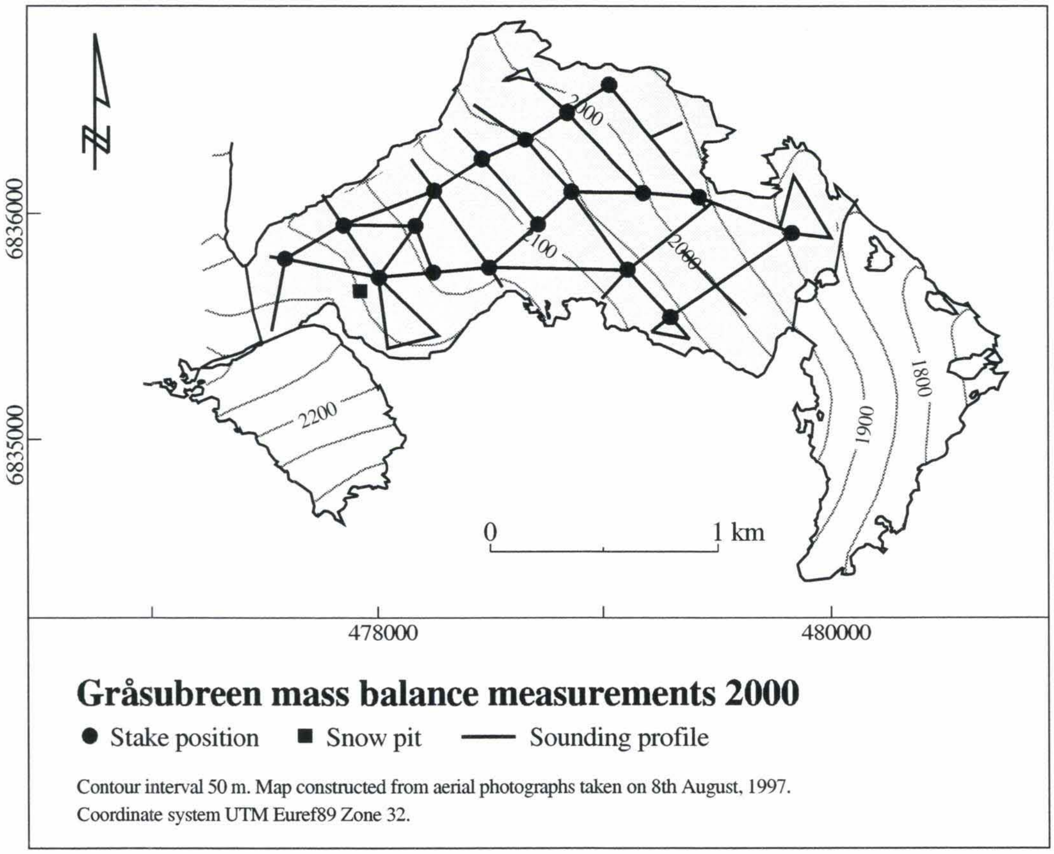


Figure 11-4

Map of Gråsubreen (shaded in grey) showing the mass balance programme in 2000. A location map of Gråsubreen and other glaciers in Jotunheimen are shown in Figure 9-1.

11.1 Mass balance 2000

Field work

Accumulation measurements were carried out on 15th May. Stakes in 18 locations were measured. 163 snow depth measurements were made along 14 km of profiles, covering most of the glacier (Fig. 11-1). The probing conditions were good, and last years summer surface was easy to identify over the entire glacier. Snow depth varied between 0 and 3.7 m. 70 % of the soundings was between 1.0 and 2.5 m. The snow density was measured at 2180 m a.s.l. in a snow pit dug down to the last summer's surface (2.5 m snow). Ablation measurements were carried out on 21st September. Stakes in 18 locations were measured.

Results

Winter balance

Winter balance was calculated from the soundings and the density measurement. The density measurement was considered representative for the whole glacier. The density was higher than normal at 0.50 g/cm^3. The winter balance was calculated as the mean of the soundings at 50-m altitude intervals. The stake recordings showed that between 5 and 30 cm of superimposed ice had formed at six stake locations. Therefore, in this area (total of 31 soundings) an interpolated amount of superimposed ice was added to each sounding before calculating the winter balance in each interval. The specific winter balance was 0.87 m w.eqv.

Since the snow distribution at Gråsubreen varies appreciably due to wind drift, the winter balance was also calculated in a geographic information system (GIS) using Arc/Info software. All soundings were digitised. The snow depth measurement was then converted to water equivalent. Finally, winter balance was calculated by interpolating the measurements. The mean winter balance was almost the same using this method, 0.86 m w.eqv. Thus, the winter balance calculated from both methods was rounded to 0.9 ±0.2 m w.eqv.

Summer balance

Summer balance was calculated based on direct measurements of stakes in 15 locations. The density of the remaining snow was assumed to be 0.65 g/cm^3, based on the density measurement in May and previous years experience. The density of the melted ice was estimated to be 0.90 g/cm^3. The resulting summer balance was –0.9 ±0.2 m w.eqv.

Net balance

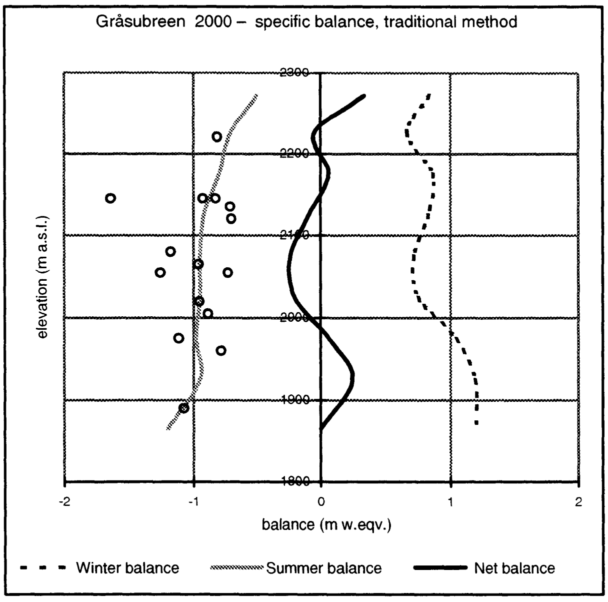
The net balance of Gråsubreen 2000 was negative, ‑0.05 ± 0.3 m w.eqv. Since 1962 the cumulative net balance was –9.9 m w.eqv. Most of this mass loss occurred in the first 20-25 years of measurements. Since 1988 the glacier has been more or less in balance (Fig 10-3). The volume change of the glacier for the period 1984-1997 has been calculated by map comparison and is described in chapter 16.5.

Mass balance Gråsubreen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 15th May 2000		Summer balance Measured 21st Sep 2000		Net balance Summer surfaces 1999 - 2000	
		Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2250 - 2290	0.04	0.84	0.04	-0.50	-0.02	0.34	0.01
2200 - 2250	0.17	0.66	0.11	-0.71	-0.12	-0.05	-0.01
2150 - 2200	0.26	0.86	0.23	-0.80	-0.21	0.06	0.02
2100 - 2150	0.34	0.83	0.28	-0.92	-0.31	-0.09	-0.03
2050 - 2100	0.37	0.72	0.27	-0.95	-0.35	-0.23	-0.09
2000 - 2050	0.42	0.75	0.31	-0.95	-0.40	-0.20	-0.08
1950 - 2000	0.36	1.05	0.37	-0.98	-0.35	0.07	0.02
1900 - 1950	0.14	1.20	0.17	-0.95	-0.14	0.25	0.03
1830 - 1900	0.15	1.20	0.18	-1.20	-0.18	0.00	0.00
1850 - 2290	**2.25**	**0.87**	**1.96**	**-0.92**	**-2.08**	**-0.05**	**-0.12**

Table 11-3

The distribution of winter, summer and net balance at 50 m altitude intervals for Gråsubreen in 2000.



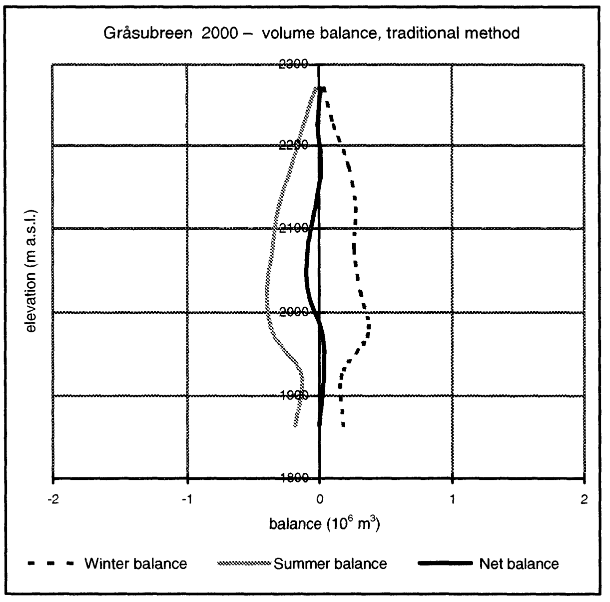


Figure 11-5

Mass balance diagram for Gråsubreen 2000 showing specific balance to the left and volume balance to the right.

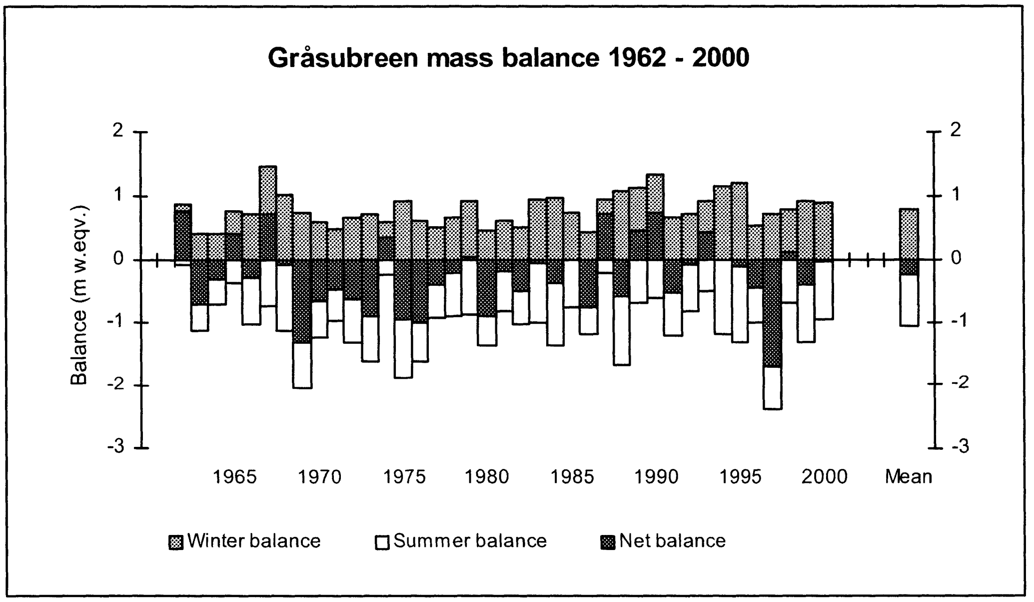


Figure 11-6

Bar graph showing winter, summer and net balance at Gråsubreen during the period 1962-2000. Gråsubreen has had an average annual mass loss of 0.22 m w.eqv. in this period.

12 Svartisheibreen (Hallgeir Elvehøy)

Svartisheibreen (66° 35' N, 13° 45' E) is located southwest of the western Svartisen icecap. It has an area of 5.5 km^2 and drains to the Glomåga river and lake Langvatnet. The glacier ranges from 1530 m a.s.l. at its highest elevation down to 774 m a.s.l. at proglacial lake Heivatn into which the glacier calves (Fig. 12-1). The glacier has been monitored in connection with a planned hydropower development (Kennett et al. 1997). In 1995 the monitoring programme was reduced to observations of the lake level in Heiavatn in order to see if jøkulhlaups occur, and observations of the snowline altitude in order to calculate annual net balance.

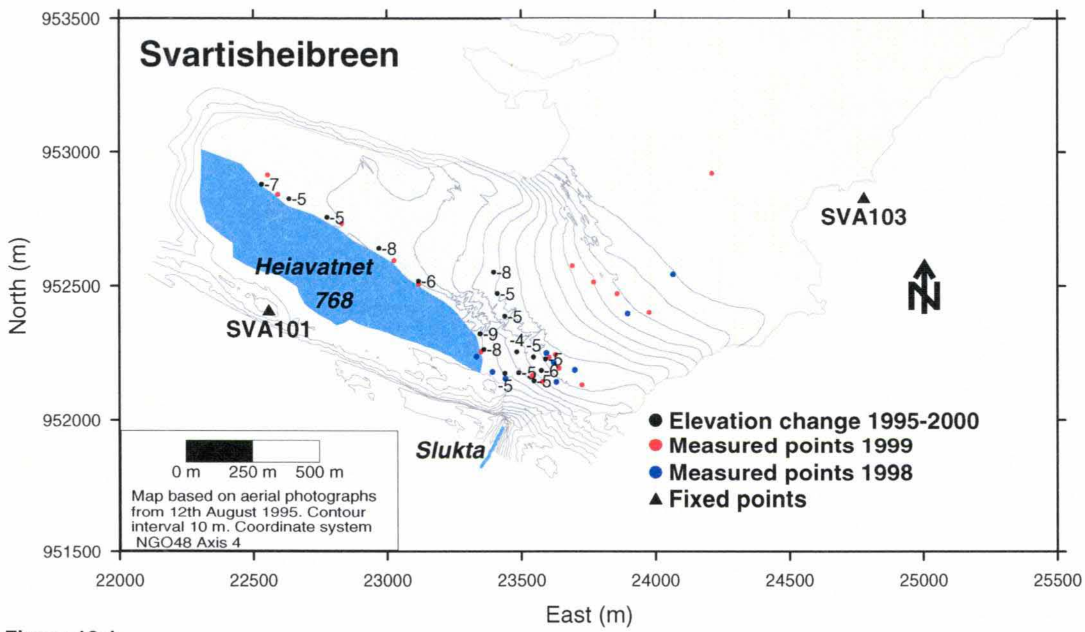


Figure 12-1

Changes in surface elevation between 12th August 1995 and 21st September 2000 (•). A small proportion of the change (about 1 m) is probably due to melting after 21st September in 1995. The pre-lowering lake level in Lake Heiavatnet is 774 m a.s.l. Glacier contour lines up to 900 m a.s.l. are shown.

12.1 Observations 2000

Heiavatnet

Lake Heiavatnet was observed and photographs taken on 21st September 2000. The river from the lake was dry, and the lake level was 768 m a.s.l., 6 m below normal. The lake level after the jøkulhlaup in April 1991 was 766.7 m a.s.l., after which the water remained low during most of the following winter (Kjøllmoen & Kennett 1995). Comparing photographs taken on 22nd September 1999 and 21st September 2000 shows that the water level was higher at some point during this period, since icebergs that probably were too large to melt away during one year were present in 1999 and not in 2000. Thus the lake has probably been filled up so that the icebergs could drift off before the lake level was lowered again during the period from September 1999 to September 2000.

Equilibrium line altitude

No fresh snow was present on 21st September. Based on visual determination of the snow line in the photographs taken from a helicopter, the equilibrium line altitude (ELA) was estimated as 950 ±10 m a.s.l.

Elevation profiling

The fixed point SVA101 (Fig. 12-1) was used to measure the surface elevation. The previously used fixed point, SVA103, was used as a reference point. The point SVA101 provides a better view of the critical part of the glacier where the lake is drained. The change of observation point may cause a shift in reported elevations. Eighteen points on the surface of the glacier were measured (Fig. 12-1); seven points along the glacier front, seven in the dam area, and three in an area at an elevation of 810 m a.s.l.

12.2 Results

Changes in ice thickness

Point observations from 2000 are not directly comparable with observations from 1998 and 1999, as the points are not spatially co-located. Thus all points are compared to the contour lines constructed from the aerial photographs acquired on 12th August 1995 (Fig. 12-1). The western part of the tongue has been afloat for several years. All the point elevations along the front, except one, are lower than the lake level in Lake Heiavatnet (774 m a.s.l.), which indicates that the part of the tongue that is floating has become larger since 1999. In 1999 only points comparable to the western two points in 2000 had elevations lower than normal lake level.

The surface was lower in 2000 than in the previous two years in the area where the glacier dams the lake. Thus the observations indicate that the glacier tongue is thinning. This is probably due to increased ice velocity towards the lake as a result of increased lake area and water depth at the glacier margin.

Changes in front position in Lake Heiavatnet

The front position in 2000 was compared with the observations from 1999. Definition of the western part of the glacier terminus was difficult due to crevasses and an increase in the area of the glacier front that is floating. There were only small changes in the eastern and central part of the front. Compared to the map from 1995 there was minor retreat in the eastern part of the glacier front.

Net balance 2000

The net balance of Svartisheibreen was estimated using two different methods; one using the observed net balance on Engabreen (b_n=1.5 ±0.3 m w.eqv.), and the other using the observed ELA at Svartisheibreen (950 ±10 m a.s.l.). Both methods are based on measurements of the mass balance of Svartisheibreen carried out between

1988 and 1994 (see Figs. 12-2 and 12-3). The model for estimating the net balance based on ELA has been changed from that used previously (Fig. 12-3). This was done because the 1989 net balance was much higher than in 1992 and 1993, while the ELA of these years were quite similar

The net balance was +1.0 m w.eqv. based on the Engabreen net balance, and +0.4 m w.eqv. based on the ELA of Svartisheibreen. Combining these results gives an estimate of net balance of 0.7±0.4 m w.eqv. The results for the period 1995-2000 are listed in Table 12-1.

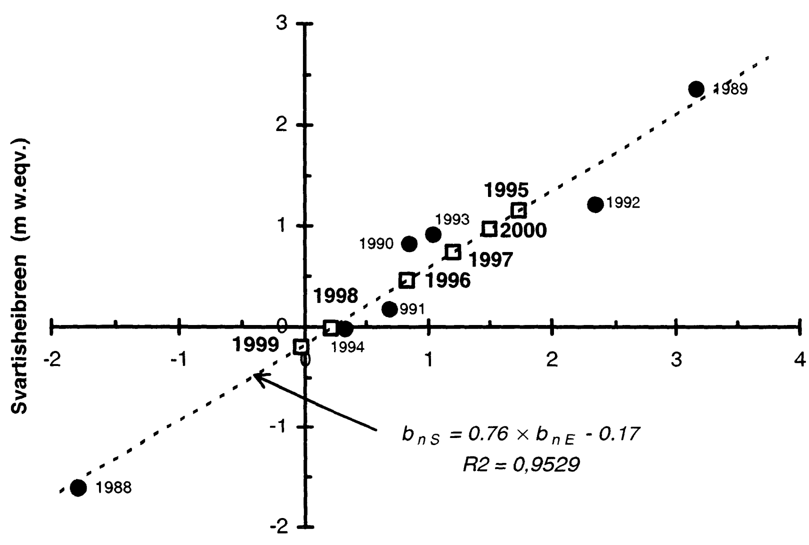


Figure 12-2

Linear regression between net balance of Engabreen and Svartisheibreen (•) based on simultaneous observations during the period 1988-94. Net balance of Svartisheibreen for the period 1995-2000 (☎) is modelled using the regression equation.

Year	Date of visit	ELA (m a.s.l.)	Heiavatnet filled ?	Net balance method 1[1]	Net balance method 2[2]	Net balance mean
1995	20th Sep	920	Yes	1,2	0,7	0,9
1996	19th Sep	960	Yes	0,5	0,3	0,4
1997	4th Oct	940[3]	Yes	0,7	0,6	0,7
1998	1st Oct	1000	Yes	0,0	0,0	0,0
1999	22nd Sep	1100	No	-0,2	-1,0	-0,6
2000	21st Sep	950	No	1,0	0,4	0,7

[1]*Based on relation between net balance of Engabreen and Svartisheibreen*

[2]*Based on relation between ELA and net balance at Svartisheibreen*

[3]*Estimated from summer observations*

Table 12-1

Observations of the equilibrium line (ELA) at Svartisheibreen and the lake level in Lake Heiavatnet, and modelled net balance of Svartisheibreen in 1995 - 2000.

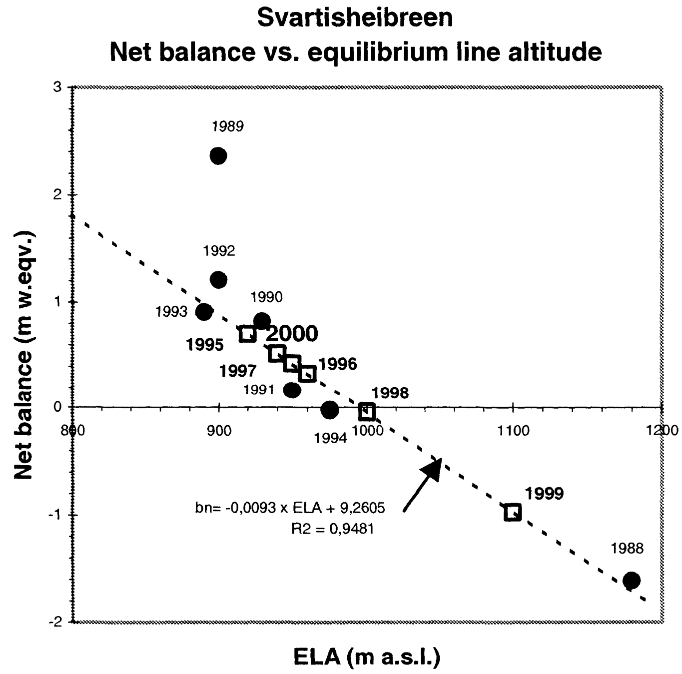


Figure 12-3

Linear regression between the equilibrium line altitude (ELA) and net balance (b_n) on Svartisheibreen based on measurements in 1988 and 1990-94 (•). The results from 1989 were discarded in the regression analysis (see text). Net balance for the period 1995-2000 (■) is modelled using the regression equation.

Using the described models for the net balance of Svartisheibreen, cumulative specific balance for the period 1969-2000 is estimated as +11.9 m w.eqv. (Fig. 12-4). Discrepancies between the measured and modelled net balance figures and volume change calculated from map comparisons, led to the conclusion that the measured and

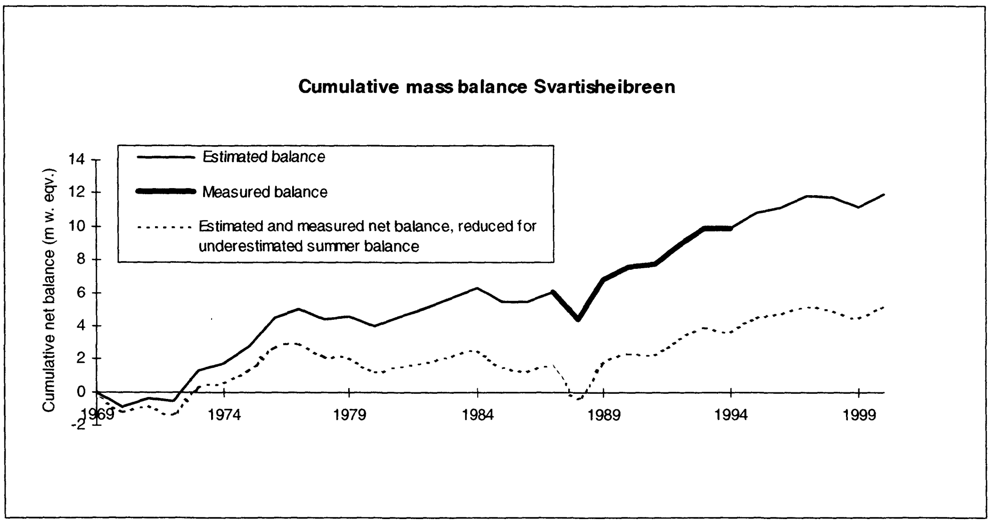


Figure 12-4

Cumulative specific net balance of Svartisheibreen for the period 1969-2000. Estimated net balance (thin solid line) is modelled from net balance on Engabreen (1969-87), and from the equilibrium line altitude on Svartisheibreen and net balance of Engabreen (1995-2000). Cumulative net balance reduced by 0.25 m w.eqv. is also shown (dashed line).

modelled mass balance figures were too high (Kjøllmoen, 2000). An annual under estimate of the summer balance in the order of 0.25 m w.eqv. per year most probably caused this. The adjusted cumulative net balance is shown in Figure 12-4.

