# Glaciological investigations in Norway in 2006

*Bjarne Kjøllmoen (Ed.)*

1
2007

REPORT

# Glaciological investigations in Norway in 2006

The Norwegian Water Resources and Energy Directorate (NVE)
2007

# Report No 1

## Glaciological investigations in Norway in 2006

**Published by:** Norwegian Water Resources and Energy Directorate

**Editor:** Bjarne Kjøllmoen
**Authors:** Liss M. Andreassen, Hallgeir Elvehøy, Miriam Jackson, Bjarne Kjøllmoen, Arve M. Tvede[*], Tron Laumann[**] and Rianne H. Giesen[***]
[*]Statkraft Energi AS
[**]Rælingen videregående skole
[***]Utrecht University, the Netherlands

**Print:** Lobo Media
**Number printed:** 250
**Frontpage photo:** Gråfjellsbrea, a westward-facing outlet glacier from the Southern Folgefonna ice cap. The photo was taken 10th October 2006 by Hallgeir Elvehøy.
**ISSN:** 1502-3540
**ISBN:** 978-82-410-0633-3

**Abstract:** Results of glaciological investigations performed at Norwegian glaciers in 2006 are presented in this report. The main part concerns mass balance investigations. Results from investigations of glacier monitoring are discussed in a separate chapter.

**Subjects:** Glaciology, Mass balance, Glacier length change, Glacier velocity, Surface elevation change, Meteorology, Subglacial laboratory, Net balance modelling

Norwegian Water Resources and Energy Directorate
Middelthunsgate 29
Post office box 5091 Majorstua
N-0301 OSLO

Telephone: +47 22 95 95 95
Telefax: +47 22 95 90 00
Internet: www.nve.no

April 2007

# Contents

# 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 investigations of several Norwegian glaciers. Measurements of mass balance, glacier length change, glacier velocity, meteorology and other glaciological investigations are presented. Most of the investigations were ordered by private companies and have been published previously as reports to the respective companies. The annual results from mass balance and glacier length changes are also reported to the World Glacier Monitoring Service (WGMS) in Switzerland.

The report is published in English with a summary in Norwegian. The purpose of this report is to provide a joint presentation of the investigations and calculations made mainly by NVEs Section for Glaciers and Environmental Hydrology during 2006. The chapters are written by different authors with different objectives, but are presented in a uniform format. The individual authors hold the professional responsibility for the contents of each chapter. The fieldwork and the calculations are mainly the result of co-operative work amongst the personnel at NVE.

Bjarne Kjøllmoen was editor and Miriam Jackson made many corrections and improvements to the text.

Oslo, April 2007

Morten Johnsrud
Director,
Hydrology Department

Rune V. Engeset
Head of section,
Section for Glaciers and
Environmental Hydrology

# Summary


## Mass balance

Mass balance investigations were performed on twelve glaciers in Norway in 2006. Ten of these glaciers are in southern Norway and two are in northern Norway.

The winter balance was lower than average for all twelve measured glaciers in Norway. Rembesdalsskåka (Hardangerjøkulen) had the lowest winter balance since measurements started in 1963.

The summer balance was greater than average for all twelve measured glaciers in the country. Ålfotbreen, Hansebreen and Langfjordjøkelen all had the greatest summer balance since measurements started on each individual glacier in 1963, 1986 and 1989, respectively. In Jotunheimen, both Storbreen and Gråsubreen had the greatest summer balance since 1949 and 1962, respectively.

All twelve measured glaciers had significantly negative net balances. The glaciers in western Norway had the greatest volume loss, and Ålfotbreen (−3.2 m w.e.), Nigardsbreen (−1.4 m w.e.) and Rembesdalsskåka (−2.2 m w.e.) had the greatest deficit since measurements started in the early 1960's. The greatest deficit was measured at Hansebreen with −4.0 m w.e., which is its greatest deficit since measurements started in 1986. All three measured glaciers in Jotunheimen had their most negative net balances ever measured. In northern Norway, Langfjordjøkelen had the greatest deficit (−2.4 m w.e.) since measurements started in 1989, and Engabreen had the second greatest deficit (−1.4 m w.e.) since measurements started in 1970.

## Glacier length change

Glacier length changes were measured at 24 glaciers in southern Norway and four glaciers in northern Norway in 2006. Twenty six of the glacier outlets had a significant retreat in length. Four outlets from the Jostedalsbreen ice cap, Kjenndalsbreen, Brenndalsbreen, Briksdalsbreen and Bergsetbreen had a frontal retreat of more than 100 metres. Gråfjellsbrea, an outlet from Folgefonna, had a retreat of almost 100 metres. Only one outlet glacier (Stegholtbreen in Jostedalsbreen) showed a slight advance (5 m).

# Sammendrag

## Massebalanse

I 2006 ble det utført massebalansemålinger på 12 breer i Norge – ti i Sør-Norge og to i Nord-Norge.

Vinterbalansen ble mindre enn gjennomsnittet på alle de 12 målte breene i Norge. Rembesdalsskåka fikk den minste vinterbalansen siden målingene startet i 1963.

Sommerbalansen ble større enn gjennomsnittet på samtlige 12 målte breer. Både Ålfotbreen, Hansebreen og Langfjordjøkelen fikk den største sommerbalansen siden målingene startet i hhv. 1963, 1986 og 1989. I Jotunheimen fikk både Storbreen og Gråsubreen den største sommerbalansen siden henholdsvis 1949 og 1962.

Samtlige tolv målte breer minket i volum i 2006. Breene på Vestlandet minket mest, og både Ålfotbreen (−3,2 m), Nigardsbreen (−1,4 m) og Rembesdalsskåka (−2,2 m) fikk det største underskuddet siden målingene startet tidlig på 1960-tallet. Det største underskuddet fikk Hansebreen med −4,0 m vannekvivalenter, som er det største underskuddet som er målt siden starten i 1986. I Jotunheimen ble det rekordunderskudd på alle de tre målte breene. I Nord-Norge fikk Langfjordjøkelen (−2,4 m) det største underskuddet siden starten i 1989, mens Engabreen (−1,4 m) fikk det nest største underskuddet siden målingene startet i 1970.

## Lengdeendringer

Lengdeendringer ble målt på 24 breer i Sør-Norge og fire breer i Nord-Norge i 2006. Tjueseks av breutløperne hadde signifikant tilbakegang. Fire utløpere fra Jostedalsbreen; Kjenndalsbreen, Brenndalsbreen, Briksdalsbreen og Bergsetbreen, hadde tilbakegang på mer enn 100 meter. Gråfjellsbrea, en utløper fra Folgefonna, hadde en tilbakegang på nesten 100 meter. Bare én breutløper (Stegholtbreen fra Jostedalsbreen) viste en liten framgang (5 m).

# 1. Glacier investigations in Norway in 2006

## 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 increases 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 decreases.

### Method

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

#### Winter balance

The winter balance is normally measured in April or May by probing to the previous year's summer surface along approximately the same profile each year. Stake readings are used to verify the probings 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 balance

Summer and net balances are obtained from stake measurements, usually performed in September or October (Fig. 1-1). Below the glacier's equilibrium line the net balance is 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 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 either measured using snow-cores or is assumed to be 0.65 g/cm$^3$. The density of melted firn is, depending on the age, assumed to be between 0.65 and 0.80 g/cm$^3$. The density of melted ice is taken as 0.90 g/cm$^3$.

**Figure 1-1**
**Final stake readings at Nigardsbreen in October 2006.**
**Photo: Ole Magnus Tønsberg.**

### Stratigraphic method

The mass balance is usually calculated using the traditional stratigraphic method (Østrem and Brugman 1991), which means the balance between two successive “summer surfaces” (i.e. surface minima). Consequently, the measurements describe the state of the glacier *after* the end of melting and *before* fresh snow has fallen. On some occasions ablation *after* the final measurements in September/October can occur. Strictly speaking, this ablation should be included in that year’s summer balance. However, measuring and calculating this additional ablation cannot be done until the following winter or spring. Thus, it is counted as a negative contribution to the next year’s winter balance.

## Accuracy

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, towers and density pit) and how representative they are. The smoothness of the snow layer is also of importance. The accuracy of soundings and core drillings depends 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 decreases with increasing snow depth.

The accuracy of summer balance is dependent on the number of ablation stakes, the height distribution, how representative they are and on the state of the stakes. Sources of error can be stakes sinking or tilting to one side.

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

As the mass balance is measured and calculated, it is very difficult to quantify the accuracy of the individual factors. The determined values of accuracy are therefore based on a subjective estimate.

## Mass balance program

In 2006 mass balance measurements were performed on 12 glaciers in Norway - 10 in southern Norway and 2 in northern Norway. In southern Norway, 6 of the glaciers have been measured for 44 consecutive years or more. They constitute a west-east profile extending from the maritime Ålfotbreen glacier with an average winter balance of 3.7 m water equivalent to the continental Gråsubreen with an average winter balance of 0.8 m w.eqv. Storbreen in Jotunheimen has the longest series of all glaciers in Norway with 58 years of measurements, while Engabreen at Svartisen has the longest series (37 years) in northern Norway. The location of the glaciers investigated is shown in Figure 1-2.

In the following chapters mass balance studies performed on Norwegian glaciers in 2006 are reported. The numbers from 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 equivalent for each 50 or 100 m height interval. The results are presented in 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.

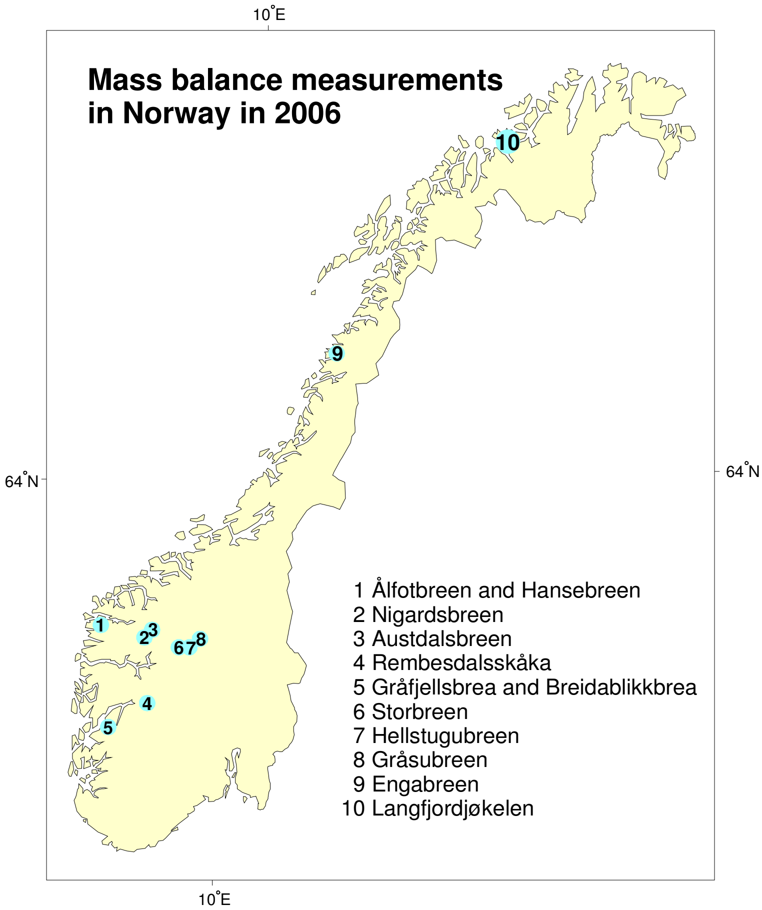



**Figure 1-2**
**Location of the glaciers at which mass balance studies were performed in 2006.**

## Weather conditions and mass balance results

### Wintry weather

In general the 2005/2006 winter season was mild and snow-poor over most of the country. There was a lot of precipitation in November, but due to high temperatures some of the precipitation fell as rain even in high mountain regions. December, January and February were mild and dry, except for some areas in northern Norway where February was snow-rich. The remaining winter season was rather variable. March was cool in the whole country, snow-rich in Finnmark county and dry in southern Norway. April was mild in the north but cold in the south and snow-rich in western Norway.

### Snow accumulation and winter balance

The winter balance was lower than average at all twelve measured glaciers in Norway. The glaciers in western Norway had results of 43 to 73 % of their average winter balance. The western part of Hardangerjøkulen, called Rembesdalsskåka, had the lowest winter balance (0.9 m w.e.) since measurements began in 1963. The glaciers in Jotunheimen had between 60 and 66 % of average and showed the second lowest winter balance since measurements started. In northern Norway, Langfjordjøkelen (65 %) and Engabreen (59 %) both had their third lowest winter balances.

### Summer weather

The summer season in 2006 was warmer than normal over the whole country. June was slightly warmer than normal, but in July and August the mean temperature was considerable higher than normal. September was also exceptionally warm, and was actually the warmest recorded in southern Norway (4.0-4.5 °C above normal) since measurements started in 1867 (according to the Norwegian Meteorological Institute).

### Ablation and summer balance

The summer balance was greater than average at all twelve measured glaciers. The glaciers in western Norway had summer balances between 160 and 170 % of their average. Ålfotbreen and Hansebreen had the greatest summer balance since measurements started in 1963 and 1986, respectively. In Jotunheimen, both Storbreen (177 %) and Gråsubreen (240 %) had the greatest summer balance since measurements started in 1949 and 1962, respectively. In northern Norway, Langfjordjøkelen had the greatest summer balance since measurements started in 1989.