Future scenarios

Projecting these changes into the near future, we suggest that the lower part of the glacier will become thinner and that the lake will increase in volume. At some point, the subglacial drainage tunnel will not close during the winter, and lake Heiavatnet will drain permanently under the glacier towards Slukta. Lowering of the lake level will probably reduce or terminate the thinning of the glacier. If the glacier continues to thin, the lake will probably start draining along lower drainage routes. Based on a bottom topography map by Kjøllmoen & Kennett (1995) a rock threshold at 720 ±20 m a.s.l. is the lower limit for the lake level.

13 Engabreen (Hallgeir Elvehøy and Miriam Jackson)

Engabreen (66°40'N, 13°45'E) is a 38 km² northwestern outlet from the western Svartisen icecap. It covers an altitude range from 1594 m a.s.l. (at Snøtind) down to 7 m a.s.l. (at Engabrevatnet), as shown in Figure 13-1. Mass balance measurements have been performed annually since 1970.

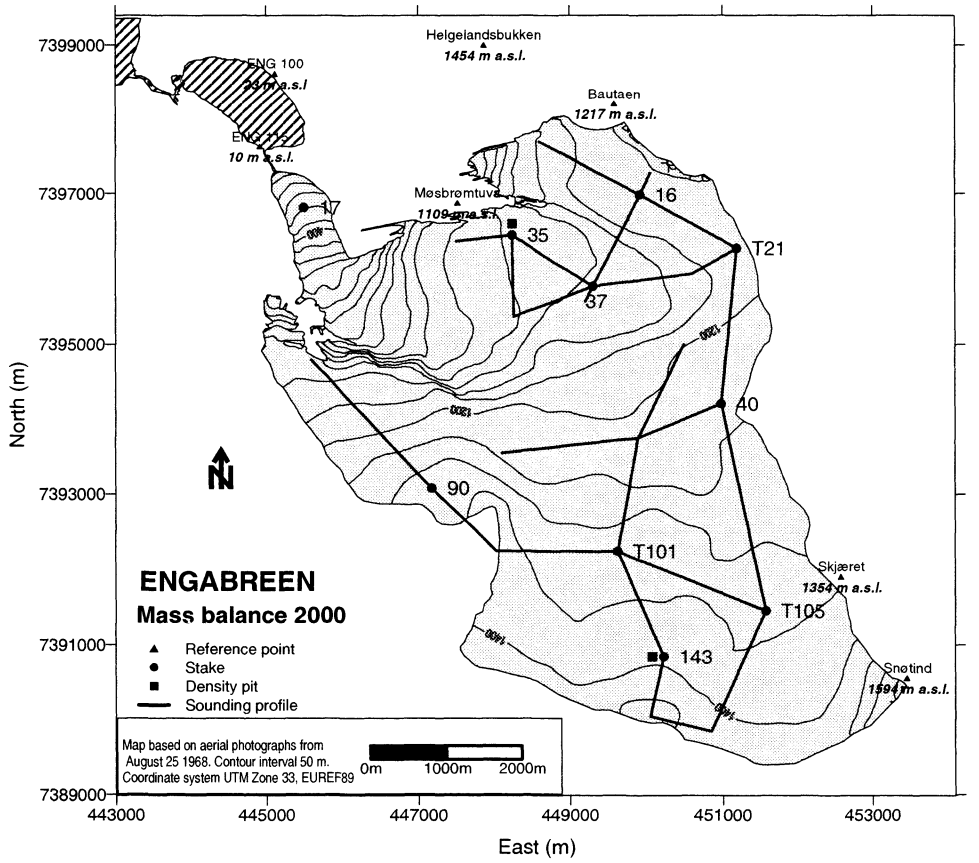


Figure 13-1

Location of stakes, density pits and sounding profiles at Engabreen in 2000.

13.1 Mass balance 2000

Field work

Winter accumulation measurements were carried out between 23rd and 27th May, as well as a provisional measurement on 12th April. The locations of stakes and towers, density pit, core samples and sounding profiles are shown in Figure 13-1. The calculation of the winter balance is based on:

- Direct measurements at stake 17 (300 m a.s.l.), and towers T21 (1185 m a.s.l.), T101 (1320 m a.s.l.) and T105 (1345 m a.s.l.) giving 0.0, 5.7, 7.4 and 7.6 m of snow. 1.4 m of ice had melted at stake 17 since 23rd September 1999.

- Core samples taken on 12th April at 1060 m a.s.l. (stake 37), 1195 m a.s.l. (stake 16), and 1245 m a.s.l. (stake 40) giving 6.1, 6.1 and 7.3 m of snow, respectively. In May, snow depth at these stakes was recorded as 5.6, 6.0 and 6.9 metres.
- Core samples collected between 23rd and 27th May 1015 m a.s.l. (stake 35), 1330 m a.s.l. (stake 90) and 1400 m a.s.l. (stake 143) gave 3.7, 6.1 and 7.3 m of snow.
- Snow density was measured to a depth of 3.5 m at 1015 m a.s.l. (stake 35) and to 7.2 m at 1400 m a.s.l. (stake 143). Mean snow densities were 0.48 and 0.49 g/cm^3.
- 142 snow depth soundings along approximately 35 km of profiles. 21 soundings along the profiles from tower T105 to stake 40 to tower T21 were carried out on 12th April. These observations were corrected for changes between 12th April and 25th May as observed at T105, stake 40 and T21. The snow depth was between 6 and 8 m in above 1200 m a.s.l., and 4 to 6 m between 950 and 1200 m a.s.l.
- The transient snow line (TSL) on 25th May in the icefall was at about 500 m a.s.l.

Summer ablation measurements were carried out between 20th and 22nd September. At that time no fresh snow had fallen on the glacier. The TSL was observed at about 1000 m a.s.l. The net balance was observed at 10 positions in the elevation range of 300 to 1400 m a.s.l. About 5 m of snow was left at stakes 143, T105 and T101, and about 2 m at the stakes at 1060 m a.s.l. All the snow and 0.25 m firn had melted at the stake at 1015 m a.s.l. At the glacier tongue (300 m a.s.l.) 6.55 m of ice had melted during the summer. During the course of the summer 2-4 m of snow melted at the stakes on the upper plateau. At T23 on Storglombreen glacier (1235 m a.s.l.) the mean snow density of the top 2.0 m was 0.59 g/cm^3. At this location 3.5 m of snow remained from the previous winter.

Results

The mass balance is calculated using the traditional method (also called the stratigraphic method), which reports the balance between two successive "summer surfaces". The calculations are performed using a map from 1968 and drainage divides calculated from bottom topography and ice thickness (Kennett & Elvehøy, 1995).

Winter balance

The calculations of winter balance are based on point measurements of snow depth (towers, probing and core drillings) and on measurement of snow density at two locations (see Fig. 13-1).

Density profiles were modelled from the snow density measured 1400 m a.s.l. and 1015 m a.s.l. Using these models, the mean snow density for the upper 5 m of snow was 0.48 g/cm^3 (1015 m a.s.l.) and 0.49 g/cm^3 (1400 m a.s.l.). The model for 1015 m altitude is used in the areas below 1200 m a.s.l., whilst the model for 1400 m altitude is used in the areas above 1200 m a.s.l.

The winter balance calculations are performed using two different methods. In the first method, specific winter balance calculated from the altitudinal distribution of the winter balance. Point values of the snow water equivalent (SWE) is plotted against altitude in a diagram. Based on visual evaluation a curve is drawn and a mean value for each 100 m height interval is estimated (Fig. 13-3). No snow depth observations were carried out below 950 m a.s.l. and the winter balance is interpolated based on the observed TSL at 500 m a.s.l. and the observed negative winter balance at stake 17 (300 m a.s.l.). Based on this altitudinal distribution curve, the winter balance was 2.8 ±0.2 m w.eqv., which gives a volume of 105 ±8 mill. m^3 of water. This is 93 % of the mean value for the period from 1970-1999 (3.02 m w.eqv.), and 88 % of the mean value for the 5-year period 1995-1999.

The second method calculates the winter balance using a gridding method based on the spatial distribution of the snow depth measurements (Fig. 13-1). Kriging-interpolation is used, and the result based on this method, which is a control of the traditional method, shows a winter balance of 3.0 m w.eqv. The results from the two methods are thus comparable. A map illustrating the snow distribution is shown in Figure 13-2.

Summer balance

The summer balance was measured and calculated directly at nine stakes and towers between 300 and 1400 m a.s.l. Based on measurements and estimates of stakes and snow density the summer balance was calculated to be -1.3 ±0.2 m w.eqv., which is equal to a volume of -48 $\pm 8 \times 10^6$ m^3 water. The result is 56 % of the average for the period 1962-1999, and 54 % of the average for the 5-year period 1995-1999. This is the second largest summer balance observed, second to the −1.2 m w.eqv. observed in 1997.

Net balance

The net balance of Engabreen for 2000 was calculated as +1.5 ±0.3 m w.eqv., which means a surplus volume of 57 ±15 mill. m^3 water. The mean value for the period 1970-1999 is +0.76 m w.eqv., and for the period 1995-1999 it is +0.79 m w.eqv. The diagram in Figure 13-3 indicates that the equilibrium line altitude (ELA) was 970 m a.s.l., which is in accordance with the observed TSL at about 1000 m a.s.l. Eighty-nine % of the glacier area (AAR) is located above the ELA.

The mass balance results are shown in Table 13-1 and Figure 13-3. Historic mass balance results since 1970 are presented in Figure 13-4.

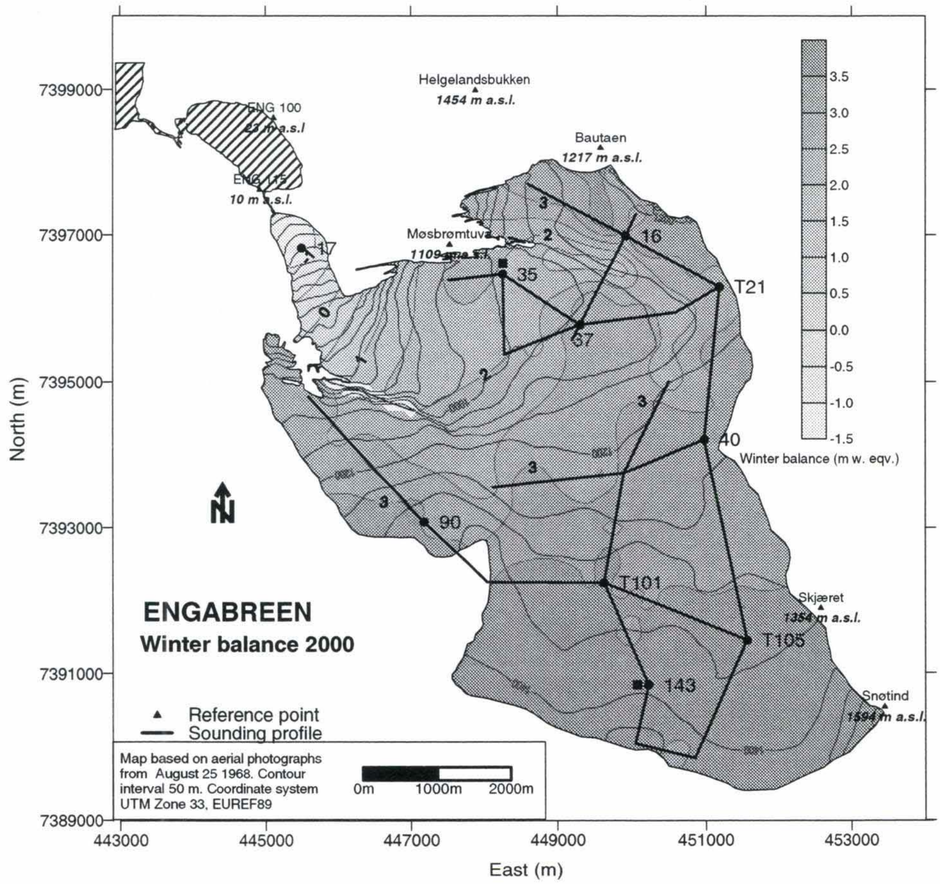


Figure 13-2

The winter balance of Engabreen interpolated from 133 snow depth observations and 10 core drillings as observed on 25th May 2000.

Mass balance Engabreen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km²)	Winter balance Measured 25th May 2000 Specific (m w.eq.)	Winter balance Volume (10^6 m³)	Summer balance Measured 21st Sep 2000 Specific (m w.eq.)	Summer balance Volume (10^6 m³)	Net balance Summer surfaces 1999 - 2000 Specific (m w.eq.)	Net balance Volume (10^6 m³)
1500 - 1594	0,12	3,00	0,4	-0,50	-0,1	2,50	0,3
1400 - 1500	2,51	3,20	8,0	-0,50	-1,3	2,70	6,8
1300 - 1400	9,35	3,47	32,4	-0,70	-6,5	2,77	25,9
1200 - 1300	8,55	3,07	26,2	-0,90	-7,7	2,17	18,6
1100 - 1200	7,60	2,82	21,4	-1,20	-9,1	1,62	12,3
1000 - 1100	4,66	2,33	10,9	-1,60	-7,5	0,73	3,4
900 - 1000	2,46	1,90	4,7	-2,10	-5,2	-0,20	-0,5
800 - 900	0,94	1,40	1,3	-2,60	-2,4	-1,20	-1,1
700 - 800	0,50	0,90	0,5	-3,20	-1,6	-2,30	-1,2
600 - 700	0,37	0,40	0,1	-3,80	-1,4	-3,40	-1,3
500 - 600	0,27	-0,10	0,0	-4,40	-1,2	-4,50	-1,2
400 - 500	0,21	-0,55	-0,1	-5,00	-1,1	-5,55	-1,2
300 - 400	0,17	-1,05	-0,2	-5,60	-1,0	-6,65	-1,1
200 - 300	0,22	-1,50	-0,3	-6,40	-1,4	-7,90	-1,7
40 - 200	0,10	-2,10	-0,2	-7,70	-0,8	-9,80	-1,0
40 - 1594	38,0	2,76	105,1	-1,27	-48,1	1,50	57,0

Table 13-1

Specific and volume winter, summer, and net balance calculated for 100 m elevation intervals at Engabreen in 2000.

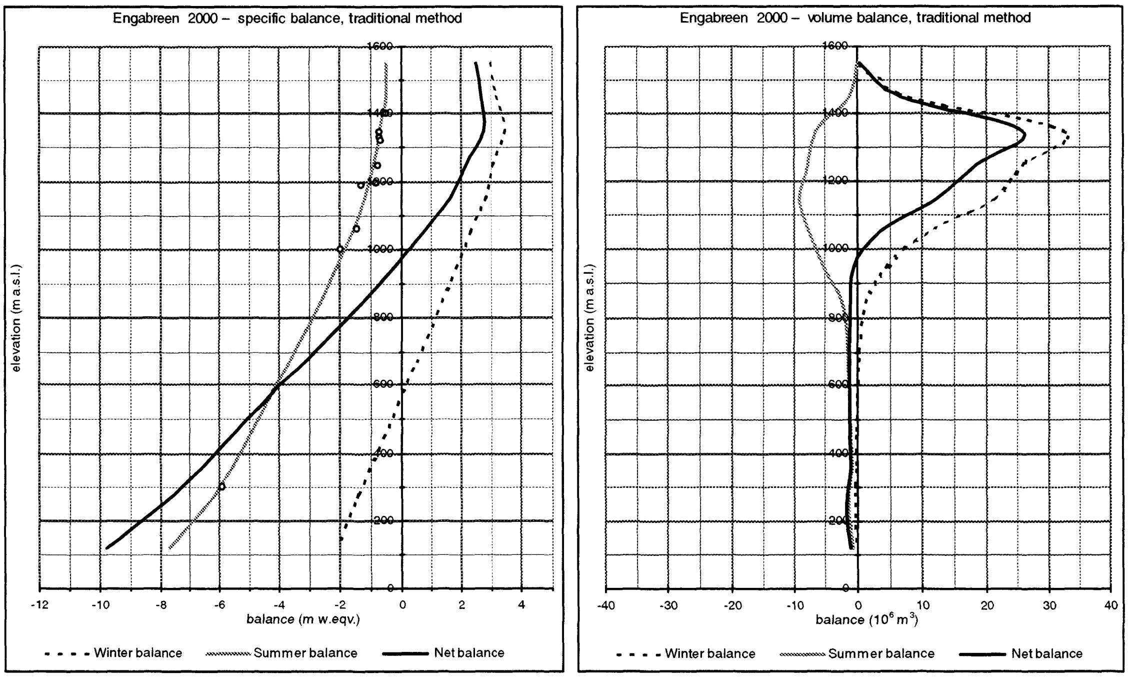


Figure 13-3

Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2000. Summer balance at stakes/towers is shown as circles (☞). The net balance curve intersects the y-axis and defines the ELA as 970 m a.s.l. Thus the AAR was 89 %.

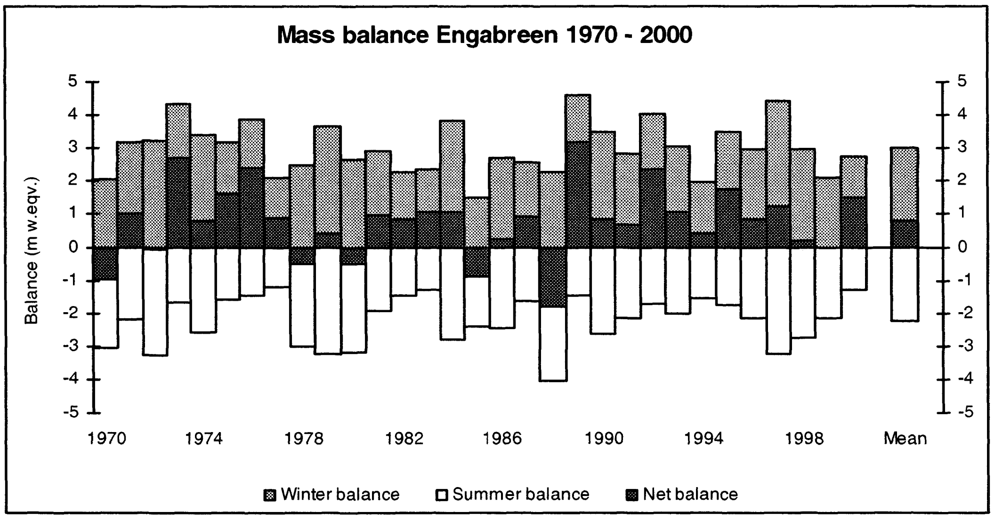


Figure 13-4

Mass balance at Engabreen during the period 1970-2000. The accumulated surplus amounts to 24 m water equivalents.

13.2 Front position change

Changes in front position are observed from fixed points along a line which is aligned along the flow direction of the glacier at the middle of the glacier front, as well as where the river exits the glacier. The glacier front melted so that the front position was 10 m further back on 21st September 2000 compared with its position on 23rd September 1999. However, since the current advance started in 1991, the glacier front has advanced a total of 190 m, and the terminus is now at the same position as in 1950. The terminus is now in contact with the delta where the river enters the lake.

13.3 Svartisen subglacial laboratory

Svartisen subglacial laboratory is a unique facility situated under Engabreen glacier. It allows direct access to the bed of the glacier for the purposes of measuring sub-glacial parameters and performing experiments on the ice.

Several load cells have been installed at the bed of the glacier for measuring pressure variations and examining the correlation of pressure with such parameters as sub-glacial discharge, precipitation at the surface etc. In 2000 there were six load cells installed, and these successfully recorded between 1st January and 27th April and between 8th June and 20th October.

No research activities took place in the laboratory in 2000, but there was a preliminary visit by Neal Iverson of Iowa State University and Tom Hooyer of Wisconsin Geological Survey, as well as two employees of NVE. The visit took place in late October and involved getting equipment ready for a large international project the following spring involving five different institutions, and assembling moraine material that could be used in an experiment to be performed then. Because of unusual conditions in the tunnel system, it was not possible to access the opening to the base of the glacier.

The first of what will be a series of biennial reports was released in 2000. This is Document 14 in NVE's document series and is entitled simply 'Svartisen Subglacial Laboratory'.

14 Storglombreen (Hallgeir Elvehøy)

Storglombreen (66°41'N, 14°00'E) is the largest outlet from the Svartisen icecap. It covers an area of 62.4 km^2 and drains the western Svartisen ice cap to Lake Storglomvatnet (Fig. 14-1). Most of its area is located between 900 and 1300 m a.s.l. Three outlet glaciers calves into the lake. Mass balance measurements were carried out during the four years from 1985 to 1988.

Lake Storglomvatnet is a reservoir for the Svartisen hydropower facility. The latest regulation of its outflow was completed in 1999. An assessment of the inflow to Storglomvatn reservoir showed that during the observation period 1985-1988 observations at Engabreen were not reliable as a proxy for the mass balance of Storglombreen (Engeset, 1999). Thus another 5-year observation programme, based on a reduced set of observation points, was initiated in 2000 (Fig. 14-1).

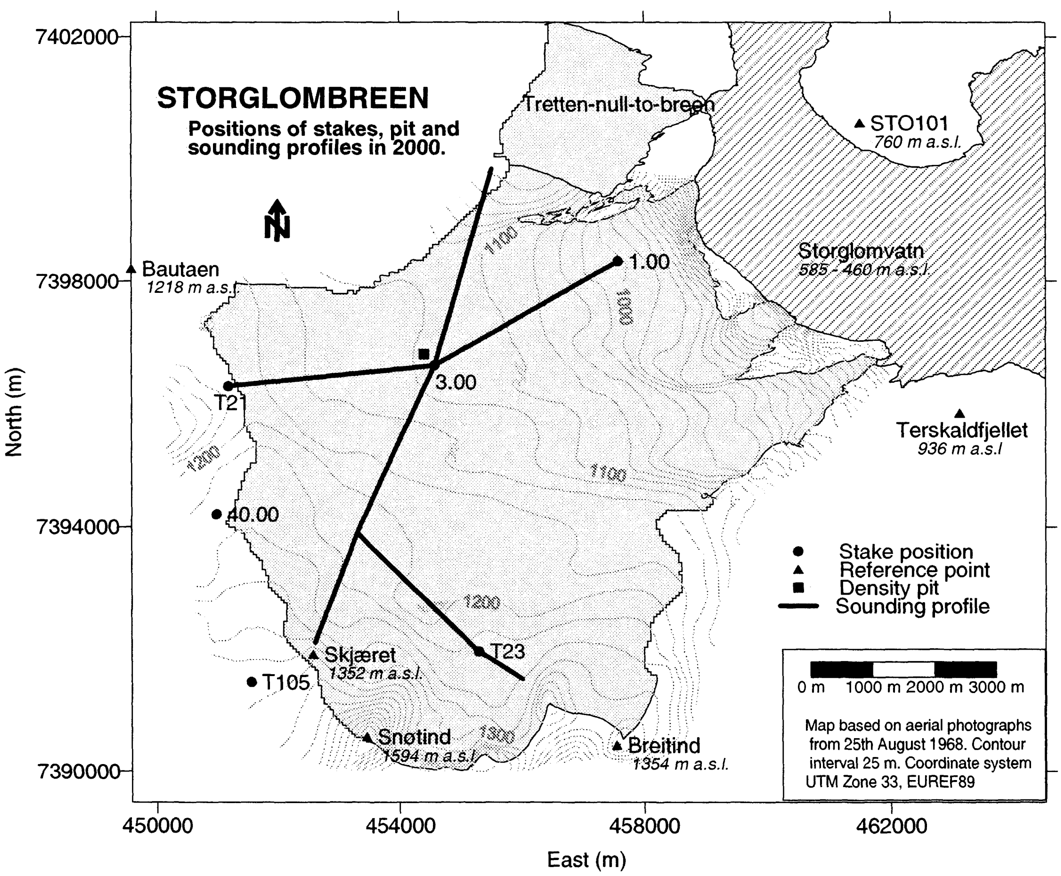


Figure 14-1

Location of stakes, density pit and sounding profiles at Storglombreen in 2000. The location of fixed points used for determining the front position is shown as STO101. Three stakes on Engabreen positioned close to Storglombreen are also used for calculation of the summer balance.