### Net balance

All twelve measured glaciers had negative net balance in 2006. The glaciers in western Norway had the greatest deficit, and Ålfotbreen (–3.2 m w.e.), Nigardsbreen (–1.4 m w.e.) and Rembesdalsskåka (–2.2 m w.e.) all had the greatest mass loss since measurements began in the early 1960s. Hansebreen had the greatest absolute deficit with –4.0 m w.e., which is the greatest mass loss since 1986. The three measured glaciers in Jotunheimen had the greatest deficit in the measuring period and Storbreen had the most negative net balance with –2.1 m w.e. In northern Norway, Langfjordjøkelen (–2.4 m w.e.) had the greatest deficit since 1989 and Engabreen (–1.4 m w.e.) had the second greatest deficit since 1970.

The results from the mass balance measurements in Norway in 2006 are shown in Table 1-1. Winter ($\mathbf{b_w}$,), summer ($\mathbf{b_s}$) and net balance ($\mathbf{b_n}$) are given in metres water equivalent (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 (minimum eight years of measurements). The net balance results are compared with the mean net balance in the same way. **ELA** is the equilibrium line altitude (m a.s.l.) and **AAR** is the accumulation area ratio (%).

**Table 1-1**
**Review of the results from mass balance measurements performed in Norway in 2006. The glaciers in southern Norway are listed from west to east. Each glacier is reported in the number system of the World Glacier Monitoring Service (WGMS). All ID's begin with N4A000, so only the last five characters are shown here.**

| *Glacier* | *WGMS No.* | *Period* | *Area (km²)* | *Altitude (m a.s.l.)* | *$b_w$ (m)* | *% of average* | *$b_s$ (m)* | *% of average* | *$b_n$ (m)* | *$b_n$ middle* | *ELA* | *AAR %* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ålfotbreen | *BL004* | 1963-06 | 4.5 | 903-1382 | 2.69 | 72 | –5.88 | 168 | –3.19 | 0.22 | >1382 | 0 |
| *Hansebreen* | *BO002* | 1986-06 | 3.1 | 930-1327 | 2.45 | 70 | –6.43 | 166 | –3.98 | –0.38 | >1327 | 0 |
| *Breidablikkbrea* | *AJ001* | 1963-68<br>2003-06 | 3.9<br>3.6 | 1219-1660<br>1236-1659 | 1.49 | [1)]65 | –4.43 | [1)]158 | –2.94 | –0.19<br>[1)]–0.52 | >1659 | 0 |
| *Gråfjellsbrea* | *AK007* | 1964-68<br>1974-75<br>2003-06 | 9.4<br>8.9 | 1039-1660<br>1051-1659 | 1.40 | [2)]58 | –4.44 | [2)]173 | –3.04 | 0.20<br>[2)]–0.16 | >1659 | 0 |
| *Nigardsbreen* | *A4014* | 1962-06 | 47.8 | 320-1960 | 1.75 | 73 | –3.15 | 160 | –1.40 | 0.42 | 1850 | 4 |
| *Austdalsbreen* | *A4023* | 1988-06 | 11.8 | 1200-1757 | 1.32 | 59 | [3)]–3.38 | 138 | –2.06 | –0.21 | >1757 | 0 |
| *Rembesdalsskåka* | *AO001* | 1963-06 | 17.1 | 1020-1865 | 0.90 | 43 | –3.12 | 158 | –2.22 | 0.13 | >1860 | 0 |
| *Storbreen* | *AD041* | 1949-06 | 5.4 | 1390-2100 | 0.86 | 60 | –3.01 | 177 | –2.15 | –0.26 | >2100 | 0 |
| *Hellstugubreen* | *AD011* | 1962-06 | 3.0 | 1480-2210 | 0.73 | 66 | –2.74 | 191 | –2.01 | –0.33 | >2210 | 0 |
| *Gråsubreen* | *AB047* | 1962-06 | 2.3 | 1830-2290 | 0.51 | 66 | –2.59 | 240 | –2.08 | –0.31 | >2290 | 0 |
| *Engabreen* | *C4011* | 1970-06 | 39.6 | 10-1575 | 1.73 | 59 | –3.16 | 135 | –1.43 | 0.64 | 1325 | 26 |
| *Langfjordjøkelen* | *ET008* | 1989-93<br>1996-06 | 3.7 | 280-1050 | 1.42 | [4)]65 | –3.83 | [4)]126 | –2.41 | –0.10<br>[4)]–0.86 | >1050 | 0 |

*[1)]Calculated for the measured periods 1963-68 and 2003-05*
*[2)]Calculated for the measured periods 1964-68, 1974-74 and 2003-05*
*[3)]Contribution from calving amounts to 0.09 m for $b_s$*
*[4)]Calculated for the measured periods 1989-93 and 1996-2005*

Figure 1-3 gives a graphical presentation of the mass balance results in southern Norway for 2006. The west-east gradient is evident for both winter and summer balances. All ten glaciers have significant negative net balance.

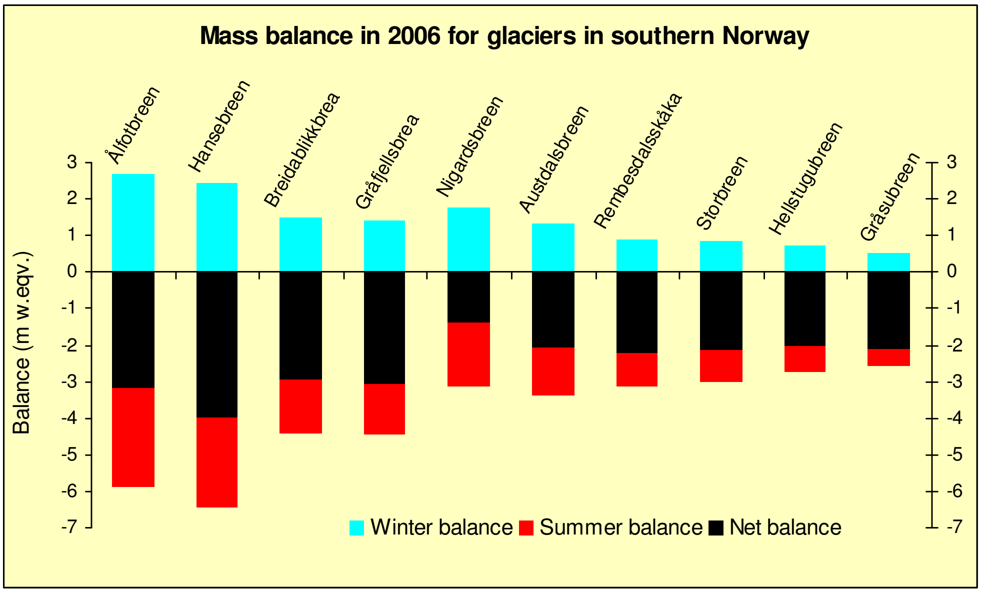



**Figure 1-3**
**Mass balance 2006 in southern Norway. The glaciers are listed from west to east.**

The cumulative net balance for glaciers in southern Norway with long-time series during the period 1963-2006 is shown in Figure 1-4. The maritime glaciers – Ålfotbreen, Nigardsbreen and Rembesdalsskåka showed a marked increase in volume during the period 1989-95. The surplus was mainly the result of several winters with heavy snowfall. The results for 2006, however, show a negative net balance for all measured glaciers, including the maritime ones. Over the period 2001-2006 the net balance was negative in five of the six years for most of the measured glaciers in southern Norway. This volume decrease is due to a combination of low winter precipitation and warm summers.

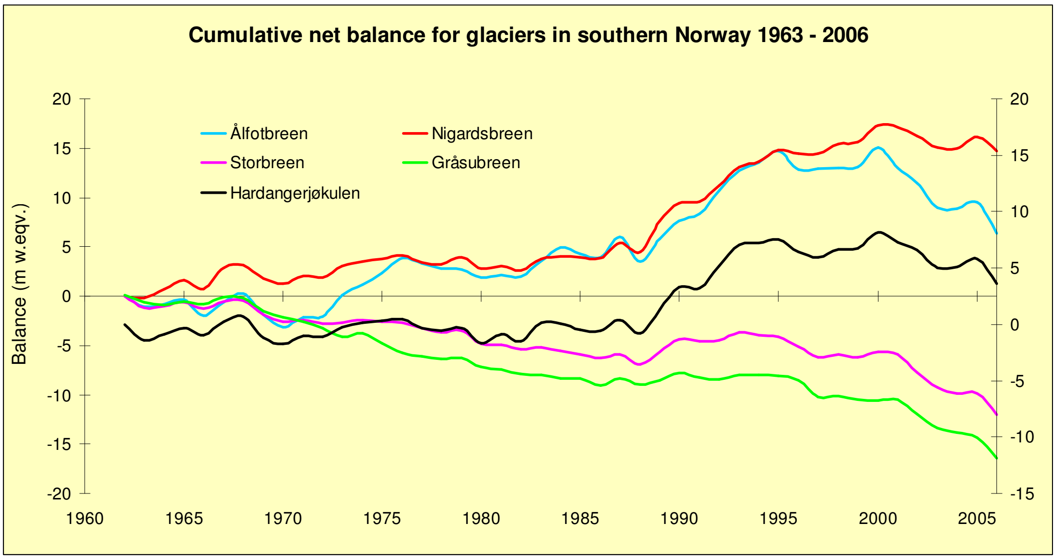



**Figure 1-4**
**Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka, Storbreen and Gråsubreen during the period 1963-2006.**

## Other investigations

Glacier length change measurements were performed at 28 glaciers in Norway in 2006. Some of the glaciers have a measurement series going back to about 1900. The length changes are described in a separate chapter (chap. 13).

Glacier dynamics (velocity and surface elevation change) have been studied at Austdalsbreen since 1987 (chap. 5), at Engabreen since 2000 (chap. 11) and at Storbreen since 2004 (chap. 8). The measurements continued in 2006.

Recent changes on some small glaciers in the Aurland mountains have been studied (chap. 7).

Meteorological observations have been performed at Hardangerjøkulen (chap. 6), Storbreen (chap. 8) and Engabreen (chap. 11).

Svartisen Subglacial Laboratory was initiated in 1992 and has since been used by researchers from several different countries (Jackson 2000). An overview of activities in the laboratory is given in chapter 11.

Due to avalanche risk Baklibreen is the subject of a simple monitoring program which continued in 2006 (chap. 13).

Differences between measured cumulative length change and mapped or photographed changes on Briksdalsbreen have been considerable. To resolve this, supplementary information from repeated mapping and photographs has been analysed, and the glacier length record has been revised (chap. 13).

Based on regression analyses the net balances for 2006 are modelled for Tunsbergdalsbreen (chap. 4) and Svartisheibreen (chap. 11).

# 2. Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45'N, 5°40'E) has an area of 17 $km^2$, and is both the westernmost and the most maritime glacier in Norway. Mass balance studies have been carried out on two adjacent north-facing outlet glaciers - Ålfotbreen (4.5 $km^2$) and Hansebreen (3.1 $km^2$). The westernmost of these two 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 names 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 surroundings, is shown in Figure 2-1.