14.1 Mass balance 1985-1988 and a new observation network

Mass balance 1985-1988

During the period 1985-1988 an extensive snow depth network was used for the winter balance measurements, covering about 300 samples above 1000 m a.s.l. A snow density profile was collected from one point on Storglombreen (stake 3, Fig. 14.1) or Engabreen. Summer balance was observed at 5-10 stakes between 1000 and 1300 m a.s.l. Maps of winter and summer balance distributions were made based on these point measurements and values extrapolated for the areas below 1000 m a.s.l. Average values for each 100-m elevation interval were calculated using a planimeter on the map. The contribution of calving and avalanches from the terminus was estimated roughly without considering the changes in front position, ice thickness and ice velocity at the terminus. Ice calving contributed 3 - 6 % of the total summer balance in the 1985-1988 period.

A map from 1968 was used for calculation of the mass balance. The elevation-area distribution used for the period 1985-1988 was based on drainage boundaries drawn from the map of 1968. The drainage divides for Storglombreen has been calculated from bottom topography, and ice thickness (Kennett & Elvehøy, 1995). This analysis gave an area of 62.4 km^2 for Storglombreen, which is 5 % more than the estimate of 59.2 km^2 based on the 1968 maps. The difference translated into specific summer and winter mass balance is about +1 %, which is much lower than the assumed uncertainty of the mass balance observations.

Simplified observation network 2000

Snow depth and stake observations from the period 1985-1988 were assessed. A representative set of depth sounding profiles and stake positions was selected, and used as the basis for a reduced observation network (Fig. 14-1). The criteria applied for the selection of sounding profiles were that the profile was used in the period 1985-1988, and that the selected profiles are representative for all soundings and the estimated mean value for the entire glacier area (as compared to the winter balance maps). The selection of stake positions required that the selected stakes were used in the period 1985-1988 and represents the mean specific summer balance for the entire glacier. An additional requirement was that two people could carry out all observations (depth soundings, one vertical density profile, and 2-3 stakes) during one day of fieldwork.

Figure 14-2 shows a linear regression between mean water equivalent for all snow depth points along the profiles (which in 1985-1988 corresponded to those shown in Fig. 14-1), and specific winter balance for the entire glacier. Linear regression was performed between summer balance at stake 3 and specific summer balance for the entire glacier. The data used for the regression analysis is shown in Table 14-1.

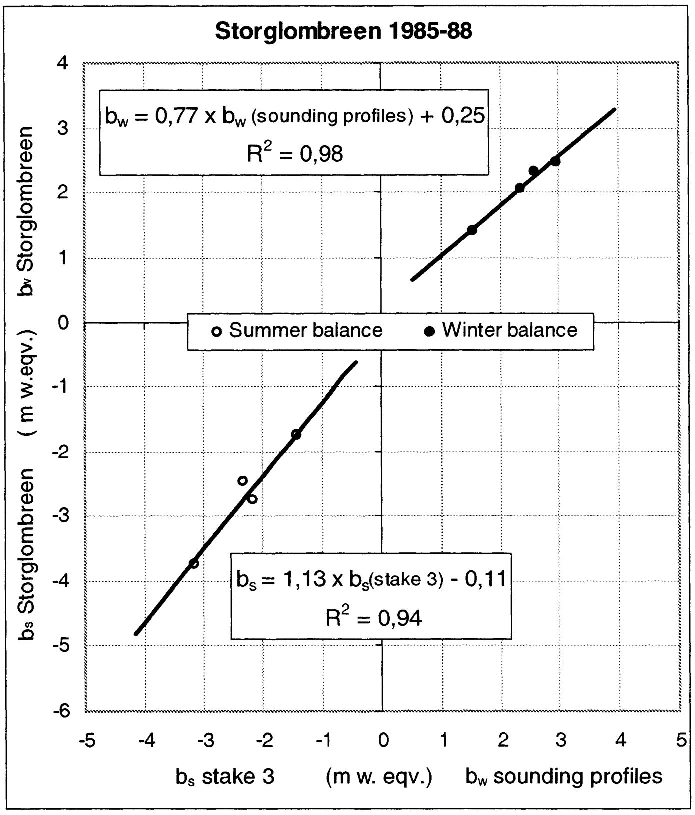


Figure 14-2

The diagram shows the relationship between winter and summer balance, calculated from balance maps (Y-axis), and from stake 3 and selected snow depth profiles (X-axis).

	b_w arithmetic average of all depth soundings	b_w arithmetic average of selected depth soundings, see Fig. 14-1	b_w winter balance map	b_s stake 3	b_s summer balance map
1985	1.54	1.53	1.40	-2.32	-2.46
1986	2.70	2.95	2.45	-2.16	-2.75
1987	2.52	2.60	2.32	-1.43	-1.75
1988	2.31	2.36	2.06	-3.16	-3.75
Average	2.27	2.36	2.06	-2.27	-2.68

Table 14-1

Data used to estimate winter- (b_w) and summer (b_s) balances for Storglombreen based on a reduced observation network. Winter balance is taken from the winter balance map, and summer balance from the summer balance map, calculated using a glacier area of 59.2 km^2. Calving and ice avalanching from the terminus (0.12 m w.eqv.) are not included in the summer balance.

14.2 Mass balance 2000

Field work

Winter accumulation measurements were carried out on 23rd and 24th May. The locations of stakes, density pit, core samples and sounding profiles are shown in Figure 14-1. The calculation of the winter balance is based on:

- Core samples taken at 1005 m a.s.l. (stake 1), 1125 m a.s.l. (stake 3), and 1235 m a.s.l. (tower T23) giving 3.8, 5.6, and 6.5 m of snow.
- Snow density measured to a depth of 5.3 m at 1125 m a.s.l. (stake 3). Mean snow density was 0.51 g/cm^3.
- 71 snow depth soundings along approximately 18 km of profiles in the area located between 1000 and 1300 m a.s.l. Most observations showed between 5 and 7 m of snow, and the summer surface was generally well defined.

Summer ablation measurements were carried out between 20th and 22nd September. At that time no fresh snow had fallen on the glacier. The transient snow line (TSL) was observed at about 1000 m a.s.l. The net balance was observed at three positions, at 1005, 1125 and 1235 m a.s.l. At T23 (1235 m a.s.l.) the mean snow density of the top 2.0 m was 0.59 g/cm^3. At this location 3.5 m of snow remained from the previous winter. At stake 1 and 3 about 0.4 and 2.6 m snow remained, respectively. During the course of the summer 3-3.5 m of snow had melted at these stakes.

Results

The mass balance is calculated using the traditional method (also called the stratigraphic method), which reports the balance between two successive "summer surfaces" (SS). The calculations are performed using a map from 1968 and drainage divides calculated from bottom topography and ice thickness (Kennett & Elvehøy, 1995).

The mass balance was also calculated using the regression equations established from the common observation period 1985-1988 (Fig. 14-2).

Winter balance

The calculations of winter balance are based on point measurements of snow depth (towers, probing and core drillings) and measurements of snow density at one location (Fig. 14-1). A water equivalent profile was modelled from the snow density measurements at stake 3. According to this model, the mean snow density for the upper 5 m of snow was 0.51 g/cm^3. This model is used to convert all snow depth observations to water equivalent values.

The specific winter balance is calculated from the altitudinal distribution of the winter balance. Point values of the snow water equivalent is plotted against altitude.
A representative curve is drawn based on the mean value in each 100-m elevation interval, the observed altitude of the transient snow line (about 1040 m a.s.l.) and the

summer balance calculated at stake 1.00 (1005 m a.s.l., b_s = -1.6 m w.eqv.) (Fig. 14-3). As snow depth was observed between 1000-1300 m a.s.l. only, the mean balance curve for the period 1985-1988 is used to guide the curve below 1000 m a.s.l. and above 1300 m a.s.l. Based on this method, the calculated winter balance was 2.6 ±0.2 m w.eqv., which corresponds to a volume of 170 mill. m^3 of water. The winter balance is shown in Figure 14-3 and Table 14-2.

The winter balance was calculated using the regression equation defined in Figure 14-2 also. The mean water equivalent for 71 points along the profile shown in Figure 14-1 was 2.98 m, which gives a specific winter balance for Storglombreen of 2.54 m. This implies that the calculated winter balance for 2000 is comparable to the winter balances calculated for 1985-88. The winter balance for 2000 is 123 % of the 1985-88 mean and the highest ever recorded at Storglombreen,.

Summer balance

The summer balance was measured and calculated directly at three positions (1005, 1125 and 1235 m a.s.l.) on Storglombreen. Stakes T21 (1190 m a.s.l.), 40-00 (1250 a.s.l.) and T105 (1345 m a.s.l.) on Engabreen are located very close to the ice divide (Fig. 14-1) and are considered to be representative for Storglombreen too. The summer balance curve was drawn based on these six point measurements with support of the mean balance curve for the period 1985-1988 (Fig. 14-3).

The contribution from calving and ice avalanches is estimated, as it was for the period 1985-1988. This contribution totals –7 mill. m^3 water, based on an estimated total terminus length of 1.6 km, a mean terminus height of 50 m and a glacier velocity of 100 m/a.

The total summer balance, including the calving contribution, totals –100 ±20 mill. m^3 water, which is equal to a specific balance of –1.6 ±0.3 m w.eqv. This is the lowest mass loss recorded, and is only 56 % of the average summer balance for the period 1985-1988.

The summer balance was also calculated with the regression equation shown in Figure 14-2. The summer balance at stake 3 was –1.3 m w.eqv, which gives a specific summer balance excluding calving for Storglombreen of –1.58 m w.eqv., and –1,70 m w.eqv. when calving is included. This implies that the calculated summer balance for 2000 is comparable to the summer balances calculated for 1985-88.

Net balance

The net balance of Storglombreen for 2000 was +1.1 ±0.3 m w.eqv., which is a surplus volume of 70 ±20 mill. m^3 water. The mean value for 1985-1989 was -0.75 m w.eqv. Figure 14-4 indicates that the equilibrium line altitude (ELA) was 1000 m a.s.l., which is marginally lower than the observed TSL at about 1040 m a.s.l. Based on the estimated ELA, the accumulation area ratio (AAR) is 86 %.

The mass balance results are shown in Table 14-2 and Figure 14-3. The results from 2000 are compared to mass balance results for the period 1985-1988 in Figure 14-4.

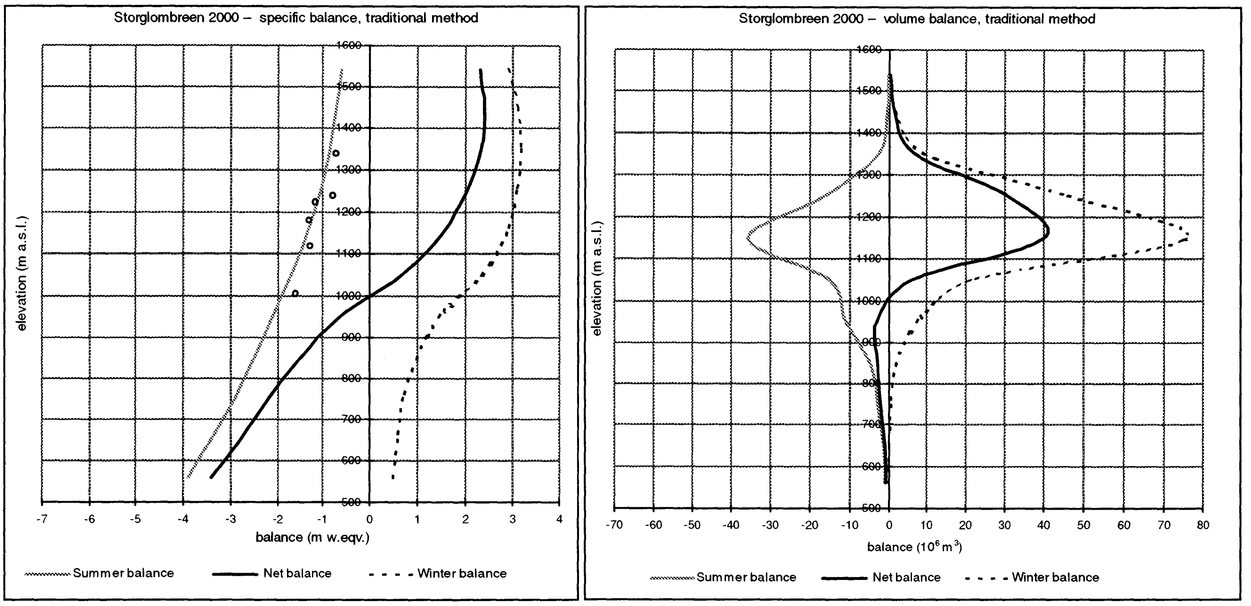


Figure 14-3

Mass (winter, summer and net) balance diagram showing specific balance (left) and volume balance (right) for Storglombreen in 2000. Summer balance at stakes/towers is shown as circles (☛).

Mass balance Storglombreen 1999/00 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 23rd May 2000 Specific (m w.eq.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 21st Sep 2000 Specific (m w.eq.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 1999 - 2000 Specific (m w.eq.)	Net balance Volume (10^6 m^3)
1500 - 1580	0,18	2,90	0,52	-0,60	-0,11	2,30	0,41
1400 - 1500	0,58	3,10	1,79	-0,70	-0,40	2,40	1,38
1300 - 1400	2,89	3,18	9,18	-0,85	-2,45	2,33	6,73
1200 - 1300	15,02	3,08	46,26	-1,05	-15,77	2,03	30,49
1100 - 1200	26,23	2,88	75,55	-1,36	-35,68	1,52	39,88
1000 - 1100	8,91	2,38	21,20	-1,70	-15,14	0,68	6,06
900 - 1000	5,16	1,48	7,64	-2,10	-10,85	-0,62	-3,20
800 - 900	1,91	1,00	1,91	-2,50	-4,77	-1,50	-2,86
700 - 800	0,95	0,70	0,66	-2,90	-2,75	-2,20	-2,08
600 - 700	0,38	0,60	0,23	-3,40	-1,28	-2,80	-1,06
520 - 600	0,22	0,50	0,11	-3,90	-0,87	-3,40	-0,76
Calving					-7,2		-7,2
520 - 1580	62,43	2,64	165,1	-1,56	-97,3	1,09	67,8

Table 14-2

Specific (left) and volume (right) winter, summer, and net balance calculated for 100 m elevation intervals at Storglombreen 2000.

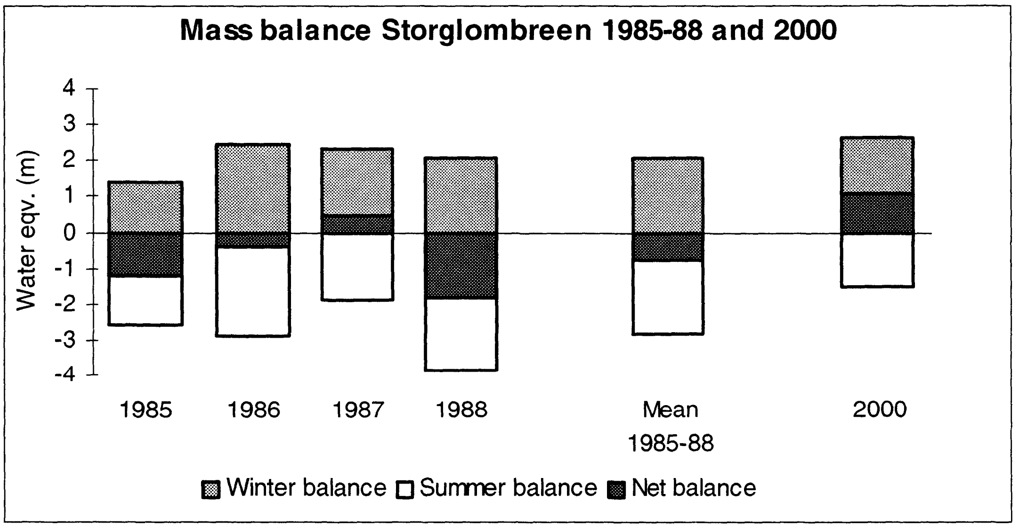


Figure 14-4

Mass balance at Storglombreen during the period 1985-1988 and 2000.

14.2 Front position change

Storglombreen has three distinct front segments (here named South, Middle and North Storglombreen) that calve into the Storglomvatnet reservoir (Fig 14-5). The reservoir has been modified several times, and before the most recent changes in 1989, Middle and North Storglombreen calved into the reservoir. Observation of the front position changes began in autumn 2000, and will be carried out in order to document changes associated with changes in water level of the reservoir. The front of the calving outlet from glacier Tretten-null-to-breen is observed also (Fig. 14-5).

Fixed point

The terminus of South Storglombreen reaches the lake only when the water level is at its highest at 585 m a.s.l. Therefore it was excluded from the observation programme. The other three outlets could be measured using one fixed point, STO101 (Fig. 14-5).

STO101 was positioned using three Ashtech Z-Surveyor two-phase GPS receivers. The GPS receivers were used to determine vectors from two fixed points at Bautaen and Terskaldfjellet (Fig. 14-1). Each vector was GPS-logged for 87 minutes, which gave an error of 0.07 m horizontally and 0.11 m vertically.

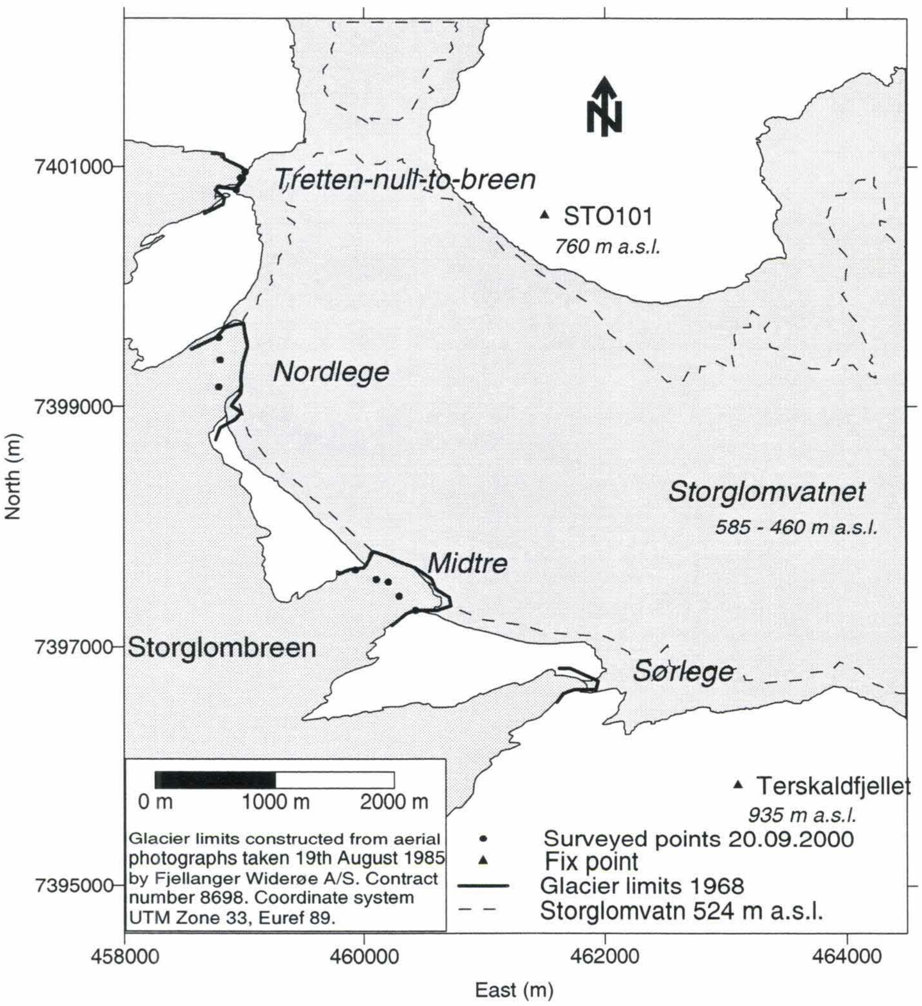


Figure 14-5

Front position changes of the termines that calve into the Storglomvatnet reservoir.

Front position observations 2000

The terminus position was measured on 20th September from STO101 using Terskaldfjellet as a reference point (Fig. 14-5). A Geodimeter total station and 8 reflectors located in the helicopter window were used. The terminus was positioned by observing the reflectors as the helicopter touched the ice edge, if possible, along the front perimeter. The accuracy of this method depends on the geometry of the glacier front and the flight conditions, and such measurements may therefore be relatively uncertain. Horizontal uncertainty of individual points is estimated to be less than ±2 m, while vertical uncertainty is much less when the helicopter touches the ground. Figure 14-5 shows the observations, and the observed terminus position in 1985 and 1968. At the time of the field visit, the reservoir was at its highest level, 585 m a.s.l.

Tretten-null-to-breen

The 200 m long terminus was defined by measuring three points. There are only small changes in front position between 1968, 1985 and 2000. The glacier terminated on dry land in 1968 and 1985. The glacier tongue narrowed in this period, which suggests a negative volume change. The front widened and retreated about 25 m between 1985 and 2000. The glacier most probably has had a mass surplus, but the front has retreated due to calving caused by the regulation of the reservoir.

North Storglombreen

The 400 m long terminus was defined by measuring three points. Little change has been recorded between 1968 and 1985, but the front became narrower during this period, which suggests a negative volume change. The front retreated about 200 m between 1985 and 200, and the part of the front that terminates in the lake became much narrower. The glacier has become much thinner on the north side, which may be a dynamic response to an increase in the water level of the reservoir.

Middle Storglombreen

The terminus was defined by measuring five points. The three southern points define the width of the glacier in water (350 m), while the northern part terminates on ground. Little change was been recorded between 1968 and 1985, but the front retreated about 300 m between 1985 and 2000.

South Storglombreen

The terminus was located just at the water, but no precise measurements were made. Before the last modification of the reservoir capacity, this part of the glacier terminated on ground. Between 1968 and 1985 the glacier retreated 90 m indicating a negative volume change for this period. Between 1985 and 2000 the glacier retreated another 80 m, which may be caused by the increased water level in the reservoir.

15 Langfjordjøkelen (Bjarne Kjøllmoen)

Langfjordjøkelen (70°10'N, 21°45'E) is a plateau glacier situated on the border of Troms and Finnmark counties, approx. 60 km northwest of Alta. It has an area of about 8.4 km^2 (1994), and of this 3.7 km^2 drains eastward to the Andrevann lake (Fig. 15-1). The investigations are performed on this east facing part, ranging from 280 to 1050 m a.s.l.

The glaciological investigations in 2000 include mass balance, change in front position and air temperature measurements. Langfjordjøkelen has been the subject of mass balance measurements since 1989 except during 1994 and 1995. The winter and summer balances for these two years are estimated based on meteorological observations (Kjøllmoen 1999).