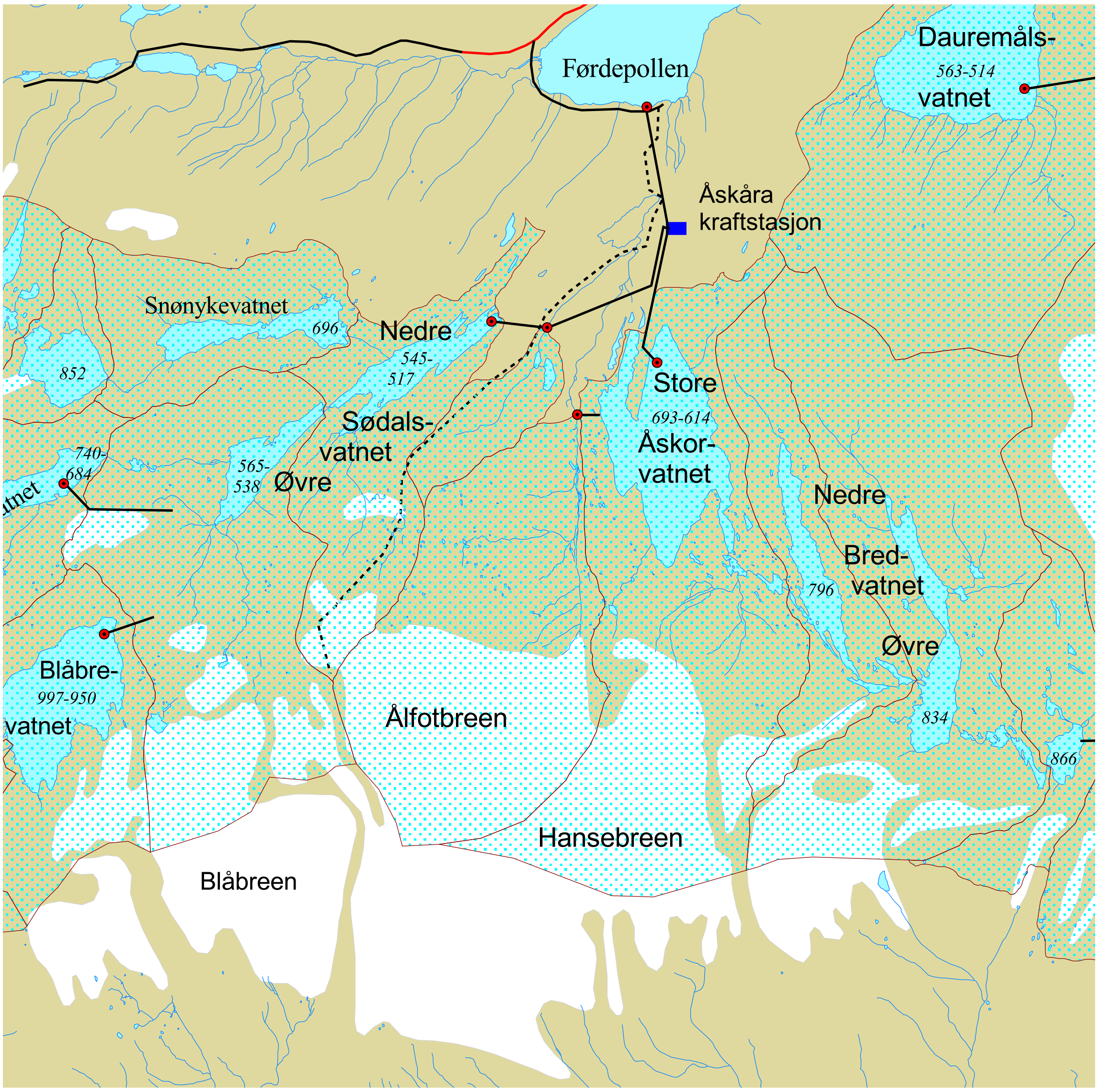



**Figure 2-1**
**Ålfotbreen ice cap and surrounding area, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.**

## 2.1 Mass balance 2006

### Fieldwork

#### Snow accumulation measurements

Snow accumulation measurements were performed from on 4th and 5th May. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Measurement of stakes at positions 12 (960 m a.s.l.), 13 (1080 m a.s.l.), 45 (1180 m a.s.l.), 37 (1225 m a.s.l.), 28 (1240 m a.s.l.) and T49 (1380 m a.s.l.) on Ålfotbreen, and measurement of stakes in positions 50 (1025 m a.s.l.), 60 (1075 m a.s.l.), 80 (1125 m a.s.l.), 85 (1195 m a.s.l.) and 90 (1305 m a.s.l.) on Hansebreen.
- 71 snow depth soundings between 925 and 1380 m elevation on Ålfotbreen, and 61 snow depth soundings between 960 and 1305 m elevation on Hansebreen. The snow depth at Ålfotbreen was generally between 5 and 6.5 m above 1200 m a.s.l. and between 4.5 and 6 m below 1200 m elevation. At Hansebreen the snow depth was generally between 3.5 and 6.5 m over the whole glacier area. The sounding conditions were reasonable on both glaciers, but several ice layers could be mistaken for the summer surface (SS). The probings showed partly varying snow depths at both glaciers. The variation is most distinctive on Hansebreen, where the snow depth could vary from 3.5 to 6.5 m within a small area. The snow depth variation can be due to a rough ice surface, or it can also be influenced by some special wind effects.
- Snow density was measured down to 4.2 m depth (SS at 4.6 m) at stake position 37.

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

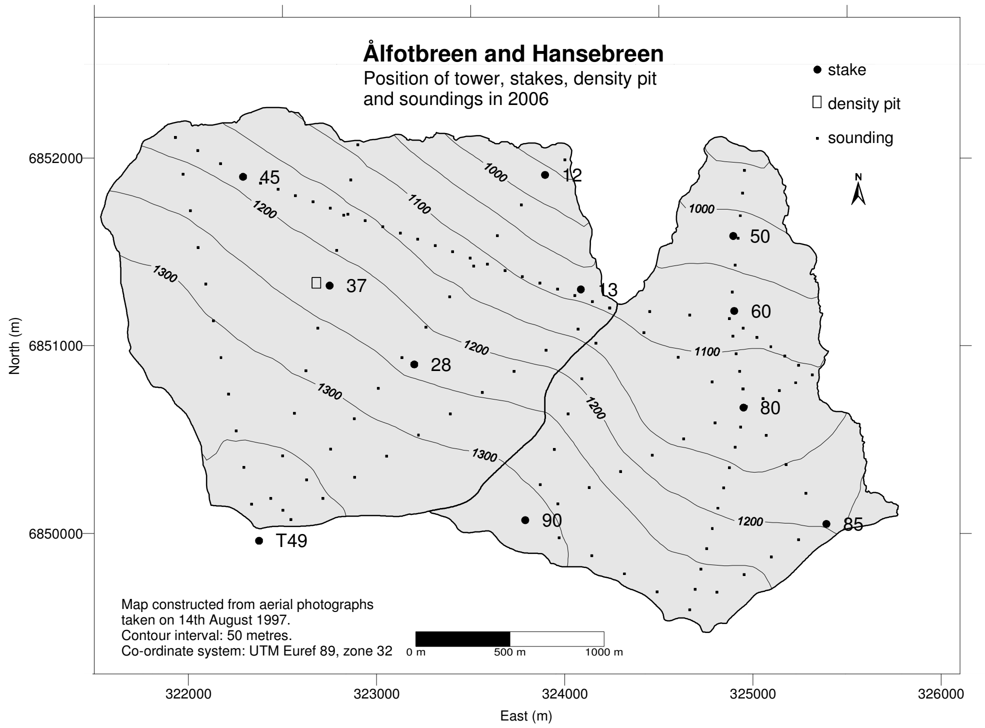



**Figure 2-2**
**Location of stakes, soundings and snow pit at Ålfotbreen and Hansebreen in 2006.**

### Ablation measurements

Ablation was measured on 12th October. The net balance was directly measured on stakes in six different positions on Ålfotbreen and five positions on Hansebreen. There was no snow remaining on the glacier from the winter season 2005/2006. The border between old firn and ice could hardly be defined, but it was probably around 1350 m a.s.l. No fresh snow had fallen at the time of the ablation measurements.

## Results

The calculations are based on a glacier map from 1997.

### 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. There was no melting after the final measurements in October 2005.

A density profile was modelled from the snow density measured at 1225 m a.s.l. The mean snow density of 4.6 m snow was 0.497 g/cm$^3$. The density model was assumed to be representative for both Ålfotbreen and Hansebreen, and all snow depths were converted to water equivalents using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalents) in a diagram. A curve was drawn based on a visual evaluation (Fig. 2-4) and a mean value for each 50 m height interval was estimated (Tab. 2-1).

Winter balance at Ålfotbreen in 2006 was 2.7 ±0.2 m w.e., corresponding to a volume of 12 ±1 mill. m$^3$ of water. The result is 72 % of the mean winter balance for 1963-2005, and 67 % of the mean for 1986-2005 (same period as Hansebreen).

The winter balance at Hansebreen was 2.5 ±0.2 m w.e., corresponding to a volume of 7 ±1 mill. m$^3$ of water. The result is 70 % of the mean value in the period of investigation. There are only three years (2001, 1996 and 1986) with a lower winter balance at Hansebreen.

The winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 2-3). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. Using this method, which is a control of the traditional method, gave the same result at both glaciers.

### Summer balance

The density of melted firn was estimated at between 0.70 and 0.75 g/cm$^3$, while the density of ice was estimated as 0.90 g/cm$^3$.

The summer balance at Ålfotbreen was measured and calculated directly at stakes in six different positions. At 1380 m elevation the measured summer balance was −5.3 m, and at 960 m elevation −7.6 m w.e. Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −5.9 ±0.3 m w.e., corresponding to −26 ±1 mill. m$^3$ of water. The result is 168 % of the average between 1963 and 2005, and 157 % of the average between 1986 and 2005. This is the greatest summer balance measured at Ålfotbreen since measurements began in 1963. The second greatest was in 2002 with −5.3 m w.e.

The summer balance for Hansebreen was measured and calculated at stakes in five different positions. It increased from −6.0 m w.e. at 1305 m elevation to −6.8 m w.e. at 1125 m elevation, and thus, the difference in maximum and minimum stake values was rather small. Usually the summer balance decreases with increasing elevation, but this correlation is not distinct at Hansebreen in 2006. The measured stake values are almost equal in the uppermost and lowest positions, and the greatest values are measured at stakes in the middle height areas. Based on the stake measurements and the estimated density, the summer balance was calculated as −6.4 ±0.3 m w.e., or −20 ±1 mill. $m^3$ of water. The result is 166 % of the mean value, and is the greatest summer balance measured at Hansebreen in the period of investigation. The second highest was in 2002 with −5.4 m w.e.

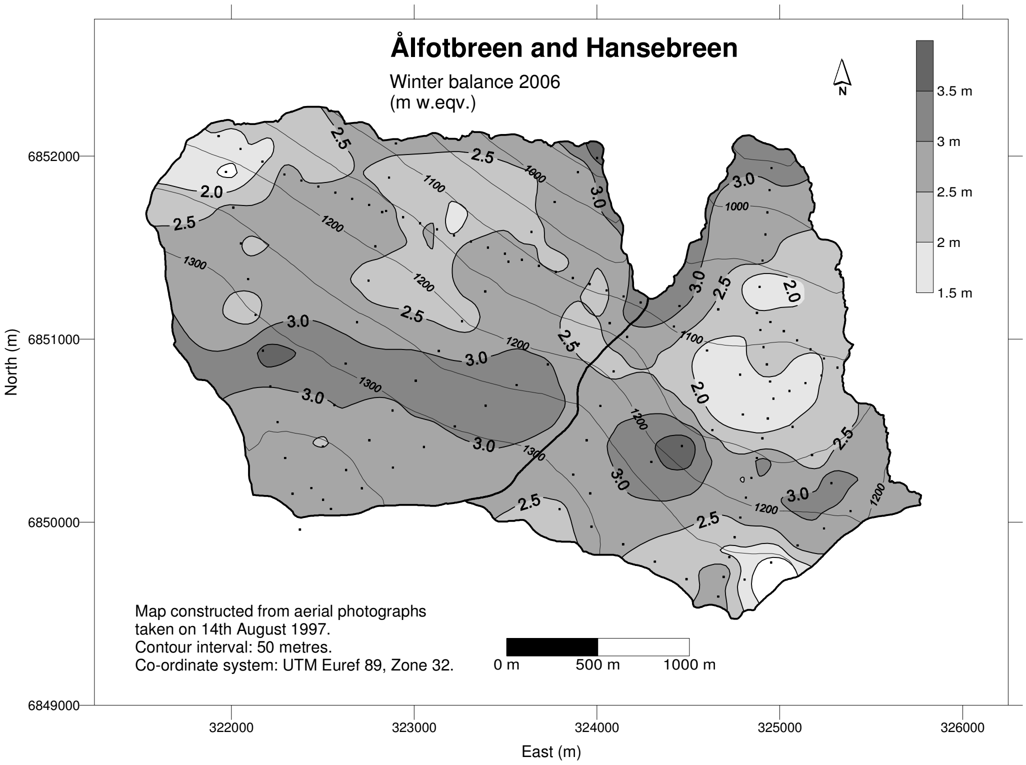



**Figure 2-3**
**Winter balance at Ålfotbreen and Hansebreen in 2006 interpolated from 132 snow depth measurements, shown by (•).**

## Net balance

The net balance at Ålfotbreen for 2006 was negative, at −3.2 ±0.4 m w.e., or a deficit of 14 ±2 mill. $m^3$ of water. The mean net balance between 1963 and 2005 is +0.22 m w.e., and +0.26 m w.e. during 1986-2005 (same measurement period as Hansebreen). This is the greatest deficit measured at Ålfotbreen since 1963. The second greatest deficit was measured in 1988 and 2003, both years with −2.5 m w.e. Since 2000 there is negative net balance for five of the six years. Since measurements started in 1963 the cumulative net balance is +6.3 m w.e. Since 1996, however, the net balance shows a deficit of −8.4 m w.e.

The net balance at Hansebreen was calculated as −4.0 ±0.4 m w.e., or a deficit of 12 ±1 mill. $m^3$ of water. The mean value for the period 1986-2005 is −0.38 m w.e. This is the greatest deficit measured at Hansebreen since 1986, and the sixth successive year with negative net balance. Since measurements began in 1986 the cumulative net balance is −11.6 m w.e.

There was net ablation over the entire glacier surface and accordingly, the equilibrium line altitude (ELA) lies *above* the highest summit on both glaciers (Fig. 2-4). Consequently, the AAR is 0 %.

The mass balance results are shown in Table 2-1. The corresponding curves for specific and volume balance are shown in Figure 2-4. The historical mass balance results are presented in Figure 2-5.

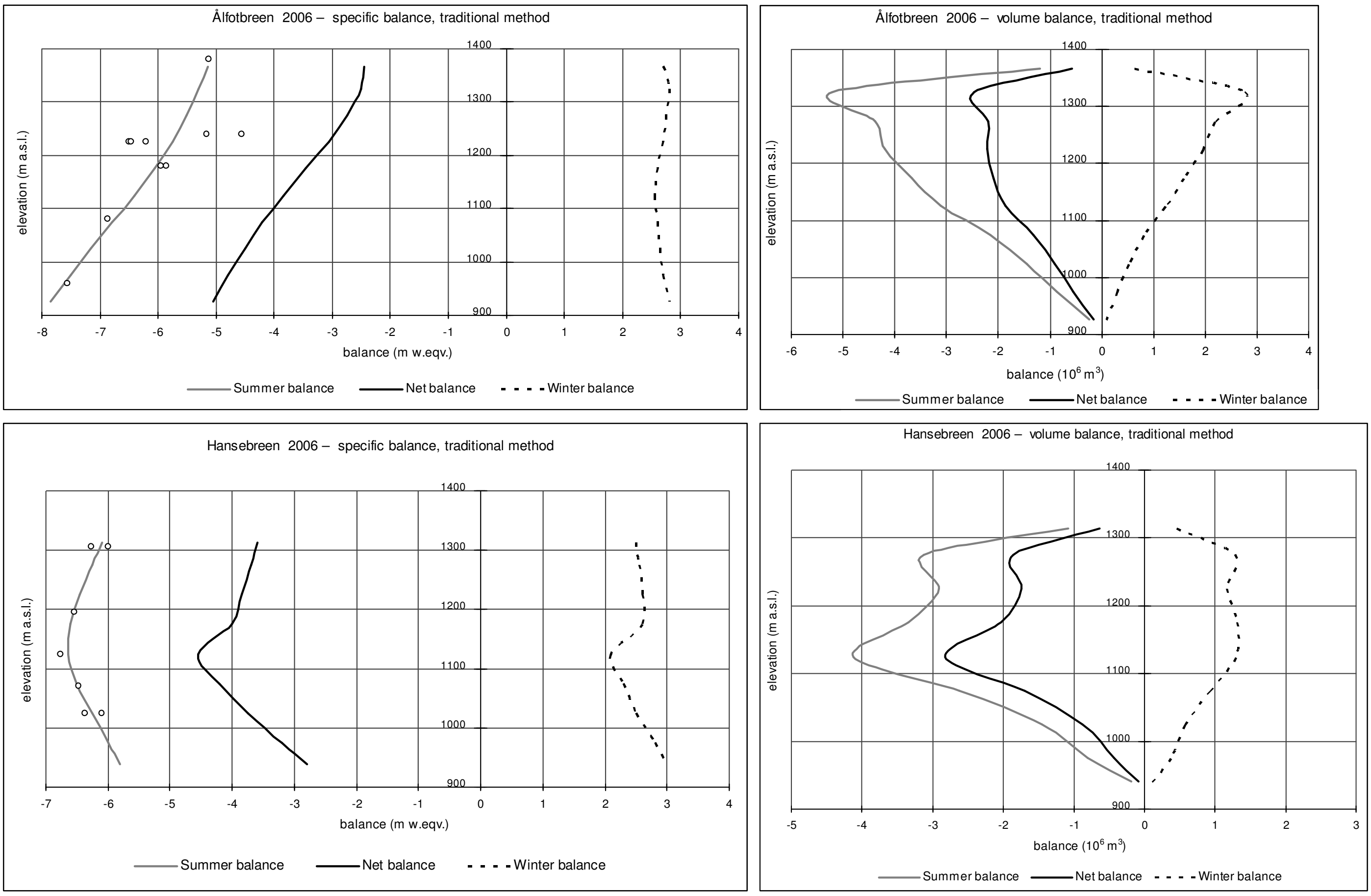



**Figure 2-4**
**Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2006 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○).**

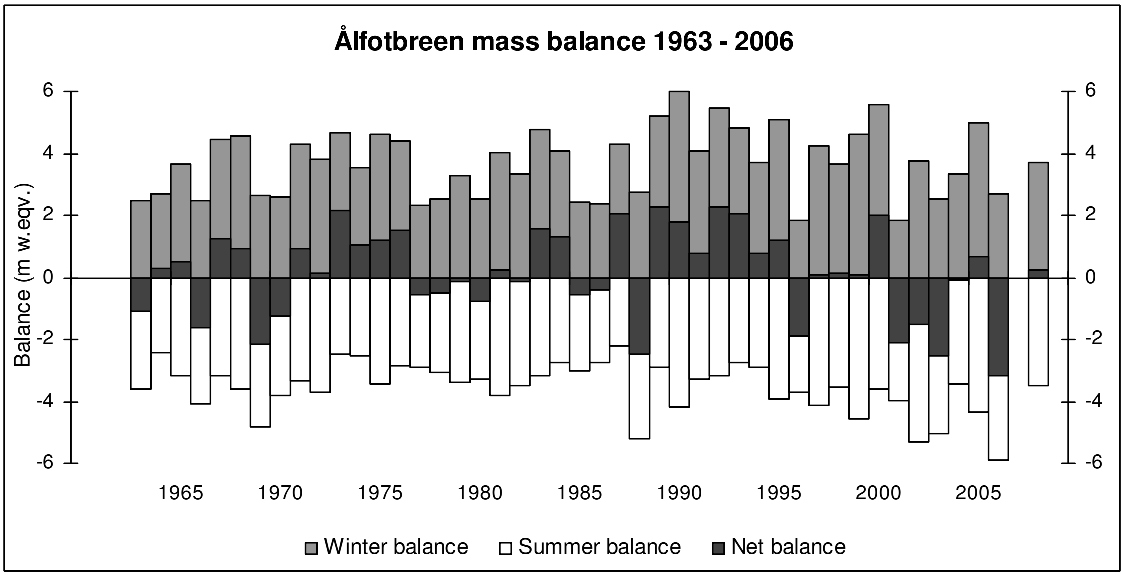
**Table 2-1**
**Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2006. The mean values for Ålfotbreen during the period 1963-2005 are 3.73 m ($b_w$), −3.51 m ($b_s$) and +0.22 m w.e. ($b_n$). The corresponding values for Hansebreen during the period 1986-2005 are 3.48 m, −3.86 m and −0.38 m w.e.**

**Mass balance Ålfotbreen 2005/06 – traditional method**

| Altitude (m a.s.l.) | Area (km$^2$) | Winter balance Measured 5th May 2006 | | Summer balance Measured 12th Oct 2006 | | Net balance Summer surfaces 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| | | 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$^3$) |
| 1350 - 1382 | 0.23 | 2.70 | 0.6 | -5.15 | -1.2 | -2.45 | -0.6 |
| 1300 - 1350 | 0.98 | 2.80 | 2.7 | -5.30 | -5.2 | -2.50 | -2.5 |
| 1250 - 1300 | 0.80 | 2.75 | 2.2 | -5.50 | -4.4 | -2.75 | -2.2 |
| 1200 - 1250 | 0.73 | 2.70 | 2.0 | -5.75 | -4.2 | -3.05 | -2.2 |
| 1150 - 1200 | 0.61 | 2.60 | 1.6 | -6.05 | -3.7 | -3.45 | -2.1 |
| 1100 - 1150 | 0.49 | 2.55 | 1.2 | -6.40 | -3.1 | -3.85 | -1.9 |
| 1050 - 1100 | 0.32 | 2.60 | 0.8 | -6.80 | -2.1 | -4.20 | -1.3 |
| 1000 - 1050 | 0.20 | 2.65 | 0.5 | -7.15 | -1.4 | -4.50 | -0.9 |
| 950 - 1000 | 0.11 | 2.70 | 0.3 | -7.50 | -0.9 | -4.80 | -0.5 |
| 903 - 950 | 0.03 | 2.80 | 0.1 | -7.85 | -0.2 | -5.05 | -0.2 |
| **903 - 1382** | **4.50** | **2.69** | **12.1** | **-5.88** | **-26.5** | **-3.19** | **-14.3** |

**Mass balance Hansebreen 2005/06 – traditional method**

| Altitude (m a.s.l.) | Area (km$^2$) | Winter balance Measured 5th May 2006 | | Summer balance Measured 12th Oct 2006 | | Net balance Summer surface 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| | | 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 - 1327 | 0.18 | 2.50 | 0.44 | -6.10 | -1.08 | -3.60 | -0.64 |
| 1250 - 1300 | 0.50 | 2.55 | 1.28 | -6.25 | -3.13 | -3.70 | -1.85 |
| 1200 - 1250 | 0.45 | 2.60 | 1.18 | -6.45 | -2.92 | -3.85 | -1.74 |
| 1150 - 1200 | 0.51 | 2.60 | 1.32 | -6.60 | -3.35 | -4.00 | -2.03 |
| 1100 - 1150 | 0.62 | 2.10 | 1.30 | -6.65 | -4.13 | -4.55 | -2.82 |
| 1050 - 1100 | 0.40 | 2.30 | 0.93 | -6.50 | -2.62 | -4.20 | -1.69 |
| 1000 - 1050 | 0.23 | 2.50 | 0.58 | -6.25 | -1.46 | -3.75 | -0.88 |
| 950 - 1000 | 0.13 | 2.80 | 0.37 | -6.00 | -0.80 | -3.20 | -0.43 |
| 930 - 950 | 0.03 | 3.00 | 0.10 | -5.80 | -0.19 | -2.80 | -0.09 |
| **930 - 1327** | **3.06** | **2.45** | **7.5** | **-6.43** | **-19.7** | **-3.98** | **-12.2** |



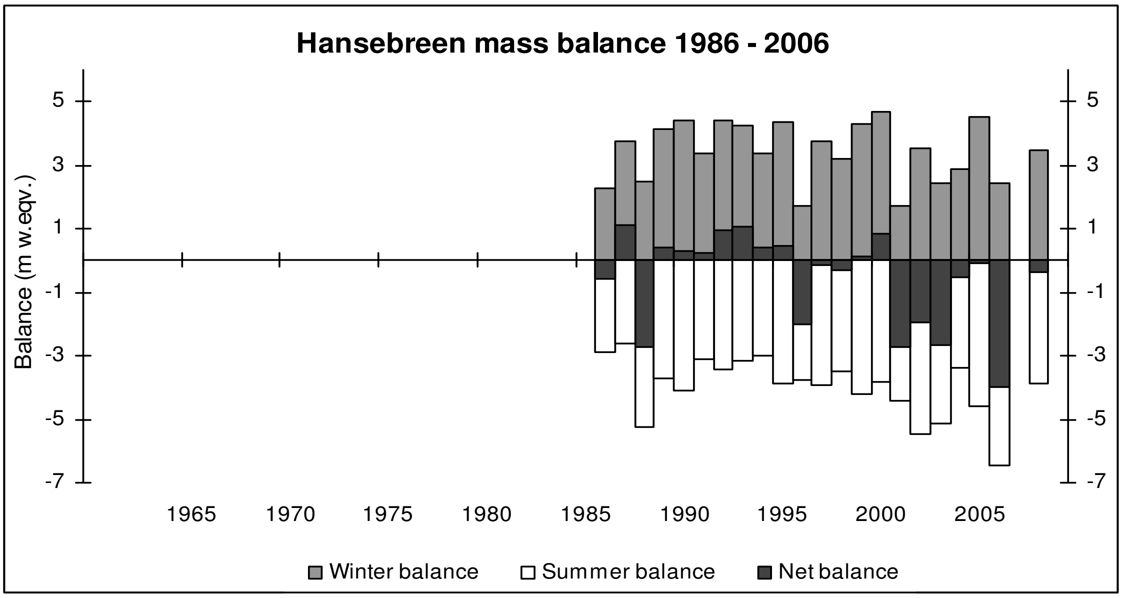




**Figure 2-5**
**Mass balance at Ålfotbreen (upper) during the period 1963-2006 and Hansebreen (lower) during the period 1986-2006. The bar furthest to the right on each figure indicates the mean values.**

# 3. Folgefonna (Bjarne Kjøllmoen)

Folgefonna is situated in the south-western part of Norway between Hardangerfjorden to the west and the mountain plateau Hardangervidda to the east. It is divided into three separate ice caps - Northern, Middle and Southern Folgefonna. In 2003 mass balance measurements began on two adjacent westward-facing outlet glaciers of Southern Folgefonna (60°4'N, 6°24'E) – Breidablikkbrea (3.6 $km^2$) and Gråfjellsbrea (8.9 $km^2$). Southern Folgefonna is the third largest (168 $km^2$ in 1981) ice cap in Norway.

Mass balance measurements were carried out at Breidablikkbrea during 1963-68 (Pytte, 1969) and at Gråfjellsbrea during the periods 1964-68 and 1974-75 (Wold and Hagen, 1977). The historical results are presented in Figure 3-4.

## 3.1 Mass balance 2006

### Fieldwork

#### Snow accumulation measurements

Snow accumulation measurements were performed on 27th April. The calculation of winter balance at Breidablikkbrea and Gråfjellsbrea is based on (Fig. 3-1):

- Measurement of stakes at positions 40 (1255 m a.s.l.), 41 (1285 m a.s.l.), 45 (1340 m a.s.l.), 46 (1360 m a.s.l.), 47 (1415 m a.s.l.), 50 (1480 m a.s.l.), 55 (1565 m a.s.l.), 56 (1570 m a.s.l.) and 60 (1645 m a.s.l.) on Breidablikkbrea and measurement of stakes in positions 10 (1095 m a.s.l.), 15 (1280 m a.s.l.), 20 (1360 m a.s.l.), 25 (1480 m a.s.l.), 30 (1550 m a.s.l.) and 60 (1645 m a.s.l.) on Gråfjellsbrea. Stake position 60 is located on the boundary between the two glaciers and is included in the calculations for both glaciers.
- 50 snow depth soundings between 1245 and 1656 m a.s.l. on Breidablikkbrea, and 70 snow depth soundings between 1095 and 1645 m a.s.l. on Gråfjellsbrea. Generally, the sounding conditions were reasonable on both glaciers, but a solid ice layer 10-30 cm above the summer surface (SS) was impenetrable in some places. The snow depth varied between 3 and 4 m, decreasing to 2 m at lower elevations.
- Core samples at positions 15 and 60, showing snow depths of 2.2 and 3.5 m, respectively.
- Snow density was measured down to the SS (3.4 m) at stake position 25 (1480 m a.s.l.) at Gråfjellsbrea.

The location of stakes, density pit and sounding profiles are shown in Figure 3-1.

#### Ablation measurements

Ablation was measured on 10th October. The net balance was measured at stakes in nine different positions on Breidablikkbrea and six positions on Gråfjellsbrea. There was no snow remaining on the glacier surface from the winter season 2005/2006. At the summit of the glacier, in position 60, the measurement showed net melting of 3.2 m firn since autumn 2005. Up to 5 cm fresh snow had fallen at the time of the ablation measurements.