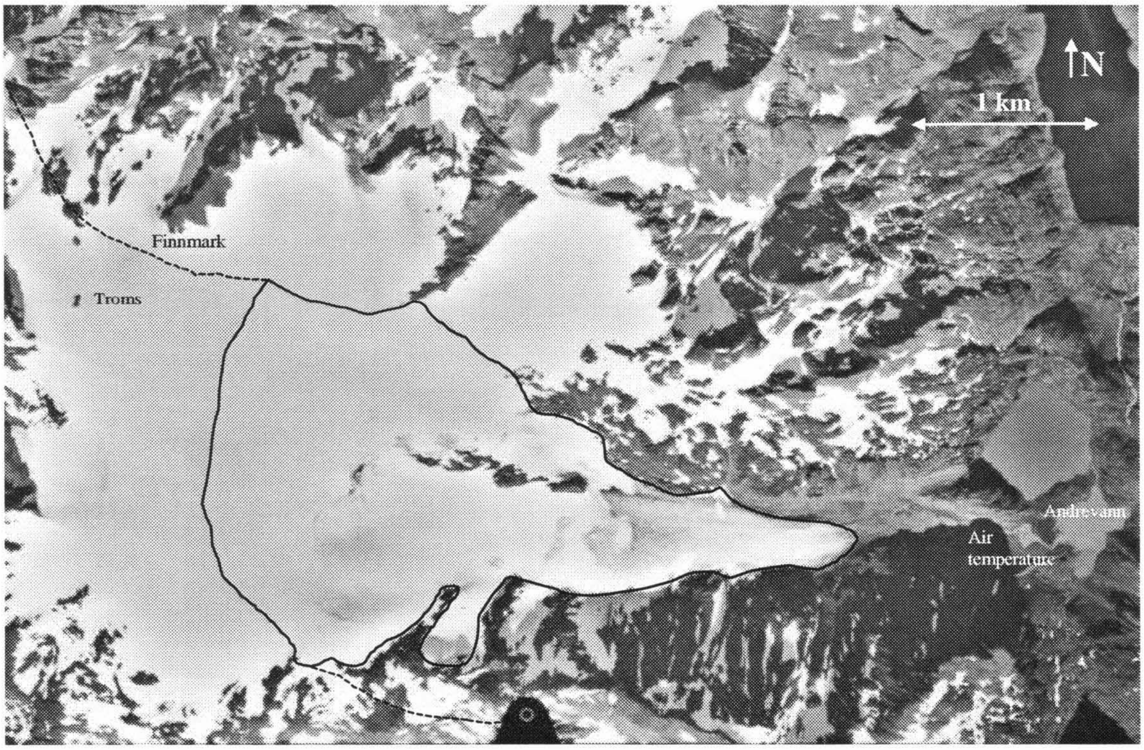


Figure 15-1

The mass balance measurements are performed at the east-facing outlet, which drains to Andrevann lake (255 m a.s.l.). A station for measuring air temperature measurings is located between the glacier terminus and the inlet of Andrevann. The solid line roughly indicates the drainage basin of Langfjordjøkelen.
Photo: Fotonor AS 1994 (Contract No. 94168).

15.1 Mass balance 2000

Field work

The accumulation was measured on 23rd May and the calculation of winter balance is based on (Fig. 15-2):

- Direct measurement of stake 10 (475 m a.s.l.) showing a snow depth of 3.6 m. It was also possible to correlate between substitute stakes and stakes that emerged by melting during the summer in the positions 20 (675 m a.s.l.), 25 (745 m a.s.l.), 30 (895 m a.s.l.) and 40 (1050 m a.s.l.). The corresponding snow depths were 4.4, 5.1, 4.7 and 5.7 m.
- Core samples at 675 (4.7 m snow), 745 (4.9 m), 895 (4.7 m) and 1050 m a.s.l. (5.6 m).
- 85 snow depth soundings along about 12 km of profiles between 300 and 1050 m a.s.l. The summer surface was distinct over the whole glacier surface. The snow depth increased from ca. 3 m at the tongue to about 6 m at higher elevation.
- Snow density was measured down to 4.4 m depth (SS at 4.7 m) at stake 30 (895 m a.s.l.).

The locations of stakes, density pit, core samples and sounding profiles are shown in Figure 15-2.

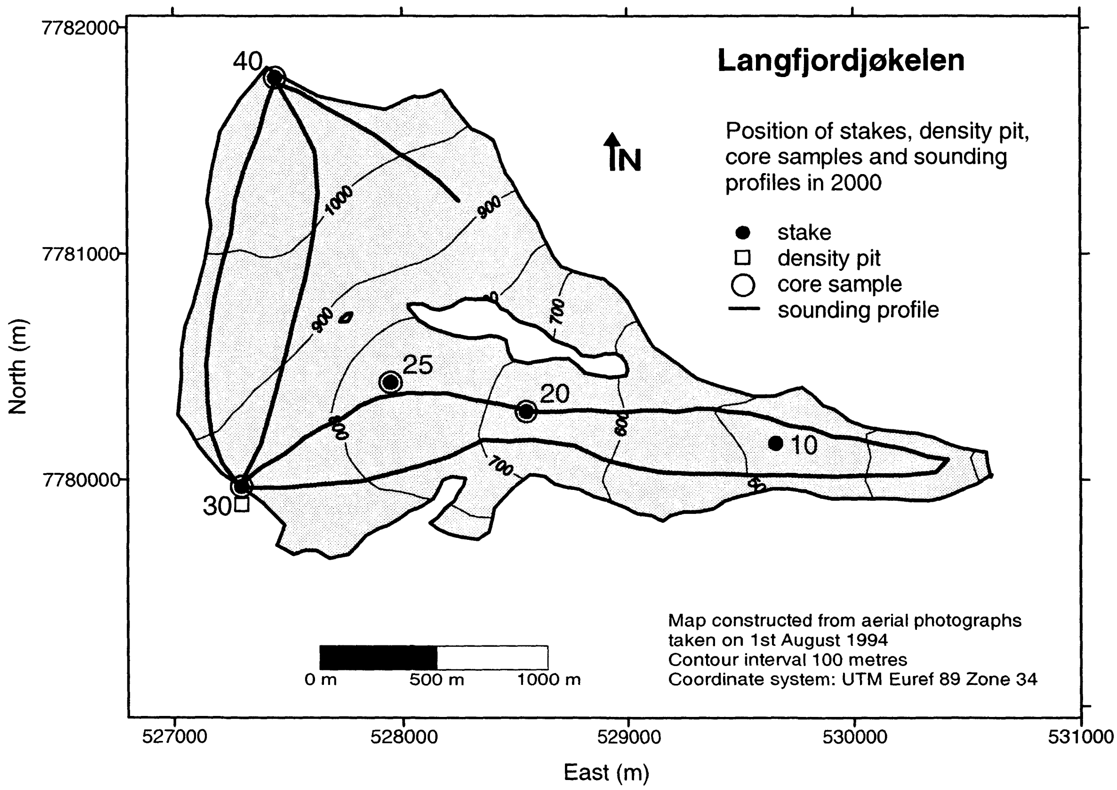


Figure 15-2

Locations of stakes, sounding profiles, core samples and density pit at Langfjordjøkelen in 2000.

Ablation was measured on 11th October. The net balance was measured directly at stakes in five locations between 475 and 1050 m a.s.l. The net melting at 700 m altitude since autumn 1999 was about 1 m of ice. The snow line was at around 900 m altitude, and there was nearly 1 m snow remaining in the upper parts. No fresh snow had fallen.

Results

The mass balance is calculated using the traditional method, which means the balance between two successive "summer surfaces". The calculations are based on a glacier map from 1994.

Winter balance

The calculations of winter balance are based on several point measurements of snow depth (stakes, probings and core drillings) and on one snow density measurement.

A density profile was modelled from the snow density measurement at 895 m altitude. The mean snow density of 4.7 m snow was 0.50 g/cm^3.

The winter balance calculations are performed using two different methods. First, the winter balance is estimated by plotting the measurements (water equivalents) in a diagram (Fig. 15-4). Based on a visual evaluation a curve was drawn and a mean value for each 100 m height interval was estimated. The calculations show a winter balance of 2.5 ±0.2 m w.eqv., corresponding to a water volume of 9 ±1 mill. m^3. The result is 113 % of the mean value for the period 1989-99 (including 1994 and 1995).

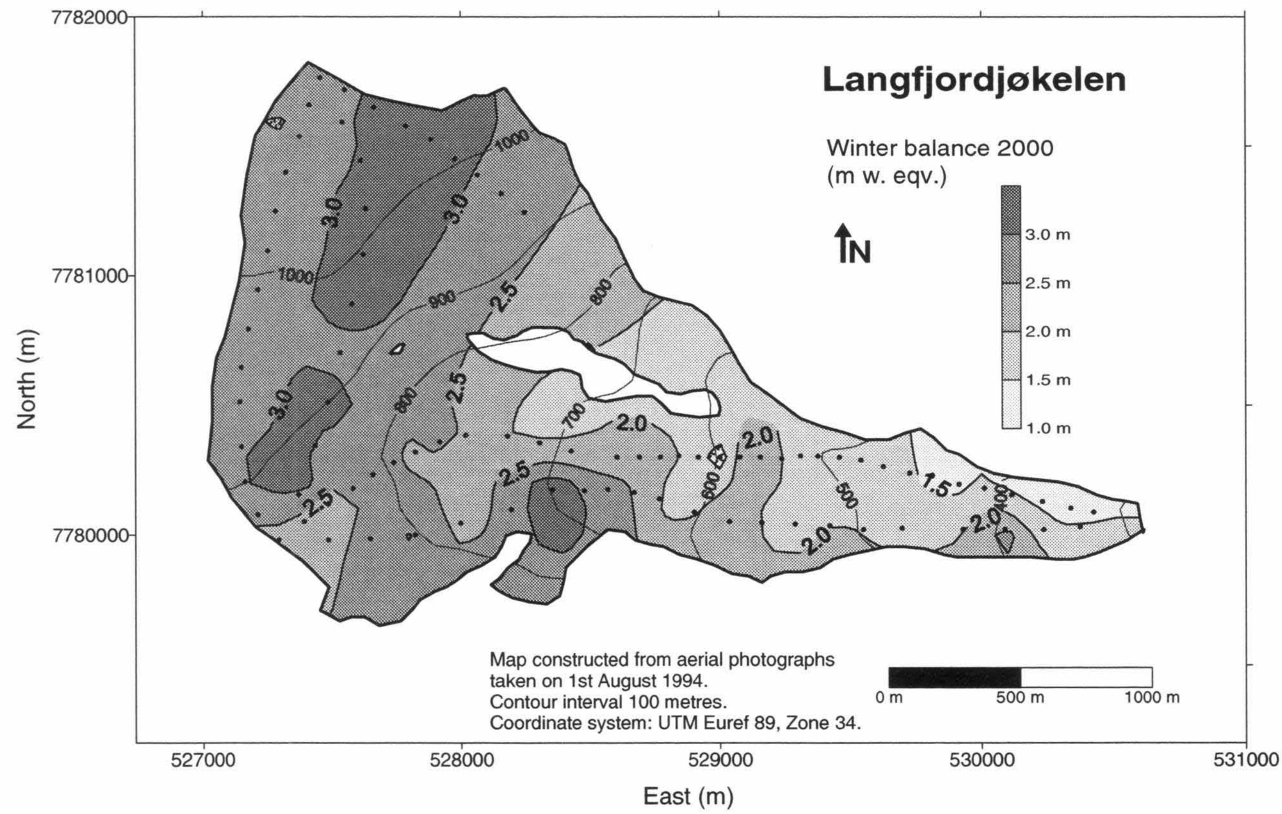


Figure 15-3

Winter balance at Langfjordjøkelen in 2000 interpolated from 85 snow depth measurements (•).

The winter balance is also calculated using a gridding method based on the spatial distribution of the snow depth measurements (15-3). Water equivalents for each cell in a 100 x 100 m grid are calculated and summarised. This calculation gives the same result as the traditional method, 2.5 m w.eqv.

Summer balance

The density of the remaining snow is empirically estimated as 0.60 g/cm^3. The density of melted firn is assumed to be 0.70 g/cm^3, whilst the density of ice that since melted is 0.90 g/cm^3.

The summer balance was measured and calculated at five stakes, and increases from -2.4 m w.eqv. in the upper parts of the glacier (1050 m a.s.l.) to -4.6 m down on the tongue (475 moh.). Based on estimated density and stake measurements, the summer balance was calculated to be -3.1 ±0.3 m w.eqv., which is -11 ±1 mill. m^3 of water. The result is 122 % of the average for 1989-99.

Net balance

Hence, the net balance at Langfjordjøkelen for 2000 was -0.6 ±0.4 m w.eqv., which means a deficit of 2 ±1 mill. m^3 of water (Tab. 15-1). Figure 15-4 indicates that the equilibrium line altitude (ELA) was 860 m a.s.l., which is about 130 m higher than during a year when the glacier is in balance. The Accumulation Area Ratio (AAR) was 44 %.

Since the mass balance measurements started in 1989 there have been only two years with a slight positive net balance (1992 and 1993, besides a modelled surplus in 1995), (Fig. 15-5). The glacier was almost in balance during two separate years (1991 and 1996), whilst a negative balance occured in six separate years (besides a modelled deficit in 1994). The mean net balance for the period 1989-1999 (modelled values included) is -0.33 m w.eqv. The accumulated negative net balance since 1989 is about 4 m w.eqv., corresponding to about 15 mill. m^3 of water (Fig. 15-5).

Mass balance Langfjordjøkelen 1999/00 – traditional method

		Winter balance Measured 23rd May 2000		Summer balance Measured 11th Oct 2000		Net balance Summer surfaces 1999 - 2000	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1000 - 1050	0,55	2,95	1,6	-2,35	-1,3	0,60	0,3
900 - 1000	0,81	2,85	2,3	-2,45	-2,0	0,40	0,3
800 - 900	0,61	2,65	1,6	-2,70	-1,6	-0,05	0,0
700 - 800	0,56	2,45	1,4	-3,00	-1,7	-0,55	-0,3
600 - 700	0,39	2,25	0,9	-3,50	-1,4	-1,25	-0,5
500 - 600	0,35	2,05	0,7	-4,10	-1,4	-2,05	-0,7
400 - 500	0,25	1,80	0,5	-4,80	-1,2	-3,00	-0,8
280 - 400	0,14	1,50	0,2	-5,70	-0,8	-4,20	-0,6
280 - 1050	**3,65**	**2,51**	**9,2**	**-3,12**	**-11,4**	**-0,61**	**-2,2**

Table 15-1

Winter, summer and net balance for Langfjordjøkelen in 2000. Mean values for the period 1989-99 (modelled values for 1994 and 1995 included) are b_w=2,23 m, b_s=-2,55 m and b_n=-0,33 m w.eqv.

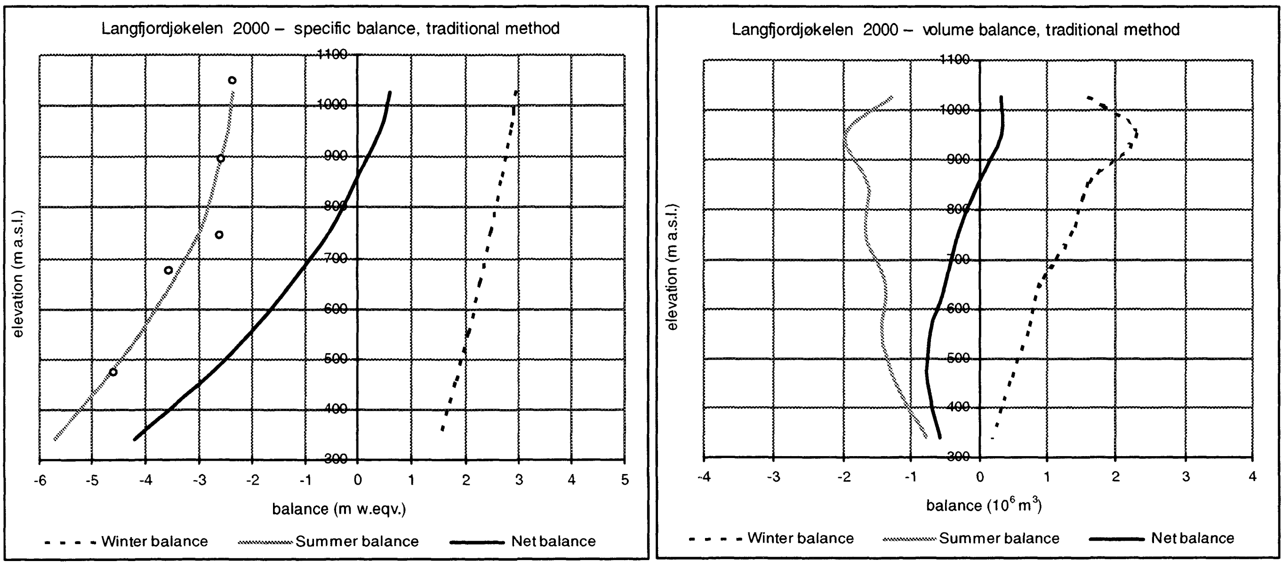


Figure 15-4

Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2000. Summer balance at five stakes is shown (○). The net balance curve intersects the y-axis and defines the ELA to 860 m a.s.l. Accordingly the AAR was 44 %.

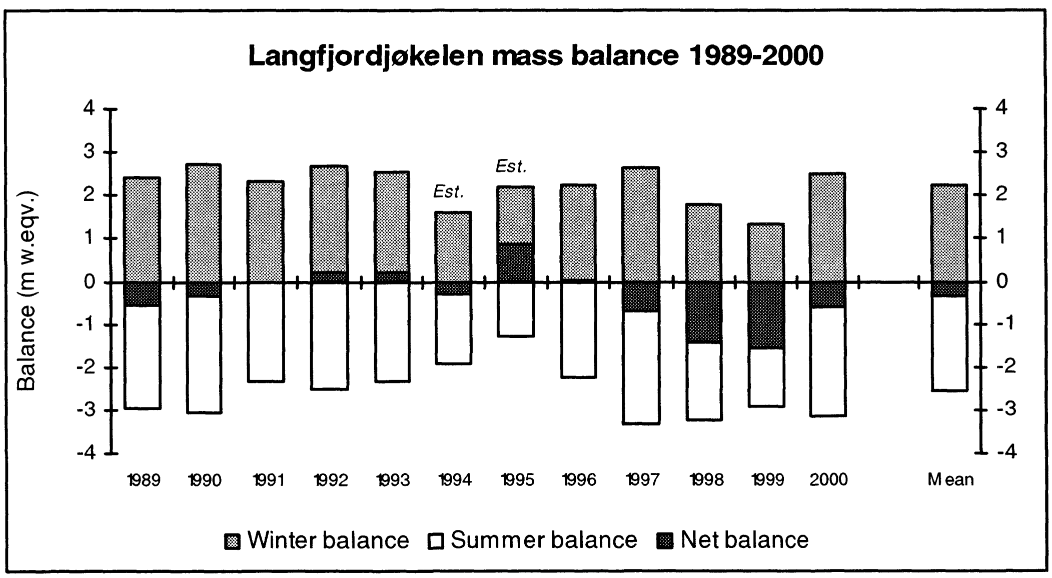


Figure 15-5

Mass balance at Langfjordjøkelen during the period 1989-2000. The accumulated deficit amounts to 4.2 m water equivalents.

15.2 Front position change

Studies of older maps and air photos show that the eastfacing outlet of Langfjordjøkelen has receded about 750 m since 1966 (Kjøllmoen 2000). The mean annual retreat during this period was 23 metres per year.

Annual measurements of the change in front position were initiated in 1998. The measurements are performed using traditional methods. The distance from the glacier terminus to marked fix points is measured using measuring tape. To achieve comparable results the measurements are always performed in the autumn.

The measurements in autumn 1998, 1999 and 2000 show continued retreat of the glacier front. During the latest period (25th September 1999 to 11th October 2000) the frontal retreat was 12 m, and since 1st October 1998 the accumulated recession is about 50 metres.

15.3 Air temperature

A station for automatically recording air temperature was initiated in August 1997. The recording station (No. 211.4, 270 m a.s.l.) is located by the glacier stream between the glacier terminus and Andrevann (Fig. 15-1).

Recorded air temperature data from Langfjordjøkelen for the period 1998-2000 are presented in Table 15-2. The results are compared with corresponding measurements from Nordstraum weather station (No. 92350, 6 m a.s.l.) in Kvænangen (ca. 35 km south of Langfjordjøkelen), operated by the Norwegian Meteorological Institute. The values in the table give the daily mean air temperature for the "summer season" (defined as 1st June to 30th September).

Daily mean values 1st June - 30th September ("Summer season")			
Year	Langfjordjøkelen (°C)	Nordstraum (°C)	Lapse rate La./No. (°C/100 m)
1998	5,9	10,7	1,80
1999	[1] 3,5	10,6	2,67
2000	[2] 6,8	10,3	1,30
Mean 1998-2000	5,4	10,5	1,93
Mean 1966-1999	-	10,1	-

1) Due to technical problems the value for 1999 is probably erroneous.

2) Data is extrapolated from 1st June to 12th July 2000.

Table 15-2

Mean air temperature at Langfjordjøkelen (ca. 270 m a.s.l.) and the Weather station Nordstraum (6 m a.s.l.) in the "Summer season" (1stJune – 30thSeptember) for the years 1998, 1999 and 2000. Mean values for 1998-2000 are shown for both stations and the average for 1966-99 is shown for Nordstraum. The lapse rates between the two stations are also shown.

Due to technical problems with the measuring instruments the results for 1999 and possibly 1998 at Langfjordjøkelen are probably erroneous. The technical failure was repaired in November 1999, and accordingly the result for 2000 is "correct".

16 Volume change

(Liss M. Andreassen and Hallgeir Elvehøy)

NVE has acquired vertical aerial photographs of glaciers in Norway for several decades. Detailed maps or digital terrain models (DTMs) have been made of selected glaciers from the aerial photographs. Multiple models of a glacier have been used to calculate changes in glacier volume and area for the interval between mappings. Analyses and results from six different glaciers in Norway are presented in this chapter.

16.1 Methods

The geodetic (also called cartographic) method calculates total volume change by comparison of topographic maps from different years. The data processing involves construction of digital terrain models (DTM) from the topographic data in a Geographical Information System (GIS). The thickness change is calculated by subtracting the DTMs. This gives a grid with the altitude differences in glacier ice, firn and partly snow. To compare this result with the volume change calculated from other methods, the altitude difference needs to be converted to the difference in water equivalents by multiplying the grid with the density of ice, usually 900 kg/m^3. We then assume that the glacier is in steady-state and that the density profile from the surface to the firn-ice transition is unchanged between mappings. The volume change values should also be modified for the additional melting that occurs from the date of photography to the end of the season when comparing with traditional mass balance measurements.

The accuracy of the final result is affected by several factors, such as errors in the original topographic data, data transformations and interpolations. One of the factors determining the accuracy of the topographic data is the photo scale of the verticals, a larger scale (lower flying height) giving a smaller standard error. Another important factor is the accuracy of the geodetic reference network. The quality of the aerial photos used is also crucial and especially the characteristics of the snow surface. Constructing contour lines over snow areas is always difficult due to the poor contrast, and the accuracy will be lower in those areas. Digitising analogue maps introduces horizontal random errors due to the accuracy of the digitiser and the condition of the analogue manuscript. GIS calculations introduce errors when converting data from local coordinate systems, generating DTMs and in the overlay operations.

16.2 Hardangerjøkulen

Hardangerjøkulen (61°30'N, 7°30'E) is the sixth largest (73 km^2) glacier in Norway and covers the altitudinal range between 1020 and 1865 m a.s.l. The glacier is on the main water divide between Hardangerfjorden and Hallingdal. Mass balance has been measured since 1963 on the southwestern part of the glacier, called Rembesdalskåka (17 km^2) (chapter 7).

Data material

Maps covering Hardangerjøkulen have been made from photographs taken on 31st August 1961 (Fjellanger Widerøe AS, contract 1230, scale 1:20 000) and 31st August 1995 (Fjellanger Widerøe AS, contract 11862, scale 1:40 000). The 1961-map was constructed analogously at scale 1:20 000 with 10 metres contour lines. The map has been digitised and transformed into EUREF89 by NVE. The 1995-map was constructed analogously with a digital encoder at a scale of 1:50 000 with 20 metre contour lines. The maps were constructed using different sets of ground control points. A comparison of point elevations did not reveal any systematic differences between the two maps. The uncertainty in the volume change is estimated as ±2 m water equivalent.

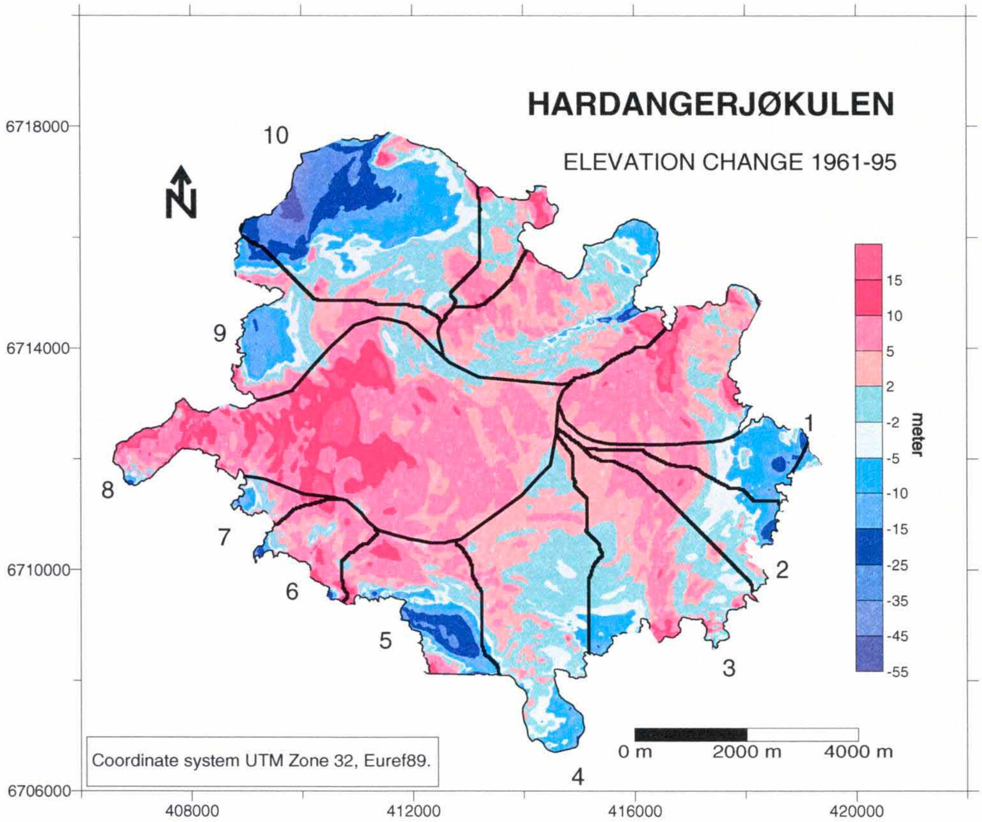


Figure 16-1

Volume change at Hardangerjøkulen between 1961 and 1995. Numbers refer to drainage areas given in Table 16-1.

Results

Hardangerjøkulen was divided into thirteen drainage areas based on surface topography and drainage divides outside the glacier (Fig. 16-1). Comparison of the glacier outlines from 1961 and 1995 show that all the outlet glaciers have retreated. The most significant retreat took place at Vestra Leirbottskåka (4) and Ramnabergbreen (10) which both receded approximately 400 metres. The total area of Hardangerjøkulen was reduced from 75.0 to 72.4 km^2.

The volume change between 1961 and 1995 in metres water equivalent is shown in Figure 16-1. Isdalskåka (5) and Ramnabergbreen (10) experienced a lowering of more than 25 metres and 45 metres, respectively. Specific volume change in each drainage area is listed in table 16-1. The largest growth has been at Rembesdalskåka (8) and Blåisen (13), while Ramnabergbreen (10) had the largest mass deficit. The total volume increase at Hardangerjøkulen is calculated to 80 mill. m^3 water corresponding to a water layer of 1.1 meter. At Rembesdalskåka (8) the calculated volume change of 7 m water equivalents is in good agreement with mass balance measurements between 1962 and 1995 which gave a cumulative net balance of 7.5 m water equivalents.

Nr	Drainage area	River	Area 1995 (km^2)	Specific volume change (m w. eqv.)
1	Torsteinsfonna	Holsno to Sysenvatn	2.3	-4
2	Part of glacier at Matskardnipa	Leiro to Sysenvatn	2.3	0
3	Austra Leirbottskåka	Leiro to Sysenvatn	11.9	1
4	Vestra Leirbottskåka	Leiro tol Sysenvatn	7.3	0
5	Isdalskåka	Isdøla	3.8	-2
6	Part of glacier at Store Tresnut	Skytjedalselva	1.8	5
7	Part of glacier at Træet	Rembesdalsvatnet	0.6	2
8	Rembesdalskåka	Rembesdalsvatnet	15.8	7
9	Part of glacier at Demmevatna	Demmevatnet transferred to Langvatnet	3.7	-2
10	Ramnabergbreen	Nordelva transferred to Langvatnet	8.8	-9
11	Bukkeskinnsbreen	Ustekveikja/Hallingdal	1.7	4
12	Middalsbreen	Ustekveikja/Hallingdal	6.7	2
13	Blåisen	Ustekveikja/Hallingdal	5.7	5
	Total Hardangerjøkulen		72.4	1.1

Table 16-1

Volume change (m w. eqv.) for the drainage areas shown in Figure 16-1.

16.3 Tverråbreen

Tverråbreen (61°36'N, 8°18'E) is a small valley glacier in central Jotunheimen (Fig. 9-1). The glacier is about 3.6 km long, covers an area of 5.4 km^2 and ranges in altitude from 1460 to 2215 m a.s.l. (Fig. 16-2). Since 1927 the glacier has retreated 1.0 km, and its area has been reduced by nearly 20 % (Fig. 16-2). Dybwadskog measured mass balance for two years from 1962 to 1963. The mean winter, summer and net balance figures are presented in Appendix C.

Data material

Tverråbreen has been mapped several times during the period 1927-1997 (Table 16-2). The early surveys in the 1920s, 1930s and 1940s are described in Koller et.al. (1962) and Liestøl (1962). Here we concentrate on the detailed maps from 1968 and 1997.

	Map			Photo		
Year	**Method**	**Scale**	**Contour interval**	**Contract no**	**Date**	**Scale**
1968	APV	1: 10,000	10	FW3207	27.Aug.68	1: 15,000
1997	DPV	1: 10,000*	10*	FW12173	08.Aug.97	1: 30,000

Explantion:
APT: analogue photogrammetry, terrestrial photos; APV: analogue photogrammetry, vertical aerial photos; DPV: digital photogrammetry, scanned vertical aerial photos. FW: Fjellanger Widerøe A/S;
**: originally constructed as a DTM.*

Table 16-2

Detailed maps constructed of Tverråbreen.

Data processing

First, the analogue glacier maps from 1968 were digitised. A regular grid was created from the contour map. The 1997 map was constructed directly as a DTM and converted to a regular grid. Volume change was then calculated by extracting grids and converting to water equivalents as described in section 16.1.

Volume change 1968-1997

Between 27th August 1968 and 8th August 1997 Tverråbreen had a total mass loss of 28×10^6 m^3 w.eqv. or a specific mass loss of – 4.9 m w.eqv. (Fig. 16-3). The change in mass varied between +23 and – 52 m w.eqv. However, these extreme values are unusual; nearly 90% of the glacier experienced a mass change between –10 and +5 w.eqv. 85 % of the glacier had a negative change. The largest losses occurred on the glacier tongue. There is no ablation data at Tverråbreen in 1968 or 1997, but from Hellstugubreen we know that there was additional ablation of 1.5 m w.eqv. after 8th of August 1997. Tverråbreen had 60 % higher ablation than Hellstugubreen during the two years of mass balance measurements on Hellstugubreen. We therefore assume that the average net mass change on Tverråbreen must be reduces by about 2.0 m w.eqv. Thus, the net result for the period 1968 to 1997 is –6.9 m.w.eqv. with an estimated uncertainty of ±2.0 m.weqv. The mean specific value per year is –0.23 m w.eqv.

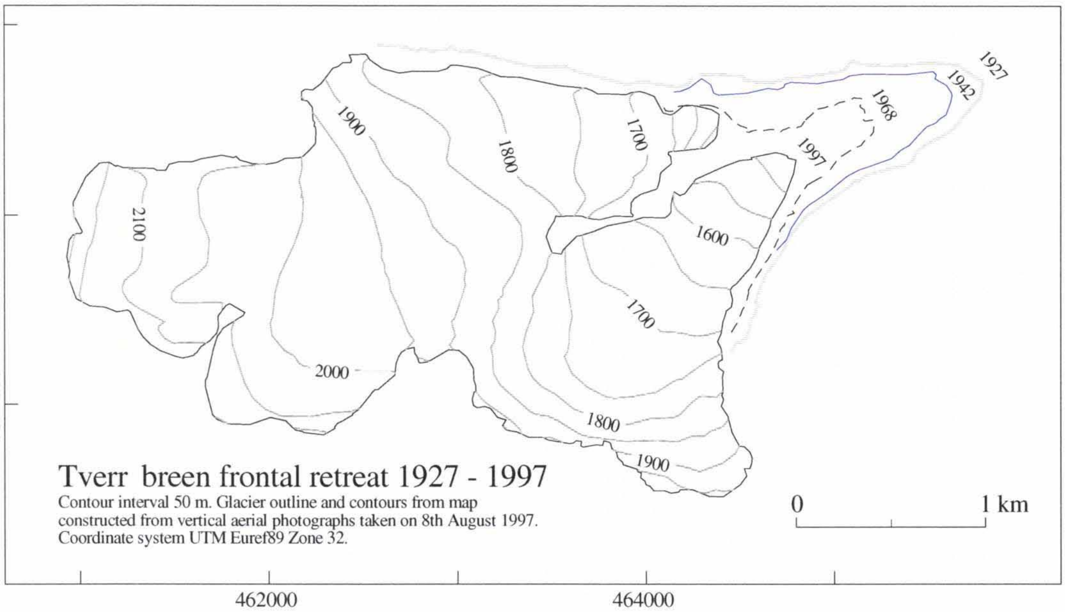


Figure 16-2

Front fluctuations of Tverråbreen from 1927 to 1997. The front positions are extracted from digital glacier maps.

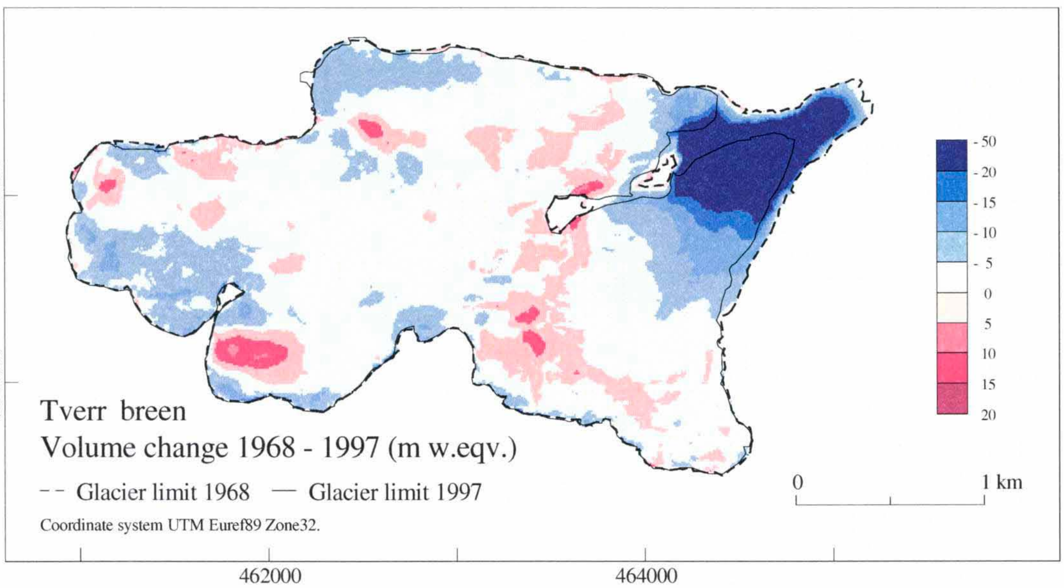


Figure 16-3

Volume change of Tverråbreen between 27th August 1968 and 8th August 1997.

16.4 Hellstugubreen

Hellstugubreen (61º34'N, 8º 26'E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 9-1). It ranges in elevation between 1480 and 2210 m a.s.l. and has an area of 3.0 km^2 (Fig. 10-1). Mass balance investigations have been performed since 1962 and are described in chapter 10.

Data material

Hellstugubreen has been mapped in detail several times. The early surveys in the 1920s, 1930s and 1940s are described in Koller et.al. (1962) and Liestøl (1962). Here we concentrate on the last three detailed maps from 1968, 1980 and 1997 (Table 16-3). The 1968 and 1997-map were both constructed from vertical aerial photographs. The verticals taken in 1997 were scanned and constructed directly as a digital terrain model (DTM). A contour map was extracted from the DTM for illustrative purposes.

	Map			Photo		
Year	Method	Scale	Contour interval	Contract no	Date	Scale
1968	APV	1: 10,000	10	FW3207	27. Aug.68	1: 15,000
1980	APV	1: 10,000	10	FW6555	26. Sep.80	1: 30,000
1997	DPV	1: 10,000*	10*	FW12173	08. Aug.97	1: 30,000

Explantion:
*APT: analogue photogrammetry, terrestrial photos; APV: analogue photogrammetry, vertical aerial photos; DPV: digital photogrammetry, scanned vertical aerial photos. FW: Fjellanger Widerøe A/S; *: originally constructed as a DTM.*

Table 16-3

Detailed maps constructed of Hellstugubreen.

Data processing

The analogue glacier maps were digitised and regular grids were created from the contour maps. Volume change was then calculated by extracting grids and converting to water equivalent as described in section 16.1.

Results

Volume change 1968-80

For the first period, 1968-80, Hellstugubreen had a specific net loss of -5.8 m w.eqv. or, expressed in volume, a loss of 18×10^6 m^3 (Fig. 16-4). The largest thinning occurred at the glacier tongue, while the uppermost parts of the glacier slightly thickened. Nearly 90 % of the glacier thinned, while the remaining 10 % gained mass during this period.

Volume change 1980-97

For the second period, 1980-97, we see a different picture (Fig. 16-4). Hellstugubreen had a minor specific mass loss of -0.5 m w.eqv. The glacier tongue underwent further thinning, but the upper parts of the glacier thickened. The verticals were taken on 8th

August, and we know from ablation records that the glacier had additional melting of about -1.5 m w.eqv. over the rest of the ablation season. The 1980 verticals were taken so late that we assume no further melting after the time of photography that year. Thus, adjusting the DTM result for this difference in additional melt, the specific net balance of Hellstugubreen is roughly -2.0 m.w eqv. This is in fairly good agreement with the measured cumulative net balance for this period, -3.5 m w.eqv. The uncertainty of the result is assumed to be ±2.0 m w.eqv.

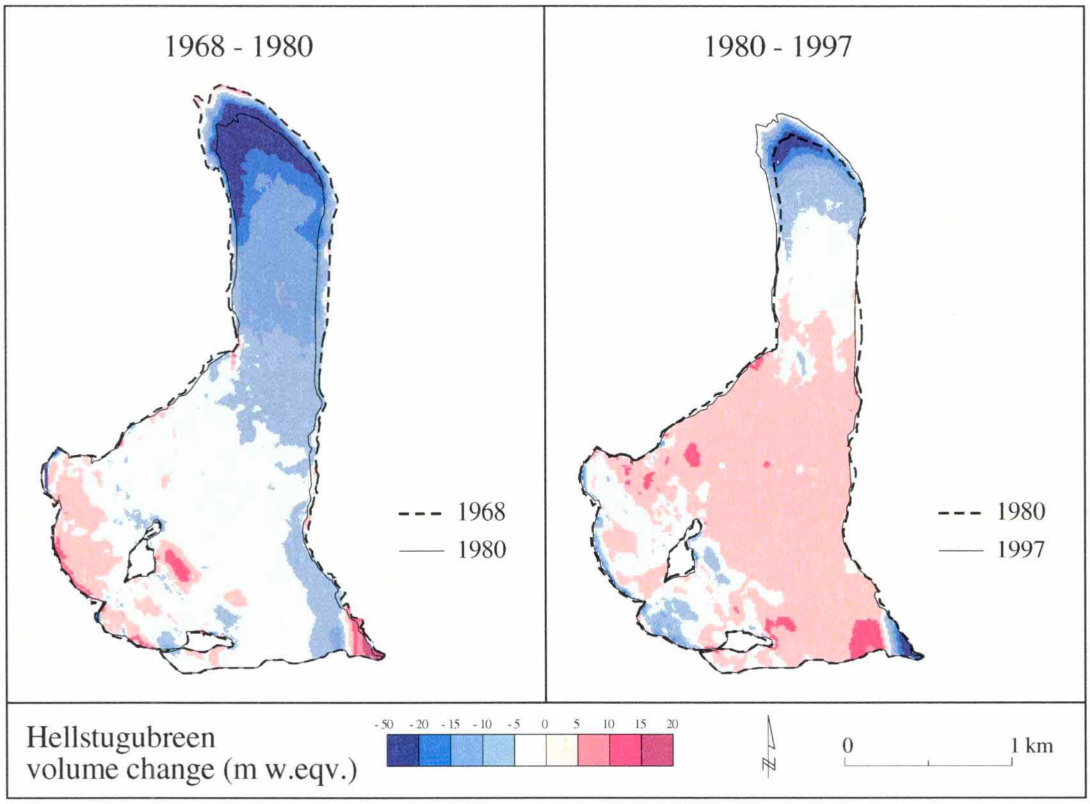


Figure 16-4

Volume change of Hellstugubreen between 1) 27th August 1968 and 26th September 1980 and 2) 26th September 1980 and 8th August 1997.

16.5 Gråsubreen

Gråsubreen (61°39' N, 8°37'E) is located in the eastern part of Jotunheimen in southern Norway (Fig. 9-1). The glacier covers an area of 2.2 km^2 and ranges from 1830 to 2290 m a.s.l. (Fig. 11-1). Gråsubreen is a polythermal glacier. Mass balance investigations have been performed there since 1962 and are described in chapter 11. A new digital terrain model of the glacier in 1997 has recently been constructed, and is compared with the map from 1984.

Data material

Gråsubreen has been mapped in detail three times, 1968, 1984 and 1997 (Table 16-4). The first two maps were constructed by analogue photogrammetry from vertical aerial photographs. They were produced at a scale of 1: 10,000 with a 10-m contour interval. The volume change of Gråsubreen for the period 1968 - 1984 has previously been calculated manually and is described in Haakensen (1986). The 1968 map was found to be inaccurate. The accuracy of the 1984 map is considered to be very good due to a detailed field survey in connection with the mapping. The 1997 map was constructed directly as a digital terrain model from scanned aerial photographs. A contour map was extracted for illustrative purposes.

	Map			Photo		
Year	**Method**	**Scale**	**Contour interval**	**Contract no**	**Date**	**Scale**
1968	APV	1: 10,000	10	FW3207	27.Aug.68	1: 15,000
1984	APV	1: 10,000	10	FW8330	23.Aug.84	1: 20,000
1997	DPV	1: 10,000*	10*	FW12173	08.Aug.97	1: 30,000

Explantion:
*APV: analogue photogrammetry, vertical aerial photos; DPV: digital photogrammetry, scanned vertical aerial photos. FW: Fjellanger Widerøe A/S; *: originally constructed as a DTM.*

Table 16-4

Detailed maps constructed of Gråsubreen.

Data processing

The analogue glacier map from 1984 was digitised and a regular grid was created from the contour map. The 1997 DTM was converted to a regular grid and used directly in the analysis. Volume change was calculated by extracting grids and converting to water equivalent as described in section 16.1.

Results

Volume change 1984-97

From 23th August 1984 to 8th August 1997 Gråsubreen had a specific mass loss of –0.30 m w.eqv. or a total volume loss of –0.67 10^6 m^3. The estimated uncertainty is ±1 m w.eqv. The change in mass varied between +7.1 and –7.7 m w.eqv. Nearly 80 % of the glacier had a specific change between –3 and +3 m w.eqv. 61 % of the glacier had a negative change in mass balance, while the rest of the glacier had a positive change. When adjusting for the -1.2 m w.eqv. that is the difference in additional melting from the data of photography to the end of the melt season, the specific net result is -1.5 m w.eqv. Using this adjustment, nearly 80 % of the glacier had a negative change between the end of the melt season in 1984 and 1997.
The cumulative net balance measured in this period is -1.9 m w.eqv. Thus, there is very good agreement between the specific volume change calculated from maps and DTMs, and the measured net balance at Gråsubreen for the period 1984-1997.

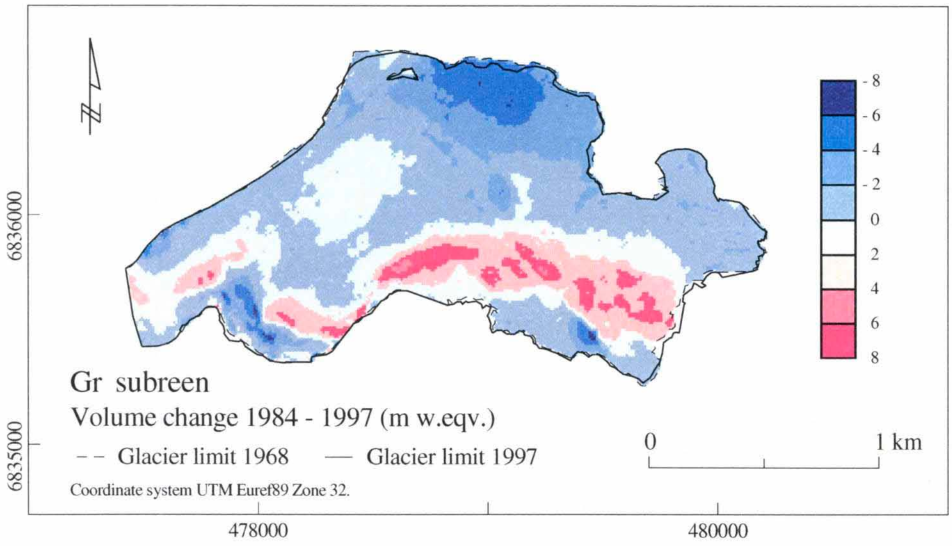


Figure 16-5

Volume change of Gråsubreen between 23rd August 1984 and 8th August 1997.

16.6 Høgtuvbreen

Høgtuvbreen is a glacier complex south of Svartisen. A mass balance program was carried out in the 1970s on part of northern Høgtuvbreen (66°27' N, 13°40' E). This east-faced outlet is a typical valley glacier and has a length of about 2.0 km and an area of 2.0 km^2 (1998). Mass balance investigations began in 1971 and measurements were carried out annually until 1977.

Data material

A detailed map of this part of Høgtuvbreen was made from vertical aerial photographs in 1972 (Tab. 16-5). This map was considered to have a low accuracy due to the inaccurate triangulation network existing at the time of mapping (1972-73). Therefore, a new digital terrain model from the 1972-verticals was constructed in 2000 together with the digital terrain model from the 1998-verticals. Both DTMs were produced from scanned vertical photographs using digital photogrammetry.

	Map			Photo		
Year	Method	Scale	Contour interval	Contract no	Date	Scale
1972	APV	1: 10,000	10	FW4079	29. Jul.72	1: 25,000
1972	DPV	1: 10,000*	-	FW4079	29. Jul.72	1: 25,000
1998	DPV	1: 10,000*	-	FW12301	01. Sep.98	1: 20,000

Explantion:
*APV: analogue photogrammetry, vertical aerial photos; DPV: digital photogrammetry, scanned vertical aerial photos. FW: Fjellanger Widerøe A/S; *: originally constructed as a DTM.*

Table 16-5

Detailed maps constructed of Høgtuvbreen.

Data processing

The new 1972 DTM and the 1998 DTM were converted to regular grids and used directly in the analysis. Volume change was then calculated by extracting grids and converting to water equivalents as described in section 16.1.