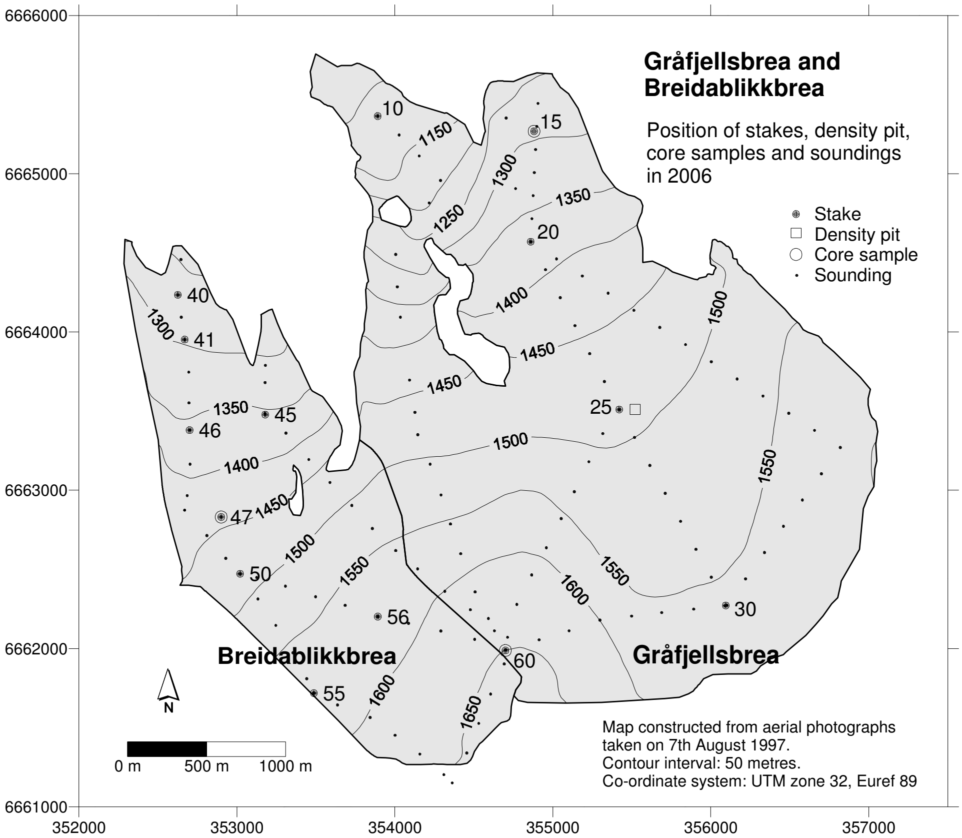



**Figure 3-1**
**Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2006.**

## Results

The calculations are based on a glacier map from 1997.

### Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes, core samples and soundings) and on measurement of snow density at one representative location. There was no melting after the final measurements in December 2005.

A density profile was modelled from the snow density measured at 1480 m a.s.l. The mean snow density of 3.4 m snow was 0.416 g/cm$^3$. The density model was assumed to be representative for both Breidablikkbrea and Gråfjellsbrea, and all snow depths were converted to water equivalent using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 3-3) and a mean value for each 50 m height interval was estimated (Tab. 3-1).

Winter balance at Breidablikkbrea in 2006 was 1.5 ±0.2 m w.e., corresponding to a volume of 5 ±1 mill. m$^3$ of water. The result is 65 % of the average for the study periods 1963-68 and 2003-05.

The winter balance at Gråfjellsbrea was 1.4 ±0.2 m w.e., corresponding to a volume of 12 ±1 mill. $m^3$ of water. The result is 58 % of the average for 1964-68, 1974-75 and 2003-05. This is the lowest winter balance measured on Gråfjellsbrea.

As verification, the winter balance was also calculated using two different gridding methods based on the aerial distribution of the snow depth measurements (Fig. 3-2). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. This method gave the same results: 1.5 m w.e. for Breidablikkbrea and 1.4 m w.e. for Gråfjellsbrea.

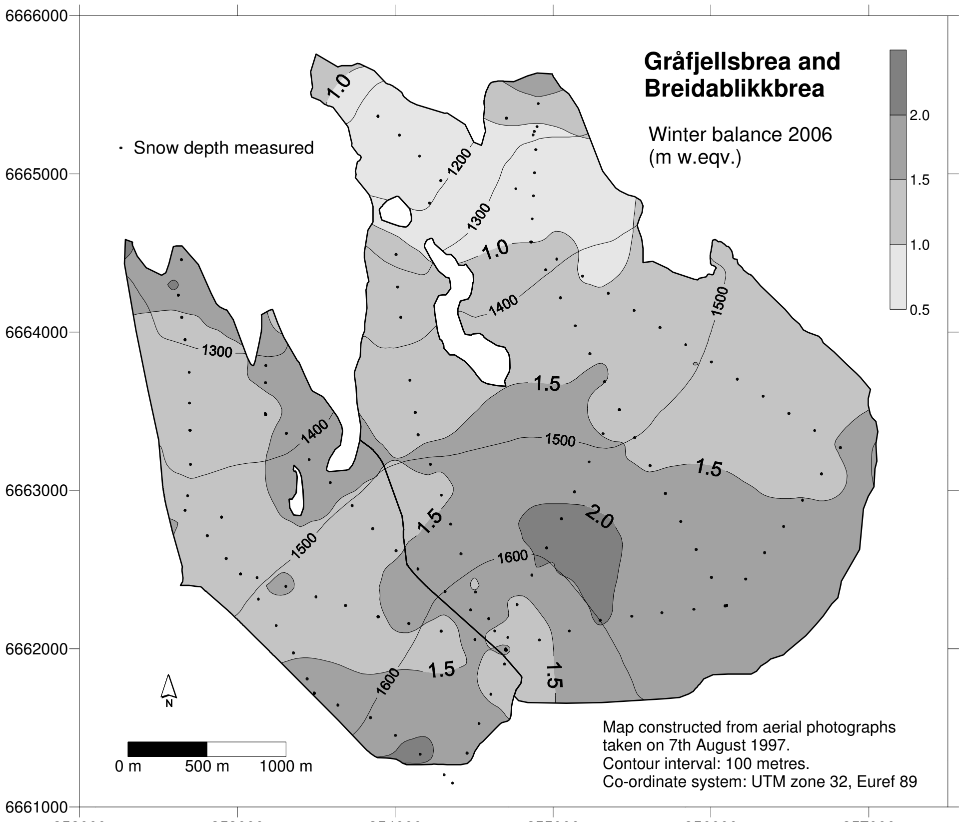



**Figure 3-2**
**Winter balance at Breidablikkbrea and Gråfjellsbrea in 2006 interpolated from 164 snow depth measurements (•).**

## Summer balance

When calculating the summer balance the density of melted firn was estimated as between 0.70 and 0.80 g/$cm^3$. The density of melted ice was assumed to be 0.90 g/$cm^3$.

The summer balance at Breidablikkbrea was measured and calculated at nine stakes. In the upper parts of the glacier, between 1645 and 1565 m a.s.l., the stake values were between 3.8 and 3.9 m w.e. Below 1500 m elevation the stake values were between 5.0 and 5.5 m w.e. Thus, the difference between measured summer balance in the upper areas and the lower areas was quite small. Usually the summer balance decreases with increasing elevation. Below 1500 m elevation this correlation does not hold on Breidablikkbrea in 2006 (Fig. 3-3). Based on estimated density and stake measurements the summer balance was calculated as −4.4 ±0.3 m w.e., corresponding to

–16 ±1 mill. m$^3$ of water. The result is 158 % of the mean value for 1963-68 and 2003-05, and is the same result as in 2003.

The summer balance for Gråfjellsbrea was measured and calculated at seven stakes. The lowest balance values were measured at two stakes in position 30 as 2.7 and 3.5 m w.e., respectively. At the lowest position (10) the stake value was 6.6 m w.e. Based on the seven stakes and the estimated density the summer balance was calculated as –4.4 ±0.3 m w.e. or –40 ±1 mill. m$^3$ of water. The result is 173 % of the mean value for 1964-68, 1974-75 and 2003-05. This is the greatest summer balance measured at Gråfjellsbrea.

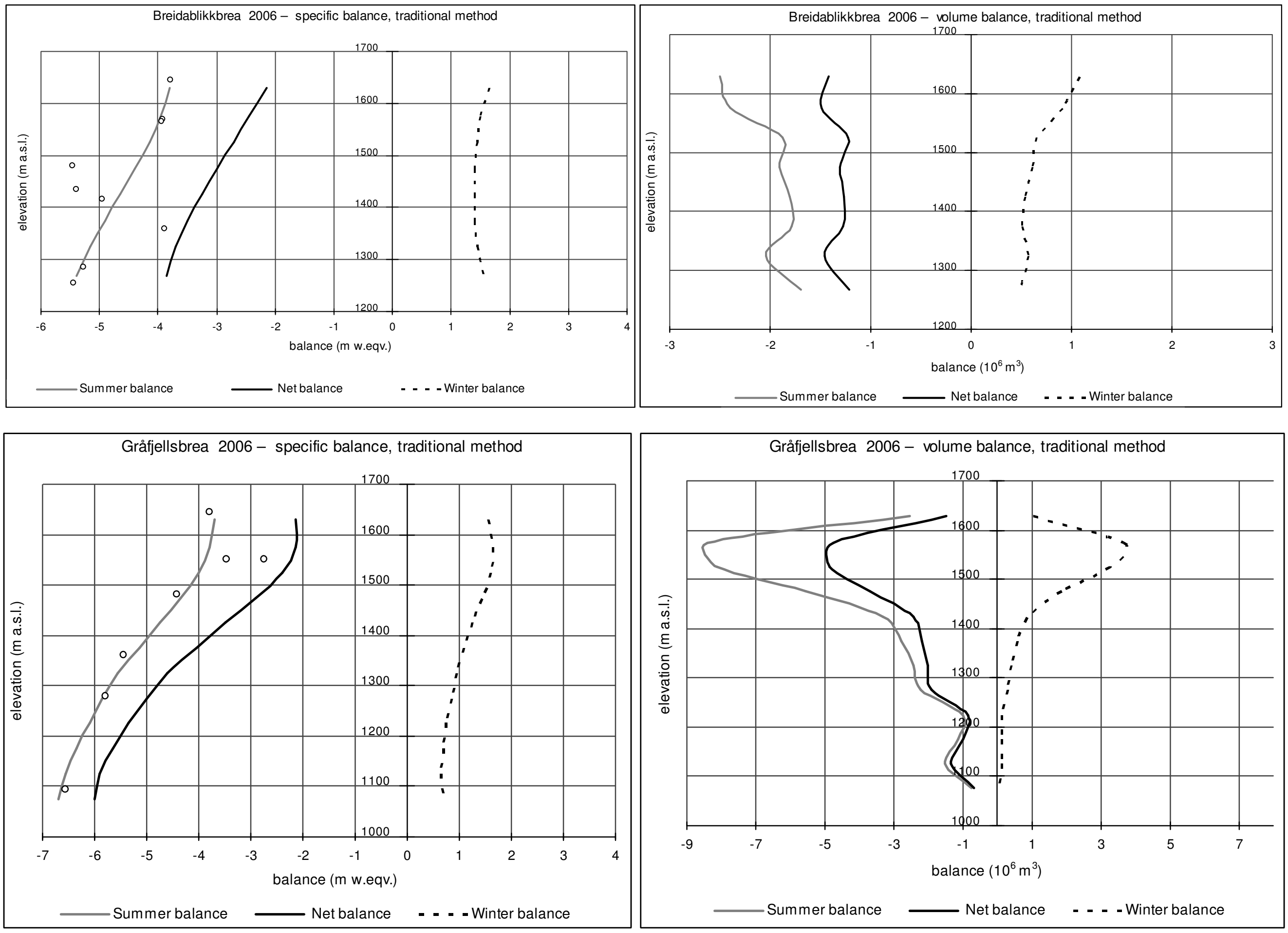



**Figure 3-3**
**Mass balance diagram for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2006 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (o).**

## Net balance

The net balance at Breidablikkbrea for 2006 was calculated as –2.9 ±0.4 m w.e., or a volume loss of 11 ±1 mill. m$^3$ of water. This is the greatest deficit measured at Breidablikkbrea during the measuring periods 1963-68 and 2003-05. The mean net balance for 1963-68 and 2003-05 is –0.52 m w.e.

The net balance at Gråfjellsbrea was calculated as –3.0 ±0.4 m w.e., or a volume loss of 27 ±1 mill. m$^3$ of water. This is the greatest deficit measured at Gråfjellsbrea during the measuring periods 1964-68, 1974-75 and 2003-05. The mean value for the years 1964-68, 1974-75 and 2003-05 is –0.16 m w.e.

As shown in Figure 3-3, the equilibrium line altitude (ELA) lies above the highest summit (1659 m a.s.l.) on both glaciers. Consequently, the Accumulation Area Ratio (AAR) is 0 %.

The mass balance results are shown in Table 3-1. The corresponding curves for specific and volume balance are shown in Figure 3-3. The historical mass balance results are presented in Figure 3-4.