Results

Between 29th July 1972 and 1st September 1998 Høgtuvbreen had a specific net loss of $^-7.3$ m w.eqv. or, expressed in volume, a loss of $^-14 \times 10^6$ m^3 (Fig. 16-6). The uncertainty of the result is ±2.0 m w.eqv. The largest mass loss was at the glacier tongue, while a thickening occurred in the accumulation area. More than 50 % of the glacier lost volume, while the remainder increased in volume. During this period the glacier lost nearly 20 % of its area and had a 25 % reduction in length. The glacier retreated more than 700 metres from 1972 to 1998, or about 27 meters annually.

The mass balance records of Høgtuvbreen are well correlated with those of Engabreen (r^2=0.87). Engabreen has a long record of mass balance observations (1970-2001). Using this correlation we can estimate the cumulative net balance at Høgtuvbreen for the period 1972-1998. The estimated cumulative net balance was $^-8.2$ m w.eqv. between 1972 and 1998. The result from the DTM-comparison adjusted for the additional melting that occurred after the time of photography is $^-6.3$ m w.eqv. ($^-7.3$ +1 m w.eqv.). Thus, the results are fairly consistent taking the uncertainties in both methods into account.

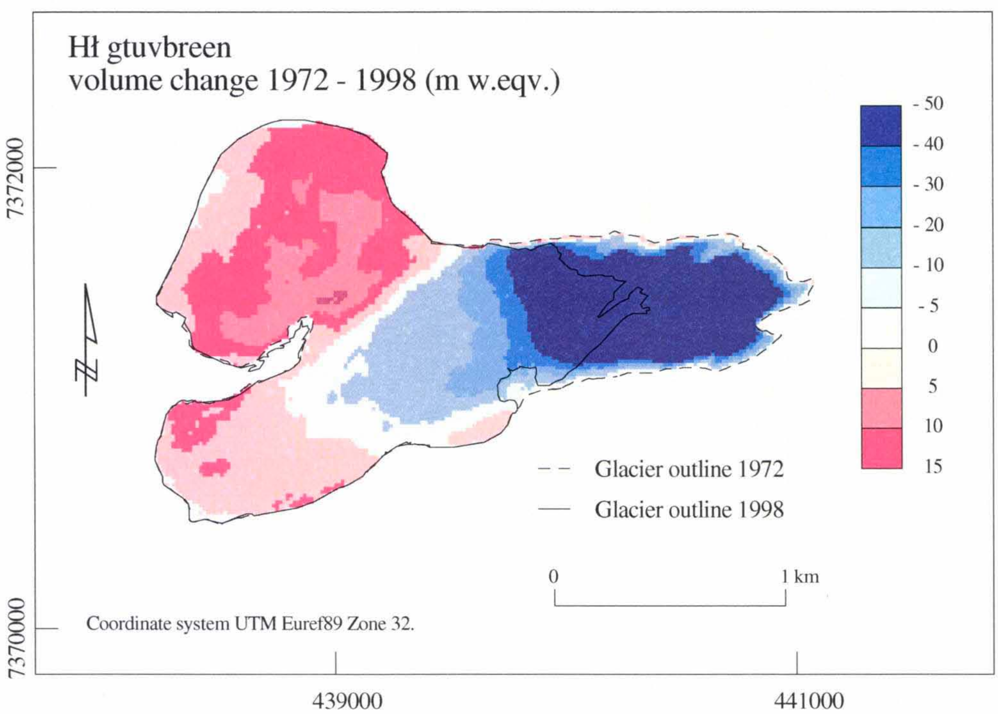


Figure 16-6

Volume change of Høgtuvbreen between 29th July 1972 and 1st September 1998.

16.7 Strupbreen and Koppangsbreen

The glacier complex Strupbreen and Koppangsbreen (69°42'N, 20°10E) is the largest continuous ice mass on the Lyngen peninsuela (Fig. 16-7), and covers a total area of 13.2 km^2. Stupbreen comprises about two thirds of this area, while Koppangsbreen covers about one third. The glacier complex ranges in altitude from about 440 (the snout of Strubreen) and 460 m a.s.l. (the snout of Koppangsbreen) to about 1350 m a.s.l. There have been no mass balance studies on these glaciers, although a number of other investigations have been performed (Whalley and Kjøllmoen, 2000).

Data material

There exist three detailed maps/DTMs covering the whole glacier complex (Tab. 16-6). High-quality vertical aerial photographs taken in August 1985 were used to construct a detailed map of the glacier complex. Aerial photographs of the glacier in 1978 and 1952 were used to construct two other glacier maps. The 1952-map covers only the lower parts of Strupbreen. These maps were printed together in 1985. New verticals were taken in 1998. These verticals were scanned and a digital terrain model was constructed using digital photogrammetry.

	Map			Photo		
Year	Method	Scale	Contour interval	Contract no	Date	Scale
1978	APV	1: 20,000	10	FW5820	21.Jul.78	1: 40,000
1985	APV	1: 10,000	10	FW8709	21.Aug.85	1: 30,000
1998	DPV	-	-	FW12297	31.Aug.01	1: 20,000

Explantion:
*APV: analogue photogrammetry, vertical aerial photos; DPV: digital photogrammetry, scanned vertical aerial photos. W: Widerøe Flyveselskap, FW: Fjellanger Widerøe A/S; *: originally constructed as a DTM.*

Table 16-6

Detailed maps constructed of Strupbreen and Koppangsbreen.

Data processing

The analogue glacier maps from 1978 and 1985 were digitised, then regular grids were created from the contour maps. The 1998 DTM was converted to a regular grid and used directly in the analysis. Volume change was calculated by extracting grids and converting to water equivalents as described in section 16.1. The estimated uncertainty of the result is roughly ±2.0 m w.eqv. for the period 1978-85 and ±1.5 w.eqv. for the period 1985-98.

Results

Volume change 1978-85

Between 21st July 1978 and 21st August 1985 the glacier complex Strupbreen/Koppangsbreen had a specific mass loss of -6.1 m w.eqv. or a volume loss of 80 10^6 m^3 (Fig. 16-8). Almost all the glacier (95 %) had a mass loss during this eight-year period. The glacier area was smaller in 1978 (12.6 km^2) than in 1985

($13.1\ km^2$), but this is explained as being due to more snow patches/glacier tributaries in the upper accumulation area being included in the 1985-outline. The glacier front of Strupbreen retreated about 30-40 meters from 1978 to 1985, while the glacier front of Koppangsbreen retreated about 100 meters.

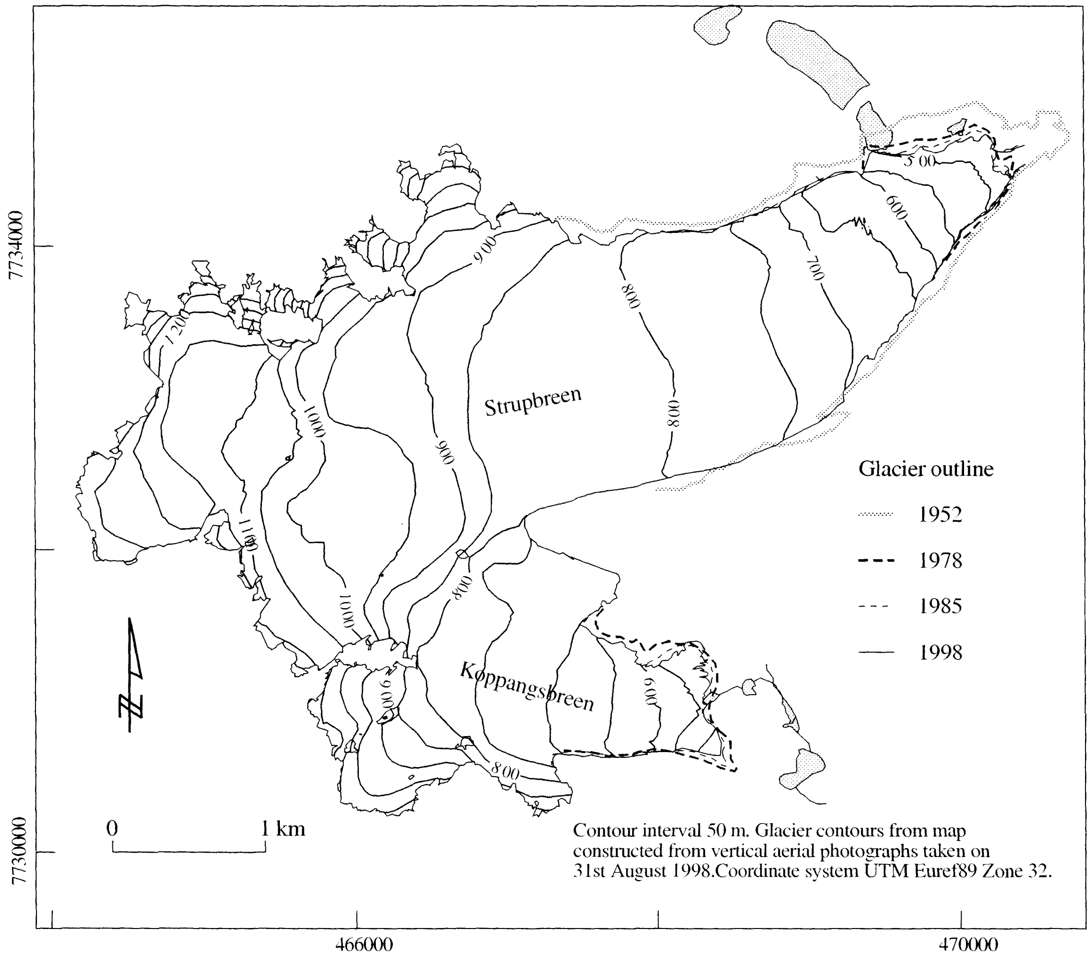


Figure 16-7

Map of Strupbreen and Koppangsbreen showing the glacier complex and front fluctuations for the period 1952-98. (The 1952-map covers only Strupbreen.)

Volume change 1985-98

For the second period, 1985-98, Strupbreen and Koppangsbreen had a minor specific mass loss of -0.8 m w.eqv or a volume loss of $11\ 10^6\ m^3$ (Fig. 16-9). Generally, the lower part of the glacier complex (below 840 m a.s.l. at Strupbreen and below 780 m a.s.l. at Koppangsbreen) lost volume. In contrast, the upper parts of the glacier have increased their volume. Overall, there was volume loss from 55 % of the glacier. Nearly 80 % of the glacier had specific mass change between -10 and + 5 m w.eqv. The total area of the glacier complex was unchanged between 1985 and 1998 and the glacier fronts were almost the same in 1998 as in 1985.

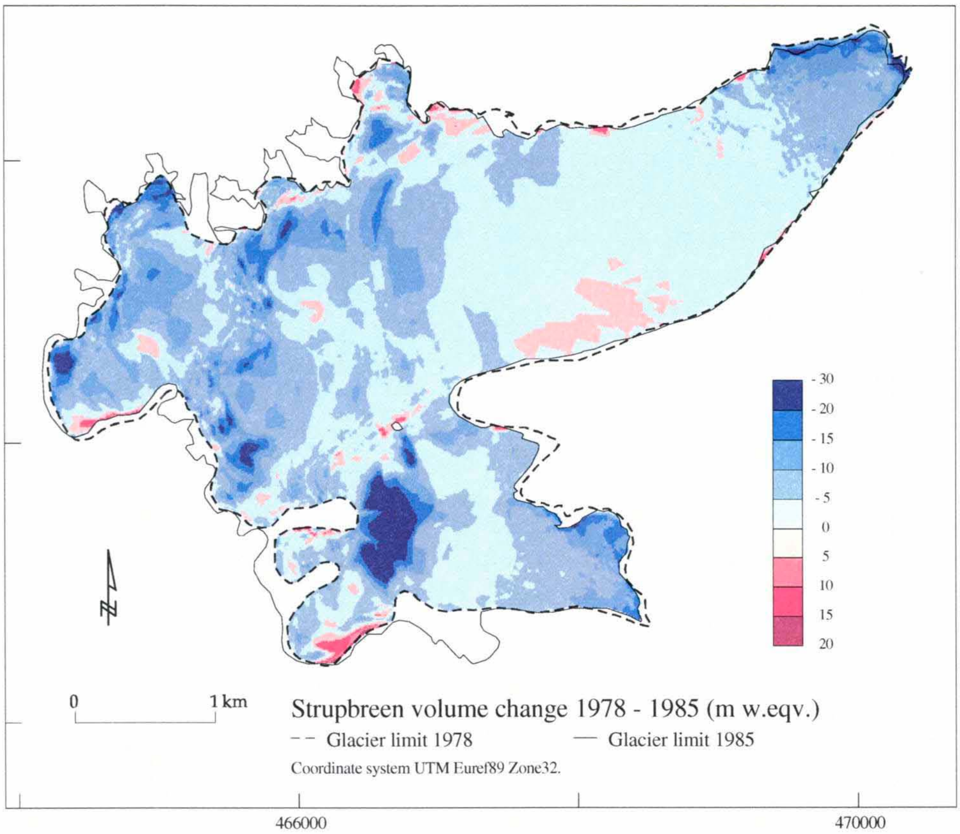


Figure 16-8

Volume change of Strupbreen and Koppangsbreen between 21st July 1978 and 21st August 1985.

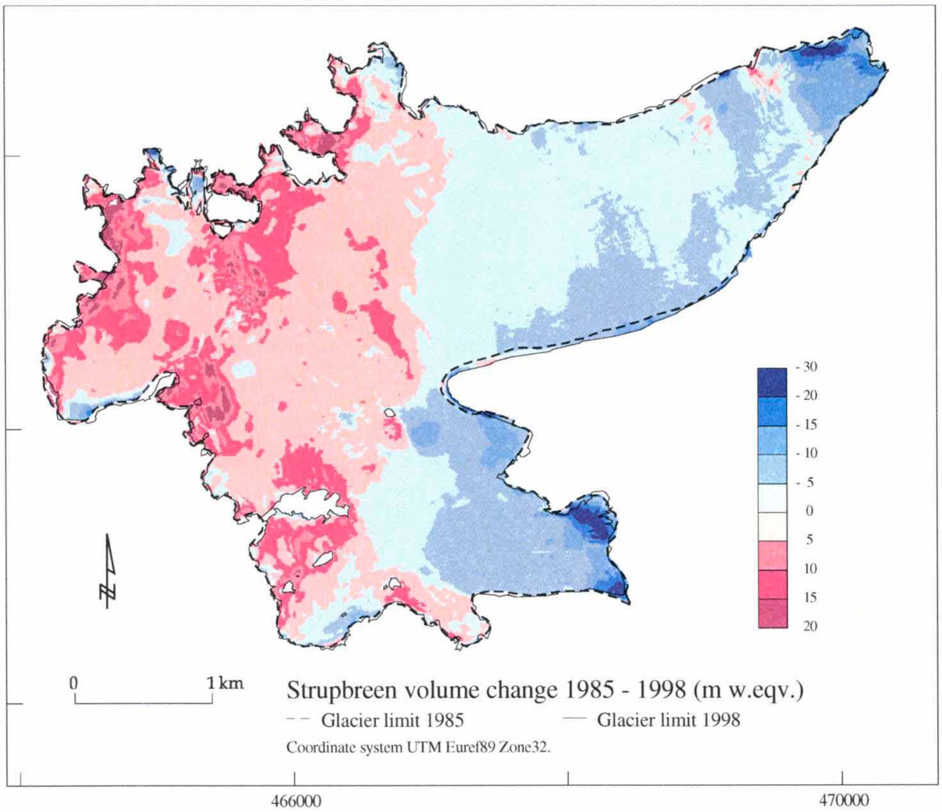


Figure 16-9

Volume change of Strupbreen and Koppangsbreen between 21st August 1985 and 31st August 1998.

17 Glacier monitoring (Hallgeir Elvehøy)

17.1 Front position change

In 2000 front position change was measured for 24 glaciers, 20 in southern Norway and four in northern Norway (Fig. 17-1).

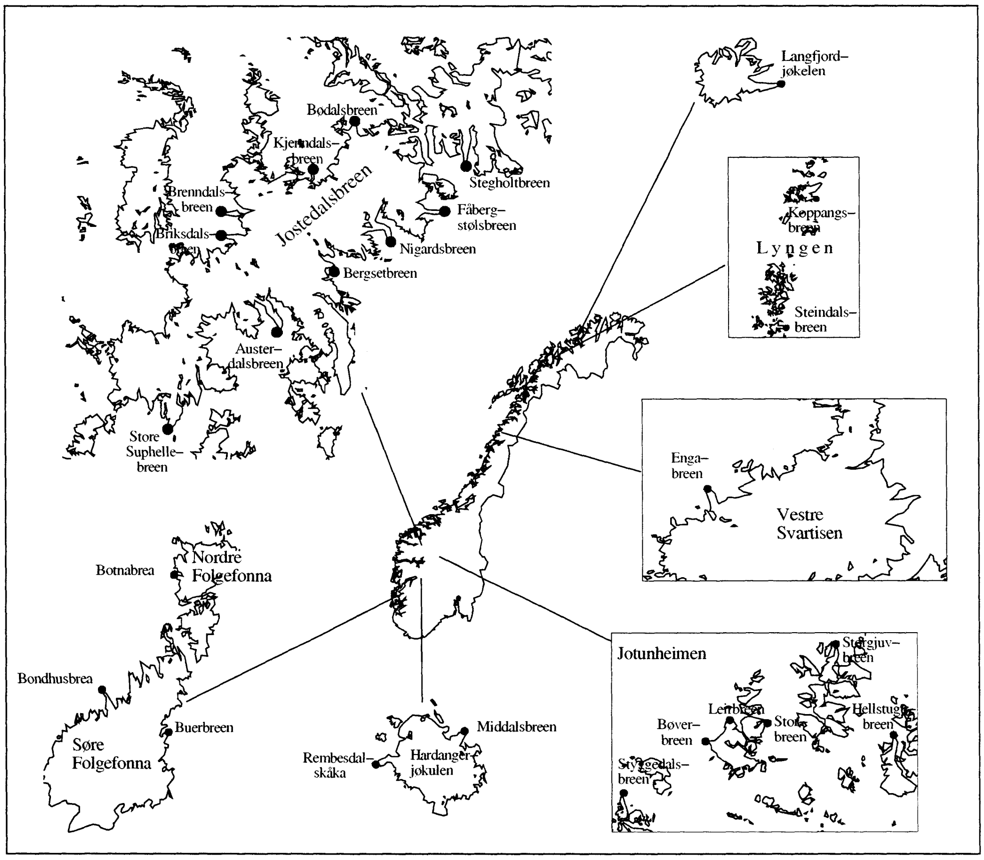


Figure 17-1

Location map showing glaciers where front position measurements were performed in 2000, and described in this chapter. Notice that the different glacier areas are not to scale.

Methods

The distance is measured from one or several established cairns or painted marks on rocks to the glacier front in defined directions, normally in September or October each year. Change in distance gives a rough estimate of the front fluctuations at one or more points at the glacier fronts. These measurements have a fairly high degree of uncertainty both in the actual length determination, and to what extent the measurement is representative for the entire glacier front. The measurements give, nevertheless, valuable information about glacier fluctuations and regional tendencies and variations when longer time periods are considered. Observations of front position change have been made for Norwegian glaciers since the 1880s, but continuous measurements started around 1900.

Results

The front position change from 1999 to 2000 is shown in Table 17-1. At Jostedalsbreen ten outlets were measured. Two glaciers have had marked advances, while two glaciers have retreated considerably. Nigardsbreen has advanced 23 metres since last year and 253 metres in 10 years. Fåbergstølsbreen advanced 25 metres last year and 190 metres since 1992. Briksdalsbreen retreated 30 metres, the largest annual retreat since 1951 when the last major recession ended at the head of lake Briksdalsvatnet. The lake was completely covered by the glacier at the termination of the last advance in 1996. Store Supphellebre is a regenerated glacier where front position change varies a lot from year to year due to avalanche activity. Last year the glacier advanced 24 metres. This year it has retreated 46 metres. The rest of the glaciers have had small changes in their front positions.

Area	Glacier	Change (m)	Measured by
Jostedalsbreen	Austerdalsbreen	5	NVE
	Bergsetbreen	9	NVE
	Brenndalsbreen	0	Universitet Trier, Germany
	Briksdalsbreen	-30	NVE
	Bødalsbreen	4	Universitet Trier, Germany
	Fåbergstølsbreen	25	NVE
	Kjenndalsbreen	-1	Universitet Trier, Germany
	Nigardsbreen	23	NVE
	Stegholtbreen	8	NVE
	Store Supphellebre	-46	Norwegian Glacier Museum
Folgefonna	Bondhusbrea	-24	Statkraft SF
	Botnabrea	6	Statkraft SF
	Buerbreen	-1	NVE
Hardangerjøkulen	Midtdalsbreen	8	University of Bergen
	Rembesdalskåka	21	Statkraft SF
Jotunheimen	Bøverbreen	4	Universitet Trier, Germany
	Hellstugubreen	0	NVE
	Leirbreen	-7	NVE
	Storgjuvbreen	6	Universitet Trier, Germany
	Styggedalsbreen	-2	NVE
Svartisen	Engabreen	-2	NVE
Lyngen	Koppangsbreen	-6	NVE
	Steindalsbreen	-9	NVE
Finnmark	Langfjordjøkelen	-12	NVE

Table 17-1

Front position change between autumn 1999 and autumn 2000 for 24 glaciers in Norway.

At Folgefonna the outlet Bondhusbrea has retreated 24 metres, and 54 metres since measurements began in 1996. Botnabrea advanced 6 metres over the last year, and 28 metres since 1996. Buerbreen was stable last year, but has retreated 15 metres since 1996.

Rembesdalskåka, the largest outlet from Hardangerjøkulen, advanced 21 metres compensating for previous year's recession of 20 metres. These fluctuations are caused by the glacier outlet river exiting the terminus close to the line of measurement. The northern outlet Midtdalsbreen showed a net advance of 8 metres.

In Jotunheimen Leirbreen is still retreating, causing the area of Lake Leirtjørnin to increase. Storgjuvbreen advanced 6 metres, and has been advancing approximately 6 metres per year since measurements began in 1997. The other glaciers in Jotunheimen had minor changes. Storbreen could not be measured due to a snowdrift covering the terminus in the line of measurement.

The only investigated outlet from Svartisen, Engabreen, had only a small change in its front position from 1999 to 2000. The three northernmost glaciers in Lyngen and Finnmark are retreating but at a slower rate than last year.

18 Historical notes: Kjølbreen and Glombreen 1953-56

(Espen Gudevang and Hallgeir Elvehøy)

18.1 Background

Kjølbreen (66°40'N, 14°05'E) is a small, east-facing outlet glacier from the West Svartisen ice cap. Glombreen (66°51'N, 13°57'E) is a small glaciated area (7.8 km^2, 1968) surrounding the mountain Istinden 15 km north of the West Svartisen ice cap. Mass balance investigations were initiated in 1953 at these two glaciers by glaciologist Olav Liestøl of the Norwegian Polar Institute. The purpose of the investigations was to assess glacier impact on discharge measured in rivers and the calculated inflow to reservoirs. The measurements were made over three years, but the results have not been published before.

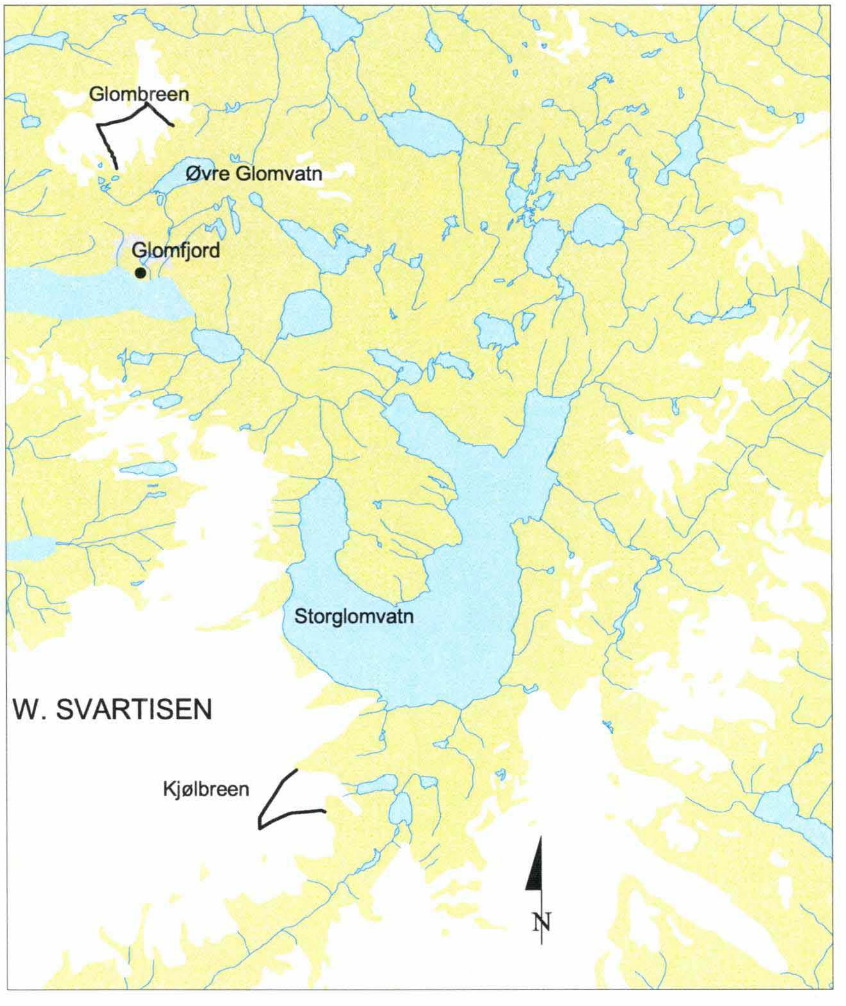


Figure 18-2

Map showing the location of Kjølbreen, Glombreen and Glomfjord.

Kjølbreen

Kjølbreen drains naturally to Kjølvatnet (705 m a.s.l.) and Terskaldvatnet, and further to Glomåga in Rana. This catchment has been artificially diverted to Storglomvatnet. The glacier terminus was mapped in 1910, 1937 and 1945 revealing a considerable retreat of the glacier and a corresponding enlargement of lake Kjølvatnet. A detailed map was constructed from terrestrial photos from 1953 and a reference point network. Observations from field workers showed that the lower part of Kjølbreen below 875 m a.s.l. was then in a state of general decay. Therefore, these investigations were concentrated on the upper part of the glacier.

Based on the topographic map from 1953 drainage divides for the glacier were defined, and the area-altitude distribution was calculated. The glacier area was 3.9 km^2, and the glacier covered the altitudinal interval between 875 and 1225 m a.s.l.

Glombreen

The investigations at Glombreen were carried out on the parts of the glacier draining towards Øvre Glomvatn, which is a water reservoir to a Norsk Hydro factory in Glomfjord. The area of the investigated part of Glombreen was approximately 2 km^2 covering the altitudinal interval between 780 and 1075 m a.s.l.

18.2 Methods and results

Kjølbreen

The field workers plotted the snow depth observations on the 1953 map. The point measurements were plotted against altitude, and an altitudinal winter balance curve was fitted to the point measurements. From this curve and the altitudinal area distribution the specific winter balance was calculated. In addition, the observations of snow depth water equivalents were digitised, winter balance maps were constructed by interpolation between the point measurements, and mean winter balance was calculated from the winter balance maps. The net balance was calculated as an average of the net balance at stake positions. The summer balance is calculated from the winter and net balance. The results from the individual years are given below, and also listed in Table 18-1.

1953-54

The winter balance was calculated from 93 soundings of snow depth taken between 900 and 1190 m a.s.l. in May 1954. From density measurements the mean density of the snow pack was calculated to be 0.45 g/cm^3. The winter balance was calculated as 1.9 m w.eqv. from both an altitudinal distribution curve and a winter balance map.

Calculations of net balance for 1953-54 are based on stake measurements taken on 19^{th} September 1953 and 31^{st} August 1954. Unfortunately, all of the stakes except two had melted out when measurements were taken on 31^{st} August. These two stakes at 1100 and 1190 m a.s.l. showed a slightly negative net balance (–0.4 and –0.3 m w.eqv., respectively).

1954-55

The winter balance was calculated from 32 soundings of snow depth between 920 and 1170 m a.s.l. taken in May 1955. From density measurements the mean density of the snow pack was calculated to be 0.47 g/cm^3. The winter balance was calculated as 2.1 m w.eqv. from an altitudinal distribution curve and as 1.9 m w.eqv. from a winter balance map.

Calculations of net balance for 1954-55 are based on stake measurements taken on 31st August 1954 and 20th September 1955. The net balance was calculated for eight stake positions between 1000 and 1190 m a.sl., and was between –0.3 and –1.2 m w.eqv with a mean value of –0.73 m w.eqv. The net balance at the two stakes used for 1953-54 showed –0.3 and –0.4 m w.eqv.

1955-56

The winter balance was calculated from 35 soundings of snow depth between 940 and 1170 m a.s.l. taken on 5th April 1956. From density measurements the mean density of the snow pack was calculated to be 0.43 g/cm^3. The winter balance was calculated as 1.1 m w.eqv. from an altitudinal distribution curve and to be 1.0 m w.eqv. from a winter balance map.

Calculations of net balance in 1955-56 are based on stake measurements taken on 20th September 1955 and 14th August 1956. The net balance was calculated for ten stake positions between 1030 and 1190 m a.sl., and was between –0.3 and +0.5 m w.eqv. with a mean value of 0.16 m w.eqv. The net balance at the two stakes used for 1953-54 showed +0.8 and +0.2 m w.eqv. There was no altitudinal trend in the stake net balance values. Since net balance measurements were taken as early as mid-August there was probably some melting after 14th August 1956. At the meteorological station in Glomfjord the average monthly temperatures in August and September 1956 were 1.0 and 1.2 below the 1931-60 mean monthly temperature. Therefore, the actual annual net balance was probably slightly more negative than the measurements show, and we estimate the net balance to be 0.0 m w.eqv.

	Winter balance (w.eqv.)	Summer balance (w.eqv.)	Net balance (w.eqv.)
1953-54	1.9	-2.6	-0.7
1954-55	2.1	-2.8	-0.7
1955-56	1.1	-1.1	0.0

Table 18-1

Specific winter, summer and net balance in metres water equivalent at Kjølbreen.

Glombreen

The field workers plotted observations on sketch maps without further information on location and altitude. The winter balance was calculated as an average of the soundings. Olav Liestøl calculated the net balance from the stake measurements supplemented by considerations of meteorological data from Glomfjord and measurements at Kjølbreen. The summer balance is calculated from the winter and net balances. The results from the individual years are given below, and the results are listed in Table 18-2.

1953-54

The winter balance was calculated from 31 soundings of snow depth taken on 10th May 1954. From density measurements the mean density of the snow pack was calculated to be 0.50 g/cm^3. Mean snow depth was 4.6 m corresponding to a winter balance of 2.3 m w.eqv.

Calculations of net balance in 1953-54 are based on stake measurements taken on 29th September and 3rd November 1953, and 1st August 1954. Unfortunately, all of the stakes melted out between 1st August and 8th September 1954. By 16th September all the winter snow had melted away. Olav Liestøl calculated the net balance to –1.2 m w.eqv.

1954-55

The winter balance was calculated from 14 soundings of snow depth taken on 13th May 1955. From density measurements the mean density of the snow pack was calculated to be 0.42 g/cm^3. Mean snow depth was 6.2 m corresponding to a winter balance of 2.6 m w.eqv.

Calculations of net balance in 1954-55 are based on measurements at 5 stake positions taken on 16th September 1954 and 14th September 1955. Snow from last winter remained at the uppermost stakes. Olav Liestøl calculated the net balance to be –0.1 m w.eqv.

	Winter balance (w.eqv.)	Summer balance (w.eqv.)	Net balance (w.eqv.)
1953-54	2.3	-3.5	-1.2
1954-55	2.6	-2.7	-0.1
1955-56	1.5	-2.1	-0.6

Table 18-2

Results from mass balance investigations at Glombreen in 1953-56 in metres water equivalents. Specific winter balance is calculated as the mean snow depth water equivalent. Olav Liestøl calculated the specific net balance from stake measurements supported by meteorological data. The specific summer balance is calculated as the sum of the winter and net balance terms.

1955-56

The winter balance was calculated from 18 soundings of snow depth taken on 9th April 1956. From density measurements the mean density of the snow pack was calculated to be 0.45 g/cm^3. Mean snow depth was 3.4 m corresponding to a winter balance of 1.5 m w.eqv.

Calculations of net balance for 1955-56 are based on stake measurements taken on 14th September 1955 and 8th September 1956. Snow from last winter remained at all except the lowermost stakes. Olav Liestøl calculated the net balance to be –0.6 m w.eqv.

18.3 Discussion

Data quality

The mass balance programs at Kjølbreen and Glombreen suffered from several problems resulting in poor data quality. The stake measurements were not continuous partly due to wooden stakes failing to withstand winter conditions, and partly due to poor stake maintenance during late summer and autumn. The quality of the data reports is also questionable.

Comparison with meteorological data

In order to put these results into a wider time frame, the meteorological record for temperature and precipitation from Glomfjord in 1953-56 has been compared to the meteorological standard periods 1931-60 and 1961-90. The winter precipitation (October-May) and summer temperature (June-September) in Glomfjord are used as proxies for winter and summer balances on the glaciers (Tab. 18-3).

The meteorological data indicate that winter 1953-54 was wetter than normal, while 1955 and 1956 had cooler than normal summers. The mass balance results do not show this clearly. The higher mass balance values at Glombreen than at Kjølbreen reflect that Glombreen is at a lower elevation and closer to the sea than Kjølbreen.

	Winter precipitation Glomfjord (m)	**Specific winter balance** (m w.eqv.)		**Summer temperature** Glomfjord (°C)	**Specific summer balance** (m w.eqv.)	
		Kjølbreen	Glombreen		Kjølbreen	Glombreen
1953-54	1.517	1.9	2.3	11.7	-2.6	-3.5
1954-55	1.288	2.1	2.6	10.6	-2.8	-2.7
1955-56	1.317	1.1	1.5	11.0	-1.1*	-2.1
1931-60	1.364			11.59		
1961-90	1.414			11.06		

* Net balance measurement taken 14th August 1956.

Table 18-3

Comparison of winter precipitation (Oct. – May) and summer temperature (June-Sep.) in Glomfjord with winter and summer balances for Glombreen and Kjølbreen.

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Appendix B

Mass balance measurements in Norway - an overview

During the period 1949-2000 there are carried out mass balance measurements at 40 Norwegian glaciers. The table below shows some characteristic data for the individual glaciers.

Area/ No. Glacier	No. of REGINE	Area (km^2)	Altitude (m a.s.l.)	Period	No. of years
Ålfotbreen					
1 Ålfotbreen	086.6C1B	4.4	890-1380	1963-	38
2 Hansebreen	086.6E	2.9	930-1320	1986-	15
Folgefonna					
3 Blomsterskardsbreen	042.G	45.7	850-1640	1970-77	8
4 Bondhusbreen	046.3C	10.7	480-1635	1977-81	5
5 Breidablikkbreen and Gråbreen	046.3B/046.32B	15.2	1030-1660	1963-68, 1974-75	8
6 Blåbreen and Ruklebreen	048.4Z/048.B1	4.5	1065-1610	1963-68	6
7 Midtre Folgefonna	046.4B3C/048.32	8.7	1100-1570	1970-71	2
Jostedalsbreen					
8 Jostefonn	078.5Z	3.8	960-1622	1996-2000	5
9 Vesledalsbreen	088.B1Z	4.2	1130-1730	1967-72	6
10 Tunsbergdalsbreen	076.BC	50.1	540-1930	1966-72	7
11 Nigardsbreen	076.EZ	47.8	320-1960	1962-	39
12 Store Supphellebreen	078.2AZ	12.0	80-300/ 720-1740	1964-67, 1973-75, 1979-82	11
13 Austdalsbreen	076.H	11.8	1200-1760	1988-	13
14 Spørteggbreen	075.4Z/076.Z	27.9	1260-1770	1988-91	4
15 Harbardsbreen	075.DC	13.2	1250-1960	1997-	4
Hardangerjøkulen					
16 Rembesdalskåka	050.4C1Z	17.2	1050-1860	1963-	38
17 Omnsbreen	012.CK3	1.5	1460-1570	1966-70	5
18 Midtdalsbreen	012.CK2	7.4	1380-1830	2000-	1
Jotunheimen					
19 Tverråbreen	002.DHBAZ	5.9	1415-2200	1962-63	2
20 Blåbreen	002.DGEB	3.6	1550-2150	1962-63	2
21 Storbreen	002.DHBBZ	5.3	1350-2100	1949-	52
22 Vestre Memurubre	002.DGG1Z	9.0	1570-2230	1968-72	5
23 Austre Memurubre	002.DGG1Z	8.7	1630-2250	1968-72	5
24 Hellstugubreen	002.DHBAZ	3.0	1450-2200	1962-	39
25 Gråsubreen	002.DGDC	2.2	1850-2290	1962-	39
Svartisen					
26 Charles Rabot Bre	155.D4Z	1,1	1090-1760	1970-73	4
27 Austre Okstindbre	155.4G	14.0	730-1750	1987-96	10
28 Høgtuvbreen	156.CCAZ	2.6	590-1170	1971-77	7
29 Svartisheibreen	156.CE	5.5	770-1420	1988-94	7
30 Engabreen	159.81	38.0	40-1594	1970-	31
31 Storglombreen	160.C	59.0 62,4	520-1580 520-1594	1985-88 2000-	5
32 Tretten-null-tobreen	160.C	4.3	580-1260	1985-86	2
33 Glombreen	160.3Z	2.2	870-1110	1954-56	3
34 Kjølbreen	156.CG	3.9	850-1250	1954-56	3
35 Trollbergdalsbreen	161.F	1.8 1.6	900-1375 900-1300	1970-75 1990-94	11
Skjomen					
36 Blåisen	174.30	2.2	850-1200	1963-68	6
37 Storsteinsfjellbreen	173.AB6Z	6.1 5.9	920-1850 970-1850	1964-68 1991-95	10
38 Cainhavarre	173.AZ	0.7	1210-1540	1965-68	4
Vest-Finnmark					
39 Svartfjelljøkelen	211.34C	2.7	500-1080	1978	1
40 Langfjordjøkelen	211.33Z	3.7	280-1050	1989-93, 1996-	10

Appendix C

Mass balance measurements in Norway - annual results

There are results from 473 years of measurements at Norwegian glaciers. The following tables show winter (bw), summer (bs) and net balance (bn) together with cumulative net balance (cum. bn) and equilibrium line altitude (ELA) for every single year at each glacier. In front of each table there is a heading containing the name and the area of the glacier. The reported year (in brackets) corresponds to the given area.

1 Ålfotbreen - 4,4 km^2 (1988)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1963	2,48	-3,58	-1,10	-1,10	1300
2	64	2,69	-2,41	0,28	-0,82	1140
3	65	3,64	-3,16	0,48	-0,34	1150
4	66	2,47	-4,08	-1,61	-1,95	>1380
5	67	4,46	-3,18	1,28	-0,67	950
6	68	4,55	-3,60	0,95	0,28	1075
7	69	2,66	-4,83	-2,17	-1,89	>1380
8	1970	2,60	-3,83	-1,23	-3,12	>1380
9	71	4,29	-3,35	0,94	-2,18	1140
10	72	3,81	-3,70	0,11	-2,07	1195
11	73	4,67	-2,49	2,18	0,11	<870
12	74	3,57	-2,54	1,03	1,14	1065
13	75	4,64	-3,43	1,21	2,35	1050
14	76	4,40	-2,87	1,53	3,88	<870
15	77	2,33	-2,89	-0,56	3,32	1280
16	78	2,56	-3,07	-0,51	2,81	1290
17	79	3,28	-3,41	-0,13	2,68	1240
18	1980	2,51	-3,30	-0,79	1,89	1275
19	81	4,04	-3,82	0,22	2,11	1210
20	82	3,35	-3,48	-0,13	1,98	1240
21	83	4,79	-3,19	1,60	3,58	1010
22	84	4,09	-2,77	1,32	4,90	1050
23	85	2,44	-3,00	-0,56	4,34	1290
24	86	2,35	-2,76	-0,41	3,93	1255
25	87	4,29	-2,22	2,07	6,00	<870
26	88	2,73	-5,21	-2,48	3,52	>1380
27	89	5,20	-2,93	2,27	5,79	1030
28	1990	5,98	-4,19	1,79	7,58	995
29	91	4,09	-3,30	0,79	8,37	1035
30	92	5,48	-3,19	2,29	10,66	1050
31	93	4,81	-2,74	2,07	12,73	<870
32	94	3,71	-2,92	0,79	13,52	925
33	95	5,10	-3,90	1,20	14,72	1120
34	96	1,83	-3,71	-1,88	12,84	>1380
35	97	4,22	-4,14	0,08	12,92	1200
36	98	3,66	-3,55	0,11	13,03	1240
37	99	4,61	-4,55	0,06	13,09	1245
38	2000	5,57	-3,58	1,99	15,08	1025
Mean 1963-2000		3,79	-3,39	0,40		

2 Hansebreen - 2,9 km^2 (1988)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1986	2,28	-2,87	-0,59	-0,59	1200
2	87	3,76	-2,63	1,13	0,54	1100
3	88	2,50	-5,24	-2,74	-2,20	>1320
4	89	4,13	-3,71	0,42	-1,78	1140
5	1990	4,42	-4,10	0,32	-1,46	1140
6	91	3,37	-3,11	0,26	-1,20	1125
7	92	4,41	-3,43	0,98	-0,22	1125
8	93	4,23	-3,15	1,08	0,86	<925
9	94	3,39	-2,97	0,42	1,28	1120
10	95	4,38	-3,90	0,48	1,76	1140
11	96	1,74	-3,76	-2,02	-0,26	>1320
12	97	3,77	-3,92	-0,15	-0,41	1160
13	98	3,21	-3,51	-0,30	-0,71	1170
14	99	4,30	-4,19	0,11	-0,60	1155
15	2000	4,69	-3,82	0,87	0,27	1075
Mean 1986-2000		3,64	-3,62	0,02		

3 Blomsterskardsbreen - 45,7 km^2 (1959)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1970			0,00	0,00	1370
2	71	2,85	-1,87	0,98	0,98	1240
3	72			0,32	1,30	1340
4	73			1,57	2,87	1180
5	74			0,51	3,38	1325
6	75			1,70	5,08	1170
7	76			1,40	6,48	1210
8	77			-1,40	5,08	>1640
Mean 1970-77				0,64		

4 Bondhusbreen - 10,7 km^2 (1979)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	77	1,96	-2,96	-1,00	-1,00	1620
2	78	2,37	-2,88	-0,51	-1,51	1540
3	79	2,82	-2,49	0,33	-1,18	1445
4	1980	2,33	-2,78	-0,45	-1,63	1500
5	81	3,32	-2,00	1,32	-0,31	1460
Mean 1977-81		2,56	-2,62	-0,06		

5 Breidablikkbreen and Gråbreen - 15,2 km^2 (1959)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1963[1)]	1,30	-2,30	-1,00	-1,00	1620
2	64	1,99	-1,62	0,37	-0,63	1410
3	65	2,30	-2,26	0,04	-0,59	1480
4	66	1,66	-3,03	-1,37	-1,96	>1660
5	67	3,51	-2,14	1,37	-0,59	1360
6	68	3,42	-2,69	0,73	0,14	1350
7	1974[2)]	2,14	-1,55	0,59	0,59	1380
8	75	2,62	-2,25	0,37	0,96	1375
Mean 1963-68		2,36	-2,34	0,02		
Mean 1974-75		2,38	-1,90	0,48		

1) Breidablikkbreen only

2) Gråbreen only

6 Blåbreen and Ruklebreen - 4,5 km^2 (1959)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1963[1)]	1,30	-3,40	-2,10	-2,10	1620
2	64	2,18	-1,68	0,50	-1,60	1350
3	65	2,53	-2,48	0,05	-1,55	1450
4	66	1,76	-3,26	-1,50	-3,05	>1620
5	67	3,86	-2,56	1,30	-1,75	1300
6	68	3,18	-2,80	0,38	-1,37	1395
Mean 1963-68		2,47	-2,70	-0,23		

1) Blåbreen only

7 Midtre Folgefonna - 8,7 km^2 (1959)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1970	2,07	-2,69	-0,62	-0,62	>1580
2	71	2,33	-1,96	0,37	-0,25	1260
Mean 1970-71		2,20	-2,33	-0,13		

8 Jostefonn - 3,8 km² (1993)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1996	1,19	-2,72	-1,53	-1,53	>1620
2	97	3,59	-3,87	-0,28	-1,81	1500
3	98	2,84	-2,54	0,30	-1,51	1250
4	99	2,92	-2,54	0,38	-1,13	1200
5	2000	3,49	-2,47	1,02	-0,11	1050
Mean 1996-2000		2,81	-2,83	-0,02		

9 Vesledalsbreen - 4,2 km² (1966)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1967	2,06	-1,71	0,35	0,35	1400
2	68	3,14	-2,50	0,64	0,99	1320
3	69	1,26	-3,44	-2,18	-1,19	>1730
4	1970	1,52	-2,66	-1,14	-2,33	>1730
5	71	2,21	-1,80	0,41	-1,92	1375
6	72	1,92	-2,27	-0,35	-2,27	1570
Mean 1967-72		2,02	-2,40	-0,38		

10 Tunsbergdalsbreen - 50,1 km² (1964)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1966	1,57	-2,66	-1,09	-1,09	1640
2	67	3,31	-1,52	1,79	0,70	1160
3	68	2,74	-2,70	0,04	0,74	1550
4	69	1,53	-3,22	-1,69	-0,95	1700
5	1970	1,54	-2,38	-0,84	-1,79	1590
6	71	2,36	-1,79	0,57	-1,22	1240
7	72	2,02	-2,52	-0,50	-1,72	1490
Mean 1966-72		2,15	-2,40	-0,25		

11 Nigardsbreen - 47,8 km² (1984)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1962	2,88	-0,63	2,25	2,25	1260
2	63	1,87	-2,09	-0,22	2,03	1550
3	64	2,13	-1,18	0,95	2,98	1400
4	65	2,29	-1,38	0,91	3,89	1395
5	66	1,76	-2,68	-0,92	2,97	1700
6	67	3,40	-1,24	2,16	5,13	1310
7	68	2,72	-2,50	0,22	5,35	1550
8	69	1,95	-3,26	-1,31	4,04	1850
9	1970	1,73	-2,29	-0,56	3,48	1650
10	71	2,11	-1,29	0,82	4,30	1400
11	72	1,88	-2,02	-0,14	4,16	1570
12	73	2,40	-1,30	1,10	5,26	1410
13	74	2,06	-1,58	0,48	5,74	1490
14	75	2,50	-2,23	0,27	6,01	1450
15	76	2,88	-2,48	0,40	6,41	1540
16	77	1,52	-2,29	-0,77	5,64	1650
17	78	2,12	-2,25	-0,13	5,51	1590
18	79	2,75	-2,04	0,71	6,22	1500
19	1980	1,77	-2,99	-1,22	5,00	1730
20	81	2,19	-1,88	0,31	5,31	1560
21	82	1,94	-2,36	-0,42	4,89	1600
22	83	3,02	-1,93	1,09	5,98	1445
23	84	2,49	-2,15	0,34	6,32	1500
24	85	1,77	-1,87	-0,10	6,22	1590
25	86	1,61	-1,71	-0,10	6,12	1590
26	87	2,73	-1,25	1,48	7,60	1350
27	88	2,24	-3,13	-0,89	6,71	1660
28	89	4,05	-0,85	3,20	9,91	1175
29	1990	3,52	-1,75	1,77	11,68	1430
30	91	1,95	-1,75	0,20	11,88	1520
31	92	3,16	-1,56	1,60	13,48	1360
32	93	3,13	-1,28	1,85	15,33	1300
33	94	2,28	-1,72	0,56	15,89	1400
34	95	3,16	-1,97	1,19	17,08	1320
35	96	1,40	-1,81	-0,41	16,67	1660
36	97	2,66	-2,62	0,04	16,71	1500
37	98	2,50	-1,53	0,97	17,68	1350
38	99	2,38	-2,21	0,17	17,85	1470
39	2000	3,38	-1,66	1,72	19,57	1250
Mean 1962-2000		2,42	-1,92	0,50		