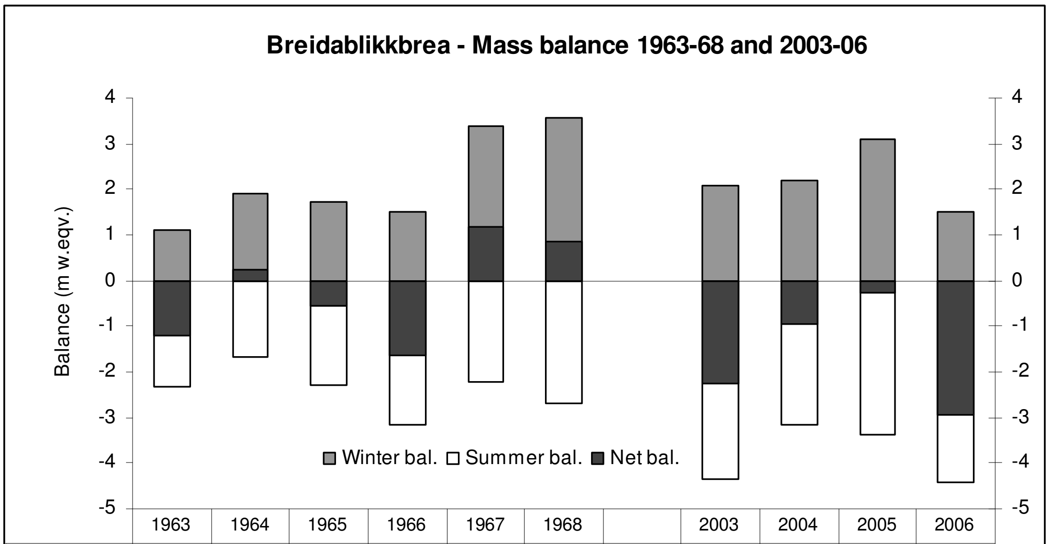
**Table 3-1**
**Winter, summer and net balances for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2006.**

**Mass balance Breidablikkbrea 2005/06 – traditional method**

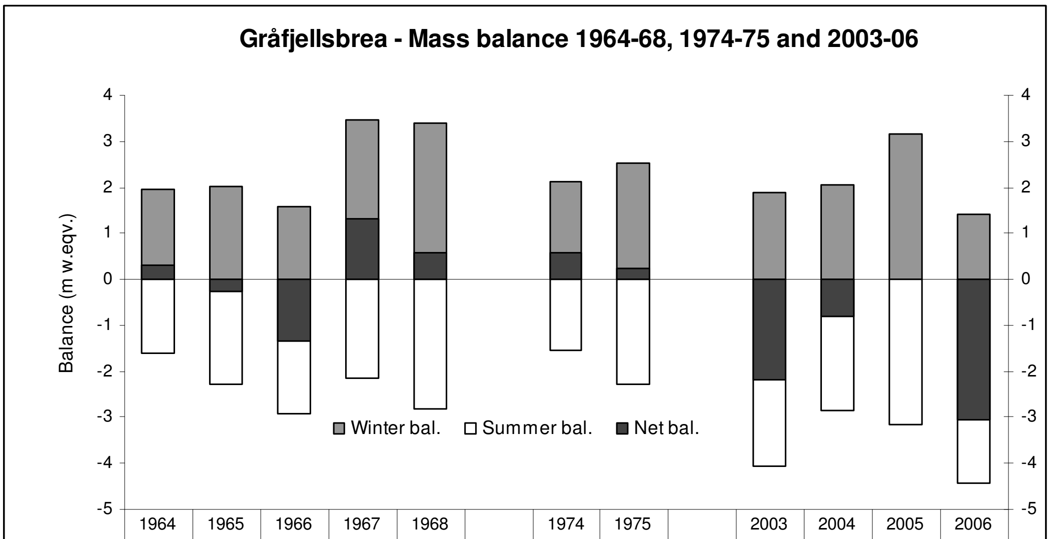
| | | Winter balance Measured 28th April 2006 | | Summer balance Measured 10th Oct 2006 | | Net balance Summer surfaces 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| Altitude (m a.s.l.) | Area ($km^2$) | Specific (m w.eq.) | Volume ($10^6$ $m^3$) | Specific (m w.eq.) | Volume ($10^6$ $m^3$) | Specific (m w.eq.) | Volume ($10^6$ $m^3$) |
| 1600 - 1659 | 0.66 | 1.65 | 1.1 | -3.80 | -2.5 | -2.15 | -1.4 |
| 1550 - 1600 | 0.61 | 1.50 | 0.9 | -3.95 | -2.4 | -2.45 | -1.5 |
| 1500 - 1550 | 0.45 | 1.45 | 0.7 | -4.15 | -1.9 | -2.70 | -1.2 |
| 1450 - 1500 | 0.43 | 1.40 | 0.6 | -4.40 | -1.9 | -3.00 | -1.3 |
| 1400 - 1450 | 0.39 | 1.40 | 0.5 | -4.65 | -1.8 | -3.25 | -1.3 |
| 1350 - 1400 | 0.36 | 1.40 | 0.5 | -4.90 | -1.8 | -3.50 | -1.3 |
| 1300 - 1350 | 0.40 | 1.45 | 0.6 | -5.15 | -2.0 | -3.70 | -1.5 |
| 1236 - 1300 | 0.31 | 1.55 | 0.5 | -5.40 | -1.7 | -3.85 | -1.2 |
| **1236 - 1659** | **3.61** | **1.49** | **5.4** | **-4.43** | **-16.0** | **-2.94** | **-10.6** |

**Mass balance Gråfjellsbrea 2005/06 – traditional method**

| | | Winter balance Measured 28th April 2006 | | Summer balance Measured 10th Oct 2006 | | Net balance Summer surfaces 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| 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 ($10^6$ $m^3$) |
| 1600 - 1659 | 0.68 | 1.55 | 1.1 | -3.70 | -2.5 | -2.15 | -1.5 |
| 1550 - 1600 | 2.21 | 1.65 | 3.6 | -3.80 | -8.4 | -2.15 | -4.8 |
| 1500 - 1550 | 2.03 | 1.60 | 3.2 | -4.00 | -8.1 | -2.40 | -4.9 |
| 1450 - 1500 | 1.28 | 1.45 | 1.8 | -4.35 | -5.5 | -2.90 | -3.7 |
| 1400 - 1450 | 0.70 | 1.25 | 0.9 | -4.75 | -3.3 | -3.50 | -2.4 |
| 1350 - 1400 | 0.54 | 1.10 | 0.6 | -5.15 | -2.8 | -4.05 | -2.2 |
| 1300 - 1350 | 0.44 | 0.95 | 0.4 | -5.55 | -2.4 | -4.60 | -2.0 |
| 1250 - 1300 | 0.38 | 0.85 | 0.3 | -5.85 | -2.2 | -5.00 | -1.9 |
| 1200 - 1250 | 0.16 | 0.75 | 0.1 | -6.10 | -1.0 | -5.35 | -0.9 |
| 1150 - 1200 | 0.18 | 0.70 | 0.1 | -6.35 | -1.1 | -5.65 | -1.0 |
| 1100 - 1150 | 0.23 | 0.65 | 0.1 | -6.55 | -1.5 | -5.90 | -1.4 |
| 1051 - 1100 | 0.11 | 0.70 | 0.1 | -6.70 | -0.7 | -6.00 | -0.7 |
| **1051 - 1659** | **8.94** | **1.40** | **12.5** | **-4.44** | **-39.7** | **-3.05** | **-27.2** |




| | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter bal. | 1.11 | 1.92 | 1.72 | 1.52 | 3.40 | 3.55 | | 2.08 | 2.21 | 3.09 | 1.49 |
| Summer bal. | -2.32 | -1.68 | -2.28 | -3.17 | -2.23 | -2.68 | | -4.35 | -3.16 | -3.37 | -4.43 |
| Net bal. | -1.21 | 0.24 | -0.56 | -1.65 | 1.17 | 0.87 | | -2.27 | -0.95 | -0.28 | -2.94 |




| | 1964 | 1965 | 1966 | 1967 | 1968 | | 1974 | 1975 | | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter bal. | 1.94 | 2.01 | 1.58 | 3.46 | 3.39 | | 2.11 | 2.53 | | 1.90 | 2.04 | 3.16 | 1.40 |
| Summer bal. | -1.62 | -2.29 | -2.93 | -2.14 | -2.82 | | -1.53 | -2.28 | | -4.07 | -2.85 | -3.15 | -4.44 |
| Net bal. | 0.32 | -0.28 | -1.35 | 1.32 | 0.57 | | 0.58 | 0.25 | | -2.17 | -0.81 | 0.01 | -3.04 |

**Figure 3-4**
**Winter, summer and net balance at Breidablikkbrea for the periods 1963-68 and 2003-06 (upper figure), and at Gråfjellsbrea for the periods 1964-68, 1974-75 and 2003-06 (lower figure).**

# 4. Nigardsbreen (Bjarne Kjøllmoen)

Nigardsbreen (61°42'N, 7°08'E) is one of the largest and best-known outlet glaciers from Jostedalsbreen. It has an area of 47.8 $km^2$ (measured in 1984) and flows south-east from the centre of the ice cap. 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 2006 include mass balance and front position change. An observation of the ice-dammed lake Brimkjelen at Tunsbergdalsbreen has also been performed. Nigardsbreen has been the subject of mass balance investigations since 1962.

**Figure 4-1**
**The glacier snout of Nigardsbreen and the delta photographed on 11th October 2006. Photo: Miriam Jackson.**

## 4.1 Mass balance 2006

### Fieldwork

#### Snow accumulation measurements

Snow accumulation measurements were performed on 6th and 7th May and the calculation of winter balance (Fig. 4-2) is based on:

- Measurement of stakes in positions 600 (575 m a.s.l.), 1000 (980 m a.s.l.), 55 (1465 m a.s.l.), 50 (1515 m a.s.l.), 54 (1610 m a.s.l.), T95 (1680 m a.s.l.), 94 (1705 m a.s.l.), 96 (1755 m a.s.l.), T56 (1795 m a.s.l.) and 57 (1960 m a.s.l.). The stake measurements on the plateau showed snow depth between 3.0 (50) and 4.8 m (96). Measured snow depths at stakes 600 and 1000 were 0.4 and 2.1 m, respectively. Stake readings did not show any clear indication of melting after the final measurements in October 2005.

- Core samples at positions 54, 94, 96 and 57 showing snow depth between 3.4 (57) and 4.1 m (96).
- 149 snow depth soundings on the plateau between 1320 and 1961 m a.s.l. A few soundings were made at 575 m elevation and at 980 m elevation on the glacier tongue. In spite of a solid ice layer 15-30 cm above the summer surface (SS), the sounding conditions were reasonable. The snow depth soundings gave snow thickness between 3.5 and 5 m in the areas above 1650 m a.s.l. and between 3 and 4.5 m in the height interval 1320-1650 m a.s.l. At 980 m elevation the snow depth was about 2 m and at 600 m elevation about 0.5 m.
- Snow density was measured down to SS (3.7 m) at position 94 (Fig. 4-3).

Location of stakes, towers, snow pit, core samples and soundings are shown in Figure 4-2.

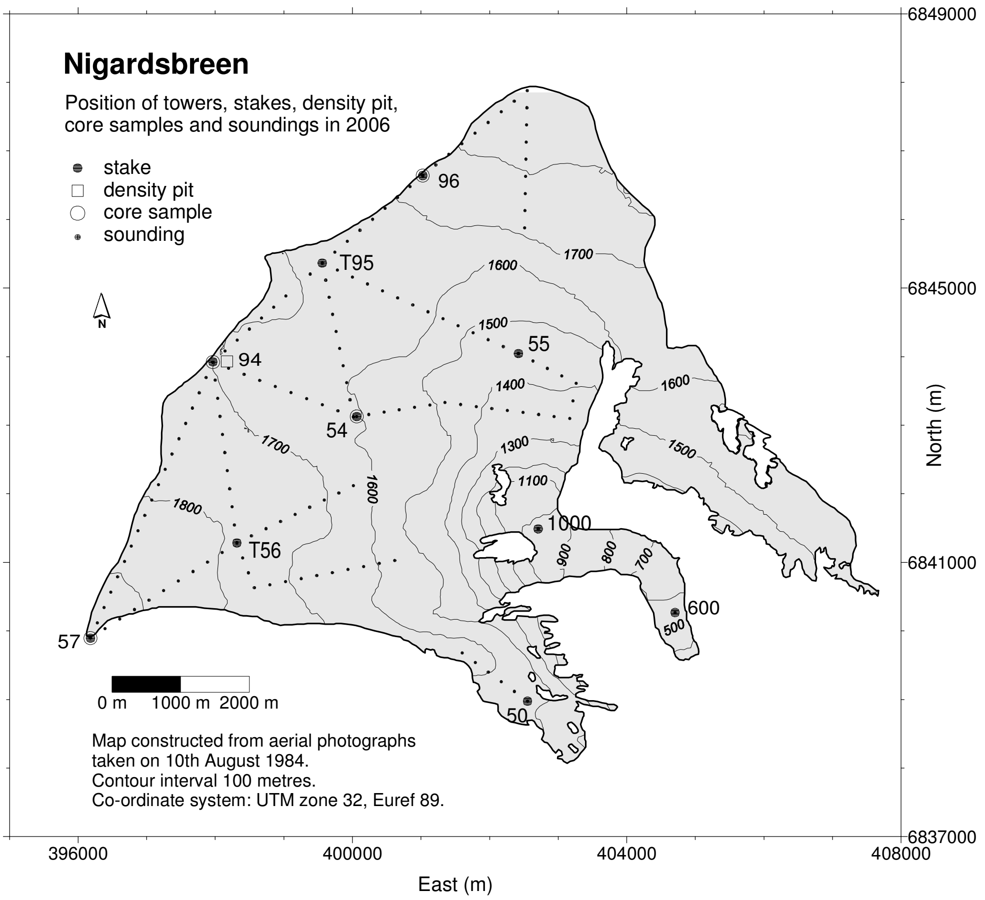



**Figure 4-2**
**Location of towers and stakes, snow pit, core samples and soundings on Nigardsbreen in 2006.**

### Ablation measurements

Ablation measurements were carried out on 11th October. Measurements were made at ten stakes and two towers in eight different positions. Since snow measurements in May the stakes on the plateau had increased in length between 3.5 (96) and 5.8 m (55). Hence, at stake 96 there was 1.4 m of snow remaining from winter 2005/2006. At the other stakes all the snow had melted away. At the time of measurement, up to 40 cm of fresh snow had fallen in the upper areas.

## Results

The calculations are based on a glacier map from 1984.

### Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes and towers, probings and core drillings) and on measurement of snow density at one representative location.

There was no melting after the final measurements in October 2005. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1705 m altitude (3.7 m depth). Using this model gave a snow density of 0.458 g/cm$^3$. This model was used for all snow depth measurements.

The winter balance calculation was performed by plotting measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 4-5), and a mean value for each 100 m height interval estimated (Tab. 4-1). The elevations above 1320 m a.s.l. were well represented with point measurements. Below this altitude the curve pattern was based on point measurements at 980 m and 575 m altitude.

These calculations give a winter balance of 1.7 ±0.2 m w.e., corresponding to a water volume of 84 ±10 mill. m$^3$. The result is 73 % of the average for 1962-2005. Only five years have shown a lower winter balance on Nigardsbreen; the lowest was in 1996 with 1.4 m w.e.

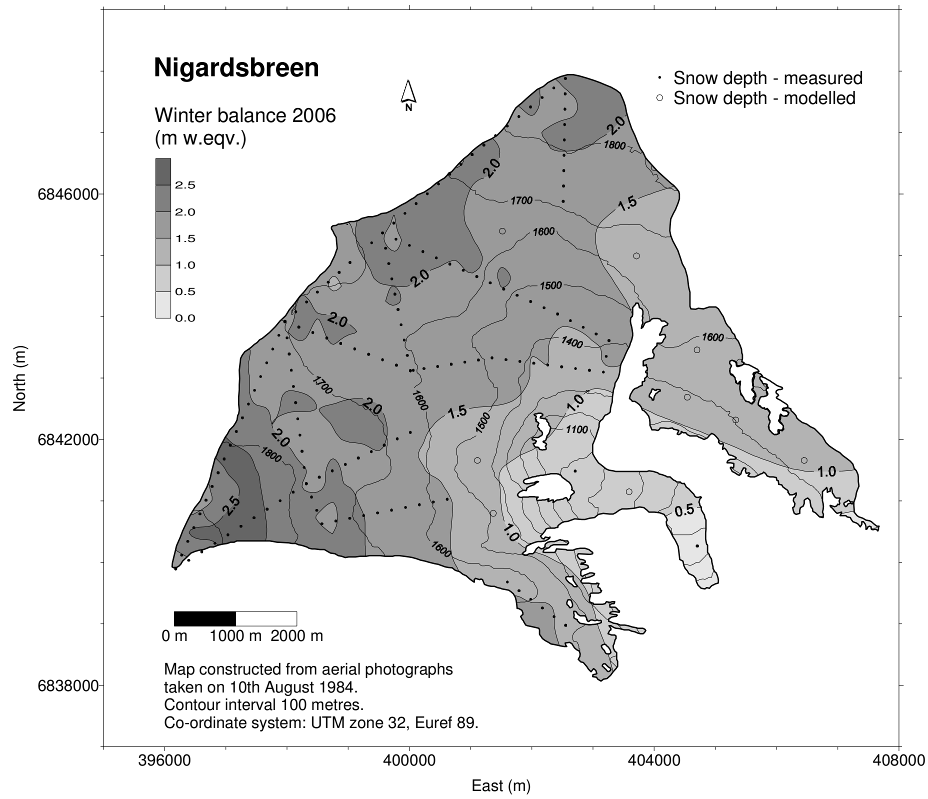



**Figure 4-3**
**Winter balance at Nigardsbreen in 2006 interpolated from 166 measurements (•) of snow depth. In areas with few or no measurements nine extrapolated points (○) are added.**

The winter balance was also calculated using a gridding method (Kriging) based on the aerial distribution of the snow depth measurements (Fig. 4-3). In areas with insufficient measurements some (nine) simulated points were extracted. These point values were modelled based on measurements from the period 1975-81, years with extensive measurements. Water equivalents for each cell in a 250 x 250 m grid were calculated and summarised. The result obtained using this gridding method was 1.6 m w.e.

### Summer balance

When calculating the summer balance the density of the remaining snow was estimated as 0.60 g/cm$^3$. The density of melted firn was estimated as between 0.70 and 0.80 g/cm$^3$, and the density of ice was taken as 0.90 g/cm$^3$.

The summer balance was calculated at stakes and towers at nine different elevations. At stake 57 the measurements were supplemented with estimated values based on correlation with other stakes. The summer balance increased (in absolute value) from −1.9 m w.e. at the glacier summit (1962 m a.s.l.) to −9.6 m down on the tongue (575 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated to be −3.1 ±0.3 m w.e., which is −150 ±15 mill. m$^3$ of water. The result is 160 % of the average for 1962-2005. Since 1962 there have been only two years with a higher summer balance, 1969 and 2002, both years with −3.3 m w.e.

### Net balance

The net balance for 2006 was calculated at stakes and towers in nine different positions. The result was a deficit of −1.4 m ±0.3 m w.e., which means a volume loss of 67 ±15 mill.m$^3$ water. This is the greatest negative net balance measured on Nigardsbreen since 1962. The mean value for the period 1962-2005 is +0.42 m w.e. (Fig. 4-6), while the average for 1996-2005 is −0.01 m w.e.

Based on Figure 4-5, the Equilibrium Line Altitude (ELA) was 1850 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 4 %.

The mass balance for Nigardsbreen in 2006 is shown in Table 4-1 and the corresponding curves are shown in Figure 4-5. The historical mass balance results are presented in Figure 4-6.

**Figure 4-4**
**In May the snow depth at T56 was 3.7 m. Five months later, in October, all this snow together with 0.8 m firn had melted away.**
**Photo: Ole Magnus Tønsberg.**

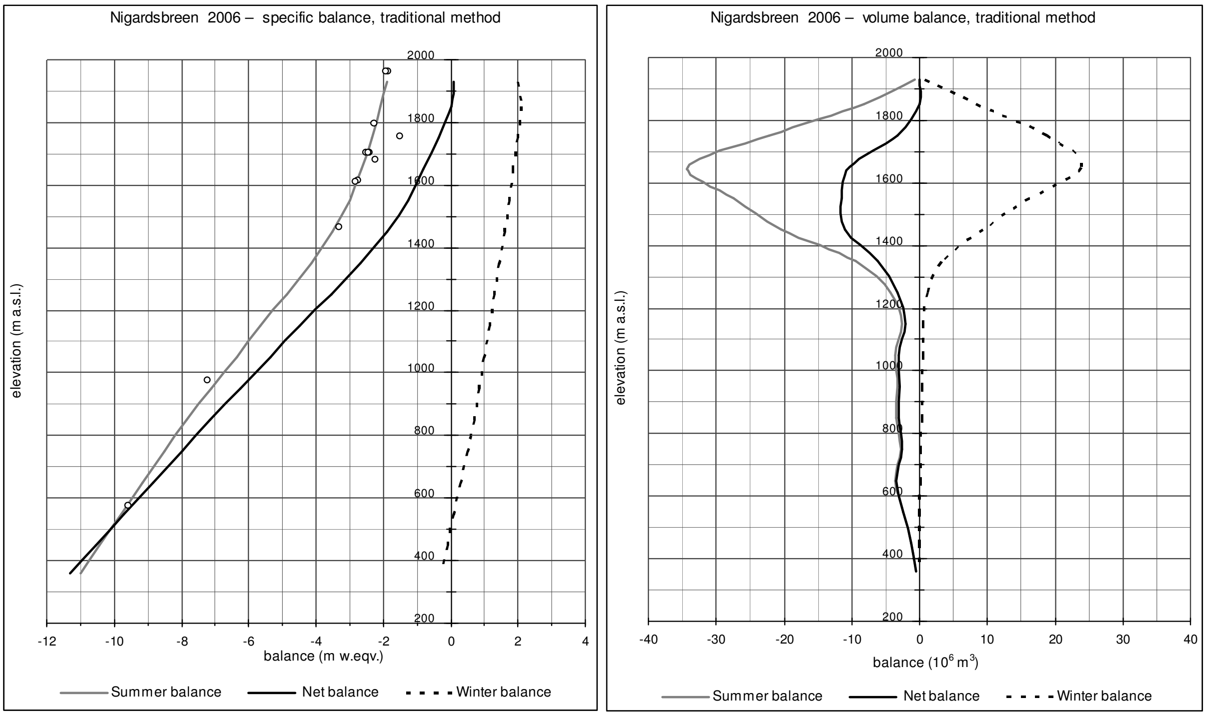



**Figure 4-5**
**Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2006. Specific summer balance at nine stake positions is shown as dots (o). The net balance curve intersects the y-axis and defines the ELA as 1850 m a.s.l. Thus, the AAR was 4 %.**

**Table 4-1**
**Winter, summer and net balance for Nigardsbreen in 2006. Mean values for the period 1962-2005 are 2.38 ($b_s$), –1.96 m ($b_s$) and +0.42 m ($b_n$) water equivalent.**

**Mass balance Nigardsbreen 2005/06 – traditional method**

| | | Winter balance | | Summer balance | | Net balance | |
|---|---|---|---|---|---|---|---|
| | | Measured 6th May 2006 | | Measured 11th Oct 2006 | | Summer surface 2005 - 2006 | |
| 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 | 2.00 | 0.8 | -1.90 | -0.7 | 0.10 | 0.0 |
| 1800 - 1900 | 3.92 | 2.10 | 8.2 | -2.10 | -8.2 | 0.00 | 0.0 |
| 1700 - 1800 | 9.39 | 2.00 | 18.8 | -2.35 | -22.1 | -0.35 | -3.3 |
| 1600 - 1700 | 12.88 | 1.85 | 23.8 | -2.65 | -34.1 | -0.80 | -10.3 |
| 1500 - 1600 | 9.18 | 1.75 | 16.1 | -3.00 | -27.5 | -1.25 | -11.5 |
| 1400 - 1500 | 5.82 | 1.60 | 9.3 | -3.50 | -20.4 | -1.90 | -11.1 |
| 1300 - 1400 | 2.28 | 1.45 | 3.3 | -4.15 | -9.5 | -2.70 | -6.2 |
| 1200 - 1300 | 0.90 | 1.30 | 1.2 | -4.85 | -4.4 | -3.55 | -3.2 |
| 1100 - 1200 | 0.45 | 1.15 | 0.5 | -5.65 | -2.5 | -4.50 | -2.0 |
| 1000 - 1100 | 0.58 | 1.00 | 0.6 | -6.35 | -3.7 | -5.35 | -3.1 |
| 900 - 1000 | 0.47 | 0.85 | 0.4 | -7.10 | -3.3 | -6.25 | -2.9 |
| 800 - 900 | 0.44 | 0.70 | 0.3 | -7.85 | -3.5 | -7.15 | -3.1 |
| 700 - 800 | 0.33 | 0.50 | 0.2 | -8.50 | -2.8 | -8.00 | -2.6 |
| 600 - 700 | 0.39 | 0.30 | 0.1 | -9.15 | -3.6 | -8.85 | -3.5 |
| 500 - 600 | 0.24 | 0.10 | 0.0 | -9.80 | -2.4 | -9.70 | -2.3 |
| 400 - 500 | 0.12 | -0.10 | 0.0 | -10.45 | -1.3 | -10.55 | -1.3 |
| 320 - 400 | 0.05 | -0.30 | 0.0 | -11.00 | -0.6 | -11.30 | -0.6 |
| **320 - 1960** | **47.82** | **1.75** | **83.5** | **-3.15** | **-150.4** | **-1.40** | **-66.9** |

Since 2000 there has been negative net balance in five of the six years. Over the last eleven years (1996-2006) the cumulative net balance is about 0, and only three years show a significant surplus; 1998, 2000 and 2005. However, during the entire period of investigation (1962-2006) the cumulative net balance is +17 m w.e.

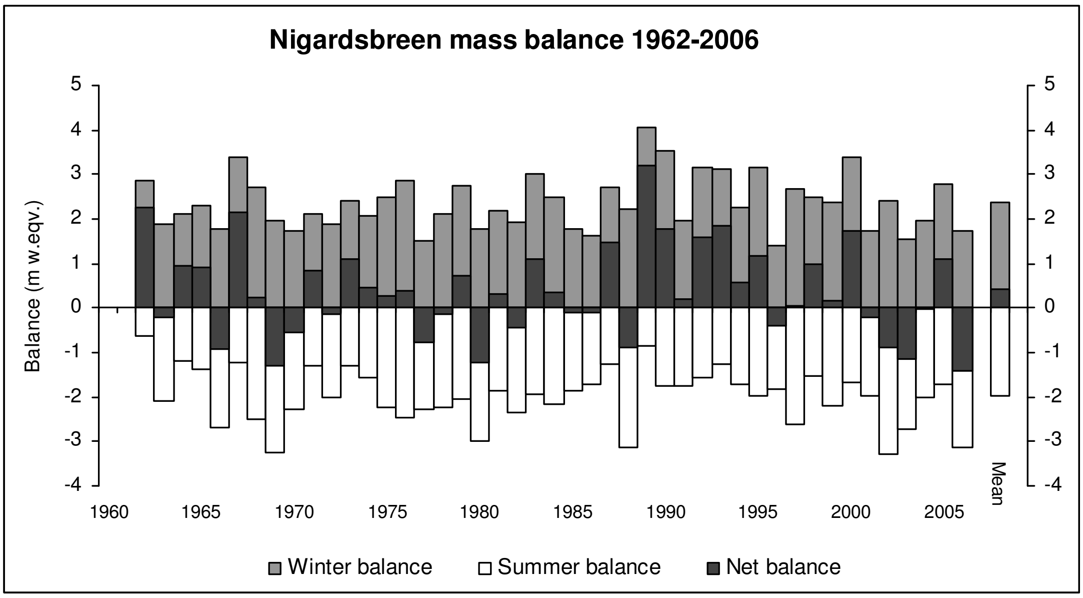



**Figure 4-6**
**Annual mass balance at Nigardsbreen during the period 1962-2006.**

# 4.2 Tunsbergdalsbreen

## Mass balance

From 1966 to 1972 mass balance measurements were made simultaneously at both Tunsbergdalsbreen (ca. 50 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:

$$bn_T = 0.987 \cdot bn_N - 0.283$$

where $bn_T$ = net balance at Tunsbergdalsbreen, and $bn_N$ = net balance at Nigardsbreen.