12 Store Supphellebreen - 12,0 km² (1966)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1964	2,20	-1,50	0,70	0,70	1190
2	65	2,32	-1,76	0,56	1,26	1250
3	66	1,63	-2,40	-0,77	0,49	1590
4	67	2,72	-1,50	1,22	1,71	1190
5	73			1,50	1,50	
6	74			0,80	2,30	
7	75			1,00	3,30	
8	79			1,10	1,10	
9	1980			-1,40	-0,30	
10	81			0,20	-0,10	
11	82			-1,70	-1,80	
Mean 1964-67		2,22	-1,79	0,43		
Mean 1973-75				1,10		
Mean 1979-82				-0,45		

13 Austdalsbreen - 11,8 km² (1988)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1988	1,94	-3,22	-1,28	-1,28	1570
2	89	3,18	-1,34	1,84	0,56	1275
3	1990	3,65	-2,45	1,20	1,76	1310
4	91	1,64	-1,64	0,00	1,76	1435
5	92	2,80	-2,26	0,54	2,30	1375
6	93	2,60	-1,69	0,91	3,21	1320
7	94	1,81	-1,88	-0,07	3,14	1425
8	95	2,72	-2,10	0,62	3,76	1360
9	96	1,20	-2,27	-1,07	2,69	1565
10	97	2,67	-3,20	-0,53	2,16	1450
11	98	2,20	-2,01	0,19	2,35	1420
12	99	2,08	-2,56	-0,48	1,87	1435
13	2000	2,77	-1,66	1,11	2,98	1315
Mean 1988-2000		2,40	-2,18	0,23		

14 Spørteggbreen - 27,9 km² (1988)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1988	1,61	-3,15	-1,54	-1,54	>1770
2	89	2,76	-1,62	1.14	-0,40	1410
3	1990	3,34	-2,33	1,01	0,61	1390
4	91	1,40	-1,37	0,03	0,64	1540
Mean 1988-91		2,28	-2,12	0,16		

15 Harbardsbreen - 13,2 km² (1996)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1997	2,17	-2,72	-0,55	-0,55	>1960
2	98	1,66	-1,60	0,06	-0,49	1500
3	99	1,81	-2,15	-0,34	-0,83	>1960
4	2000	2,30	-1,52	0,78	-0,05	1250
Mean 1997-2000		1,99	-2,00	-0,01		

16 Rembesdalskåka - 17,2 km^2 (1995)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1963	1,15	-2,55	-1,40	-1,40	>1860
2	64	1,85	-1,31	0,54	-0,86	1620
3	65	2,05	-1,54	0,51	-0,35	1620
4	66	1,60	-2,24	-0,64	-0,99	1750
5	67	2,44	-1,25	1,19	0,20	1540
6	68	2,68	-2,15	0,53	0,73	1600
7	69	1,07	-2,97	-1,90	-1,17	>1860
8	1970	1,29	-1,89	-0,60	-1,77	1780
9	71	2,02	-1,28	0,74	-1,03	1600
10	72	1,78	-1,86	-0,08	-1,11	1650
11	73	2,62	-1,79	0,83	-0,28	1570
12	74	1,91	-1,50	0,41	0,13	1615
13	75	2,25	-2,10	0,15	0,28	1620
14	76	2,45	-2,30	0,15	0,43	1620
15	77	1,20	-1,92	-0,72	-0,29	>1860
16	78	1,80	-2,10	-0,30	-0,59	
17	79	2,40	-2,10	0,30	-0,29	
18	1980	1,45	-2,85	-1,40	-1,69	>1860
19	81	2,65	-1,80	0,85	-0,84	1590
20	82	1,40	-2,10	-0,70	-1,54	1800
21	83	3,75	-2,05	1,70	0,16	1450
22	84	2,05	-2,15	-0,10	0,06	1675
23	85	1,48	-2,00	-0,52	-0,46	1715
24	86	1,47	-1,57	-0,10	-0,56	1670
25	87	2,08	-1,14	0,94	0,38	1535
26	88	1,98	-3,13	-1,15	-0,77	1860
27	89	3,48	-1,37	2,11	1,34	1420
28	1990	3,65	-1,72	1,93	3,27	1450
29	91	1,52	-1,61	-0,09	3,18	1660
30	92	3,71	-1,72	1,99	5,17	1525
31	93	2,82	-0,91	1,91	7,08	1450
32	94	1,79	-1,63	0,16	7,24	1600
33	95	2,44	-2,14	0,30	7,54	1575
34	96	0,99	-2,10	-1,11	6,43	>1860
35	97	2,94	-3,41	-0,47	5,96	1700
36	98	2,47	-1,78	0,69	6,65	1585
37	99	2,04	-1,99	0,05	6,70	1685
38	2000	2,93	-1,50	1,43	8,13	~~1400~~ 1425
Mean 1963-2000		2,15	-1,93	0,21		

17 Omnsbreen - 1,5 km^2 (1969)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1966	1,44	-2,28	-0,84	-0,84	
2	67	2,21	-1,72	0,49	-0,35	
3	68	2,20	-2,38	-0,18	-0,53	1520
4	69	1,09	-3,68	-2,59	-3,12	
5	1970	1,12	-2,62	-1,50	-4,62	
Mean 1966-70		1,61	-2,54	-0,92		

18 Midtdalsbreen - 7,4 km^2 (1995)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	2000	2,89	-1,57	1,32	1,32	1500

19 Tverråbreen - 5,9 km^2 ()

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1962	2,03	-1,28	0,75	0,75	
2	63	1,24	-2,46	-1,22	-0,47	
Mean 1962-63		1,64	-1,87	-0,24		

20 Blåbreen - 3,6 km^2 (1961)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1962	1,15	-0,35	0,80	0,80	<1550
2	63	0,85	-1,71	-0,86	-0,06	1970
Mean 1962-63		1,00	-1,03	-0,03		

21 Storbreen - 5,4 km^2 (1997)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	49	2,28	-2,08	0,20	0,20	1650
2	1950	1,52	-1,81	-0,29	-0,09	1750
3	51	1,13	-1,67	-0,54	-0,63	1770
4	52	1,44	-1,13	0,31	-0,32	1630
5	53	1,40	-2,25	-0,85	-1,17	1850
6	54	1,21	-1,98	-0,77	-1,94	1830
7	55	1,57	-2,06	-0,49	-2,43	1800
8	56	1,31	-1,48	-0,17	-2,60	1705
9	57	1,42	-1,37	0,05	-2,55	1680
10	58	1,54	-1,62	-0,08	-2,63	1700
11	59	1,07	-2,35	-1,28	-3,91	1930
12	1960	0,98	-2,07	-1,09	-5,00	1910
13	61	1,10	-1,62	-0,52	-5,52	1820
14	62	1,54	-0,82	0,72	-4,80	1510
15	63	0,96	-2,14	-1,18	-5,98	1900
16	64	1,16	-0,95	0,21	-5,77	1655
17	65	1,54	-1,2	0,34	-5,43	1650
18	66	1,25	-1,86	-0,61	-6,04	1815
19	67	1,89	-1,17	0,72	-5,32	1570
20	68	1,64	-1,59	0,05	-5,27	1700
21	69	1,22	-2,64	-1,42	-6,69	2020
22	1970	0,97	-1,69	-0,72	-7,41	1840
23	71	1,46	-1,28	0,18	-7,23	1690
24	72	1,39	-1,7	-0,31	-7,54	1770
25	73	1,48	-1,4	0,08	-7,46	1705
26	74	1,26	-1,02	0,24	-7,22	1630
27	75	1,55	-1,7	-0,15	-7,37	1760
28	76	1,81	-1,9	-0,09	-7,46	1740
29	77	0,94	-1,48	-0,54	-8,00	1840
30	78	1,26	-1,7	-0,44	-8,44	1815
31	79	1,55	-1,45	0,10	-8,34	1700
32	1980	0,99	-2,3	-1,31	-9,65	1975
33	81	1,30	-1,4	-0,10	-9,75	1730
34	82	1,28	-1,75	-0,47	-10,22	1780
35	83	1,90	-1,7	0,20	-10,02	1625
36	84	1,70	-2	-0,30	-10,32	1760
37	85	1,20	-1,6	-0,40	-10,72	1790
38	86	1,05	-1,37	-0,32	-11,04	1770
39	87	1,55	-1,23	0,32	-10,72	1580
40	88	1,45	-2,4	-0,95	-11,67	1970
41	89	2,30	-1,1	1,20	-10,47	1550
42	1990	2,60	-1,35	1,25	-9,22	1530
43	91	1,26	-1,41	-0,15	-9,37	1740
44	92	1,61	-1,53	0,08	-9,29	1715
45	93	1,81	-1,06	0,75	-8,54	1610
46	94	1,52	-1,77	-0,25	-8,79	1800
47	95	1,77	-1,93	-0,16	-8,95	1810
48	96	0,81	-1,84	-1,03	-9,98	1890
49	97	1,75	-2,78	-1,03	-11,01	1875
50	98	1,55	-1,33	0,22	-10,79	1690
51	99	1,67	-1,91	-0,24	-11,03	1850
52	2000	2,04	-1,49	0,55	-10,48	1650
Mean 1949-2000		1,46	-1,66	-0,20		

22 Vestre Memurubre - 9,0 km^2 (1966)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1968	1,70	-1,46	0,24	0,24	1820
2	69	1,05	-2,11	-1,06	-0,82	2170
3	1970	0,84	-1,63	-0,79	-1,61	1990
4	71	1,30	-1,19	0,11	-1,50	1845
5	72	1,19	-1,47	-0,28	-1,78	1885
Mean 1968-72		1,22	-1,57	-0,36		

23 Austre Memurubre - 8,7 km^2 (1966)

No. of years	year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1968	1,77	-1,76	0,01	0,01	1960
2	69	0,99	-2,45	-1,46	-1,45	2130
3	1970	0,81	-1,71	-0,90	-2,35	2090
4	71	1,33	-1,51	-0,18	-2,53	1960
5	72	1,02	-1,42	-0,40	-2,93	1985
Mean 1968-72		1,18	-1,77	-0,59		

24 Hellstugubreen - 2,9 km² (1997)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1962	1,18	-0,40	0,78	0,78	
2	63	0,94	-1,92	-0,98	-0,20	2020
3	64	0,71	-0,83	-0,12	-0,32	1900
4	65	1,29	-0,77	0,52	0,20	1690
5	66	0,95	-1,62	-0,67	-0,47	1940
6	67	1,48	-0,93	0,55	0,08	1800
7	68	1,38	-1,49	-0,11	-0,03	1875
8	69	0,95	-2,23	-1,28	-1,31	2130
9	1970	0,70	-1,70	-1,00	-2,31	2020
10	71	1,12	-1,25	-0,13	-2,44	1860
11	72	0,94	-1,43	-0,49	-2,93	1950
12	73	1,20	-1,41	-0,21	-3,14	1880
13	74	1,00	-0,76	0,24	-2,90	1785
14	75	1,35	-1,71	-0,36	-3,26	1950
15	76	1,16	-1,89	-0,73	-3,99	1970
16	77	0,68	-1,40	-0,72	-4,71	2075
17	78	1,05	-1,59	-0,54	-5,25	1890
18	79	1,43	-1,45	-0,02	-5,27	1820
19	1980	0,81	-2,05	-1,24	-6,51	2050
20	81	1,06	-1,39	-0,33	-6,84	1950
21	82	0,85	-1,20	-0,35	-7,19	1920
22	83	1,47	-1,30	0,17	-7,02	1820
23	84	1,22	-1,73	-0,51	-7,53	1965
24	85	1,11	-1,40	-0,29	-7,82	1880
25	86	0,78	-1,27	-0,49	-8,31	1940
26	87	1,15	-0,70	0,45	-7,86	1690
27	88	1,28	-2,32	-1,04	-8,90	2025
28	89	1,62	-0,90	0,72	-8,18	1660
29	1990	1,81	-1,15	0,66	-7,52	1640
30	91	0,98	-1,43	-0,45	-7,97	1950
31	92	1,17	-1,03	0,14	-7,83	1850
32	93	1,25	-0,95	0,30	-7,53	1670
33	94	1,26	-1,19	0,07	-7,46	1850
34	95	1,42	-1,54	-0,12	-7,58	1885
35	96	0,65	-1,39	-0,74	-8,32	1955
36	97	1,12	-2,77	-1,65	-9,97	2200
37	98	1,00	-1,02	-0,02	-9,99	1870
38	99	1,22	-1,64	-0,42	-10,41	1930
39	2000	1,26	-1,16	0,10	-10,31	1840
Mean 1962-2000		1,13	-1,39	-0,26		

25 Gråsubreen - 2,3 km² (1997)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1962	0,86	-0,09	0,77	0,77	1870
2	63	0,40	-1,11	-0,71	0,06	2275
3	64	0,39	-0,71	-0,32	-0,26	2160
4	65	0,77	-0,36	0,41	0,15	1900
5	66	0,72	-1,01	-0,29	-0,14	2150
6	67	1,45	-0,74	0,71	0,57	1870
7	68	1,03	-1,11	-0,08	0,49	2140
8	69	0,74	-2,04	-1,30	-0,81	2275
9	1970	0,57	-1,23	-0,66	-1,47	2200
10	71	0,49	-0,96	-0,47	-1,94	2200
11	72	0,66	-1,30	-0,64	-2,58	2240
12	73	0,72	-1,61	-0,89	-3,47	2275
13	74	0,58	-0,24	0,34	-3,13	1870
14	75	0,91	-1,86	-0,95	-4,08	2275
15	76	0,62	-1,62	-1,00	-5,08	2275
16	77	0,51	-0,90	-0,39	-5,47	2275
17	78	0,67	-0,89	-0,22	-5,69	2140
18	79	0,91	-0,87	0,04	-5,65	2025
19	1980	0,46	-1,35	-0,89	-6,54	2225
20	81	0,62	-0,81	-0,19	-6,73	2180
21	82	0,50	-1,01	-0,51	-7,24	2275
22	83	0,94	-0,99	-0,05	-7,29	2090
23	84	0,98	-1,35	-0,37	-7,66	2275
24	85	0,75	-0,75	0,00	-7,66	2100
25	86	0,42	-1,18	-0,76	-8,42	2275
26	87	0,94	-0,22	0,72	-7,70	1870
27	88	1,08	-1,66	-0,58	-8,28	2195
28	89	1,12	-0,67	0,45	-7,83	1870
29	1990	1,33	-0,60	0,73	-7,10	1870
30	91	0,67	-1,19	-0,52	-7,62	1950
31	92	0,70	-0,80	-0,10	-7,72	
32	93	0,93	-0,51	0,42	-7,30	<1850
33	94	1,16	-1,16	0,00	-7,30	2075
34	95	1,19	-1,30	-0,11	-7,41	2180
35	96	0,53	-0,98	-0,45	-7,86	2205
36	97	0,70	-2,39	-1,69	-9,55	>2290
37	98	0,78	-0,67	0,11	-9,44	undef.
38	99	0,91	-1,30	-0,39	-9,83	2210
39	2000	0,87	-0,92	-0,05	-9,88	undef.
Mean 1962-2000		0,78	-1,04	-0,25		

26 Charles Rabots Bre - 1,1 km² (1965)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1970			-1,90	-1,90	
2	71			0,47	-1,43	
3	72			-1,04	-2,47	
4	73			1,44	-1,03	
Mean 1970-73				-0,26		

27 Austre Okstindbre - 14,0 km² (1962)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1987	2,30	-1,60	0,70	0,70	1280
2	88	1,50	-3,40	-1,90	-1,20	>1750
3	89	3,70	-2,20	1,50	0,30	1275
4	1990	3,00	-2,70	0,30	0,60	1310
5	91	1,80	-2,30	-0,50	0,10	1315
6	92	2,88	-1,65	1,23	1,33	1260
7	93	2,22	-2,01	0,21	1,54	1290
8	94	1,45	-1,62	-0,17	1,37	1310
9	95	2,25	-1,79	0,46	1,83	1280
10	96	1,62	-1,92	-0,30	1,53	1330
Mean 1987-96		2,27	-2,12	0,15		

28 Høgtuvbreen - 2,6 km² (1972)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1971	3,05	-3,78	-0,73	-0,73	950
2	72	3,34	-4,30	-0,96	-1,69	970
3	73	3,90	-2,82	1,08	-0,61	720
4	74	3,46	-3,68	-0,22	-0,83	900
5	75	3,00	-2,27	0,73	-0,10	760
6	76	3,66	-2,75	0,91	0,81	730
7	77	2,20	-2,72	-0,52	0,29	900
Mean 1971-77		3,23	-3,19	0,04		

29 Svartisheibreen - 5,5 km² (1985)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1988	2,42	-4,03	-1,61	-1,61	1180
2	89	3,72	-1,36	2,36	0,75	900
3	1990	3,79	-2,97	0,82	1,57	930
4	91	2,61	-2,44	0,17	1,74	950
5	92	3,89	-2,68	1,21	2,95	890
6	93	3,50	-2,59	0,91	3,86	910
7	94	1,83	-1,85	-0,02	3,84	975
Mean 1988-94		3,11	-2,56	0,55		

30 Engabreen - 38,0 km² (1968)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1970	2,05	-3,04	-0,99	-0,99	1280
2	71	3,20	-2,19	1,01	0,02	1070
3	72	3,22	-3,29	-0,07	-0,05	1150
4	73	4,37	-1,65	2,72	2,67	830
5	74	3,39	-2,59	0,80	3,47	1030
6	75	3,18	-1,57	1,61	5,08	960
7	76	3,86	-1,45	2,41	7,49	910
8	77	2,08	-1,20	0,88	8,37	1000
9	78	2,48	-2,99	-0,51	7,86	1250
10	79	3,64	-3,22	0,42	8,28	1130
11	1980	2,68	-3,18	-0,50	7,78	1270
12	81	2,91	-1,93	0,98	8,76	965
13	82	2,27	-1,43	0,84	9,60	1030
14	83	2,34	-1,28	1,06	10,66	1020
15	84	3,83	-2,78	1,05	11,71	1000
16	85	1,50	-2,40	-0,90	10,81	1375
17	86	2,70	-2,45	0,25	11,06	1170
18	87	2,57	-1,63	0,94	12,00	1000
19	88	2,26	-4,05	-1,79	10,21	1400
20	89	4,62	-1,45	3,17	13,38	890
21	1990	3,49	-2,64	0,85	14,23	1035
22	91	2,83	-2,14	0,69	14,92	1090
23	92	4,05	-1,71	2,34	17,26	875
24	93	3,06	-2,02	1,04	18,30	985
25	94	1,95	-1,53	0,42	18,72	1050
26	95	3,50	-1,76	1,74	20,46	940
27	96	2,97	-2,14	0,83	21,29	970
28	97	4,44	-3,22	1,22	22,51	1010
29	98	2,98	-2,77	0,21	22,72	1100
30	99	2,12	-2,15	-0,03	22,69	1215
31	2000	2,76	-1,27	1,49	24,18	970
Mean 1970-2000		3,01	-2,23	0,78		

31 Storglombreen - 62,4 km^2 (1968)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1985	1,40	-2,59	-1,19	-1,19	1300
2	86	2,45	-2,87	-0,42	-1,61	1100
3	87	2,32	-1,87	0,45	-1,16	1020
4	88	2,06	-3,88	-1,82	-2,98	1350
5	2000	2,66	-1,55	1,11	1,11	1000
Mean 1985-88		2,06	-2,80	-0,75		

32 Tretten-null-tobreen - 4,9 km^2 (1968)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1985	1,47	-3,20	-1,73	-1,73	>1260
2	86	2,40	-2,84	-0,44	-2,17	1100
Mean 1985-86		1,94	-3,02	-1,09		

33 Glombreen - 2,2 km^2 (1953)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1954	2,30	-3,50	-1,20	-1,20	
2	55	2,60	-2,70	-0,10	-1,30	
3	56	1,50	-2,10	-0,60	-1,90	
Mean 1954-56		2,13	-2,77	-0,63		

34 Kjølbreen - 3,9 km^2 (1953)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1954	1,90	-2,60	-0,70	-0,70	
2	55	2,10	-2,80	-0,70	-1,40	
3	56	1,10	-1,10	0,00	-1,40	
Mean 1954-56		1,70	-2,17	-0,47		

35 Trollbergdalsbreen - 1,6 km^2 (1985)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1970	1,74	-4,21	-2,47	-2,47	>1370
2	71	2,14	-2,47	-0,33	-2,80	1100
3	72	2,44	-3,68	-1,24	-4,04	1160
4	73	3,19	-2,43	0,76	-3,28	<900
5	74	2,57	-2,97	-0,40	-3,68	1090
6	75			-0,28	-3,96	1090
7	1990	2,94	-3,23	-0,29	-0,29	1075
8	91	2,29	-2,45	-0,16	-0,45	1070
9	92	2,63	-2,13	0,50	0,05	<900
10	93	2,45	-2,38	0,07	0,12	1045
11	94	1,49	-2,59	-1,10	-0,98	1180
Mean 1970-74(75)		2,42	-3,15	-0,66		
Mean 1990-94		2,36	-2,56	-0,20		

36 Blåisen - 2,2 km^2 (1960)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1963	2,60	-2,40	0,20	0,20	1050
2	64	2,30	-1,67	0,63	0,83	980
3	65	2,00	-1,46	0,54	1,37	960
4	66	1,12	-2,39	-1,27	0,10	>1200
5	67	1,38	-2,35	-0,97	-0,87	1175
6	68	1,62	-1,36	0,26	-0,61	1010
Mean 1963-68		1,84	-1,94	-0,10		

37 Storsteinsfjellbreen - 5,9 km^2 (1993)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1964	1,85	-1,20	0,65	0,65	1220
2	65	1,69	-1,25	0,44	1,09	1270
3	66	1,05	-1,88	-0,83	0,26	1500
4	67	1,37	-1,77	-0,40	-0,14	1450
5	68	1,44	-0,99	0,45	0,31	1275
6	1991	1,59	-1,63	-0,04	-0,04	1395
7	92	2,21	-1,10	1,11	1,07	1250
8	93	2,10	-1,29	0,81	1,88	1260
9	94	1,15	-1,35	-0,20	1,68	1375
10	95	1,81	-1,24	0,57	2,25	1280
Mean 1964-68		1,48	-1,42	0,06		
Mean 1991-95		1,77	-1,32	0,45		

38 Cainhavarre - 0,7 km^2 (1960)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1965	1,41	-1,20	0,21	0,21	1300
2	66	1,12	-2,07	-0,95	-0,74	>1550
3	67	1,63	-1,79	-0,16	-0,90	1450
4	68	1,31	-1,05	0,26	-0,64	1290
Mean 1965-68		1,37	-1,53	-0,16		

39 Svartfjelljøkelen - 2,7 km^2 (1966)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1978	2,30	-2,40	-0,10	-0,10	
2	79	2,10				
Mean 1978-79		2,20				

40 Langfjordjøkelen - 3,7 km^2 (1994)

No. of	year	bw	bs	bn	Cum. bn	ELA
years		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	89	2,40	-2,96	-0,56	-0,56	870
2	1990	2,74	-3,06	-0,32	-0,88	780
3	91	2,31	-2,31	0,00	-0,88	710
4	92	2,68	-2,49	0,19	-0,69	700
5	93	2,55	-2,35	0,20	-0,49	740
6	96	2,25	-2,23	0,02	0,02	700
7	97	2,65	-3,34	-0,69	-0,67	820
8	98	1,80	-3,24	-1,44	-2,11	>1050
9	99	1,33	-2,91	-1,58	-3,69	970
10	2000	2,51	-3,12	-0,61	-4,30	860
Mean 1989-93		2,54	-2,63	-0,10		
Mean 1996-2000		2,11	-2,97	-0,86		

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