For 2006 the net balance at Tunsbergdalsbreen was estimated as −1.66 ±0.45 m w.e., corresponding to a deficit of about 83 ±20 mill. m$^3$ of water. Since 1962 the estimated accumulated net balance is about +3.9 m w.e.

Based on 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 2006 was about 1730 m a.s.l.

## Brimkjelen

About 3 km above the western side of the glacier snout lies an ice-dammed lake called Brimkjelen. Due to 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. Annual observations were resumed in autumn 1997 and continued in 2006 by photography on 11th October (Fig. 4-7). At the time of observation the lake was empty.

**Figure 4-7**
**Brimkjelen photographed on 11th October. Photo: Miriam Jackson.**

# 5. Austdalsbreen (Hallgeir Elvehøy)

Austdalsbreen (61°45'N, 7°20'E) is an eastern outlet of the northern part of Jostedalsbreen, ranging in altitude from 1200 to 1757 m a.s.l. The glacier terminates in Austdalsvatnet which has been part of the hydropower reservoir Styggevatnet since 1988. Glaciological investigations at Austdalsbreen started in 1986 in connection with the construction of the hydropower reservoir.

The glaciological investigations in 2006 included mass balance, front position change and glacier velocity. Mass balance has been measured at Austdalsbreen since 1988.

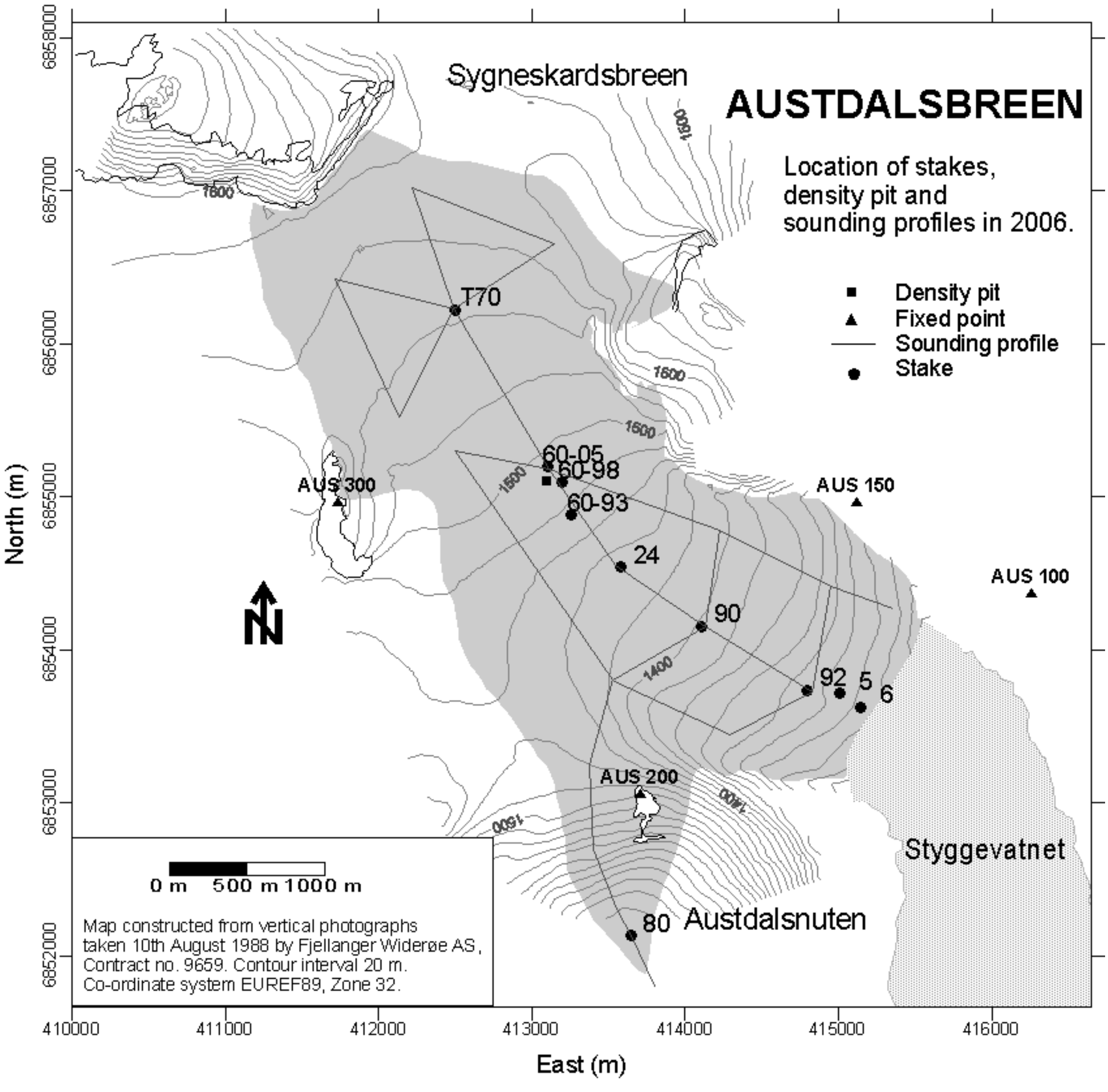



**Figure 5-1**
**Location of stakes, density pit and sounding profiles at Austdalsbreen in 2006.**

# 5.1 Mass balance 2006

## Fieldwork

The winter balance was measured on 5th May. The calculation of winter balance was based on the following data (Fig. 5-1):

- Snow depth at stakes 5 (1.0 m), 92 (2.1 m), 90 (2.3 m), 60-05 (3.35 m) and T70 ( 3.25 m).
- Snow depth by coring at stakes 24 (2.9 m) and 80 (3.2 m).
- 82 snow depth measurements along 19 km of profiles. At Austdalsnuten above 1500 m a.s.l. the snow depth was 3 to 4 m. Between 1450 and 1600 m a.s.l. the snow depth was between 3.0 and 3.5 m at most locations. Between 1300 and 1450 m a.s.l. the snow was 2 to 3 m deep. The summer surface (SS) from 2005 was easy to detect in all areas.
- Snow density down to 3.2 m depth at stake 60-05 (1495 m a.s.l.). Mean snow density was 0.45 g/cm$^3$. The previous summer surface was located at 3.35 m depth.

On 4th July the transient snow line was 1300 m a.s.l., and by 11th August all the winter snow had melted.

Summer and net balance measurements were carried out on 11th October. Since all the winter snow had melted, the equilibrium line altitude was above the top of the glacier (>1760 m a.s.l.). The firn line was at about 1420 m a.s.l. At Austdalsnuten (stake 80), 2.3 m of firn had melted. At stakes 60 and T70 around 2 m of firn had melted. At stake 24 close to the firn line, 2.9 m of firn/ice had melted. At stakes 90 and 92, 3.3 m and 3.8 m of ice, respectively, had melted. At stake 5 close to the terminus, 5.4 m of ice had melted.

## Results

The mass balance was calculated according to the stratigraphic method (see chap.1). The calculations are based on a map from 10th August 1988 reduced for the areas below the highest regulated lake level (below 1200 m a.s.l., 0.11 km$^2$).

### Winter balance

There are no observations indicating significant melting after the stake measurements on 17th October 2005.

The winter balance was calculated from snow depth and snow density measurements on 5th May. A function correlating snow depth with water equivalent was calculated based on snow density measurements at stake 60 (1495 m a.s.l.).

Snow depth water equivalent values of all snow depth measurements were plotted against altitude. Mean values of altitude and SWE in 50 m altitude intervals were calculated and plotted. An altitudinal winter balance curve was drawn from a visual evaluation of the mean values, and from this a mean value for each 50 m altitude interval was determined. The winter balance was 16 ±2 mill. m$^3$ water or 1.3 ±0.2 m w.e., which is 59 % of the 1988-2005 average (2.24 m w.e.). This is the third smallest winter balance measured at Austdalsbreen, only 2001 (1.0 m w.e.) and 1996 (1.2 m w.e.) being smaller.

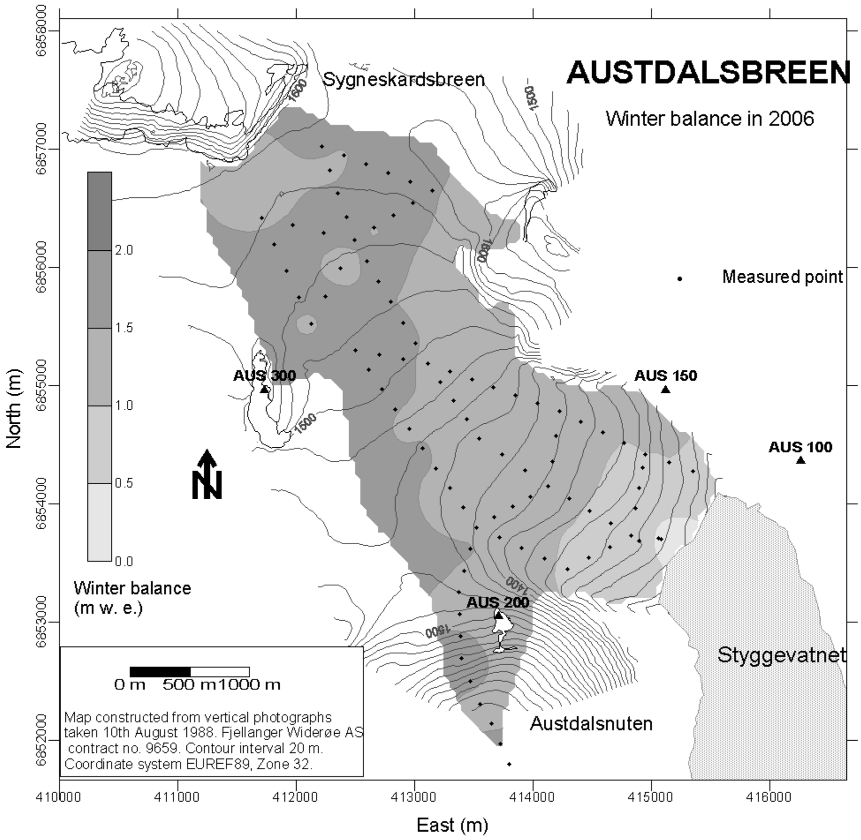



**Figure 5-2**
**Winter balance at Austdalsbreen in 2006 from 90 water equivalent values calculated from snow depth measurements.**

The winter balance was also calculated using a gridding method based on the spatial distribution of the snow depth measurements (Fig. 5-2). Water equivalents for each cell in a 50 x 50 m grid were calculated and summarised. The result based on this method, which is a control of the traditional method, showed a winter balance of 1.4 m w.e.

## Summer balance

The summer balance was calculated for ten stakes in seven positions between 1260 and 1730 m a.s.l. The summer balance curve was drawn from these values (Fig. 5-3).

Calving from the glacier terminus was calculated as the annual volume of ice (in water equivalent) 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 $\rho_{ice}$ is 0.9 g/cm$^3$, $u_{ice}$ is annual glacier velocity (50 ±10 m/a, chapter 5.3), $u_f$ is front position change averaged across the terminus (+24 ±5 m/a, chapter 5.2), W is terminus width (1060 ±25 m) and H is mean ice thickness at the terminus (45 ±5 m) based on surface altitude surveyed on 17$^{th}$ October 2005 and 11$^{th}$ October 2006, and a bottom topography map compiled from radar ice thickness measurements (1986), hot water drilling (1987) and lake depth surveying (1988 and 1989). The resulting calving volume was 1 ±1 mill. m$^3$ water or 0.1 ±0.1 m w.e. averaged over the glacier area (11.8 km$^2$).

The summer balance, including calving, was calculated as −3.4 ±0.3 m w.e., which corresponds to −40 ±3 mill. $m^3$ of water. The calving volume was 3 % of the summer balance. The result is 138 % of the 1988-2005 average (−2.45 m w.e.). This is the third largest summer balance measured at Austdalsbreen, only 2002 and 2003 (−3.9 m w.e.) being larger.

## Net balance

The net balance at Austdalsbreen was calculated as −2.1 ±0.3 m w.e., corresponding to −24 ±3 mill. $m^3$ water. The 1988-2005 average is −0.21 m w.e. This is the second most negative net balance measured at Austdalsbreen. The most negative net balance was measured in 2003 (−2.3 m w.e.). The equilibrium line altitude (ELA) was above the top of the glacier. Correspondingly, the Accumulation Area Ratio (AAR) was 0 % in 2006. The altitudinal distribution of winter, summer and net balances is shown in Figure 5-3 and Table 5-1. Results from 1988-2006 are shown in Figure 5-4.

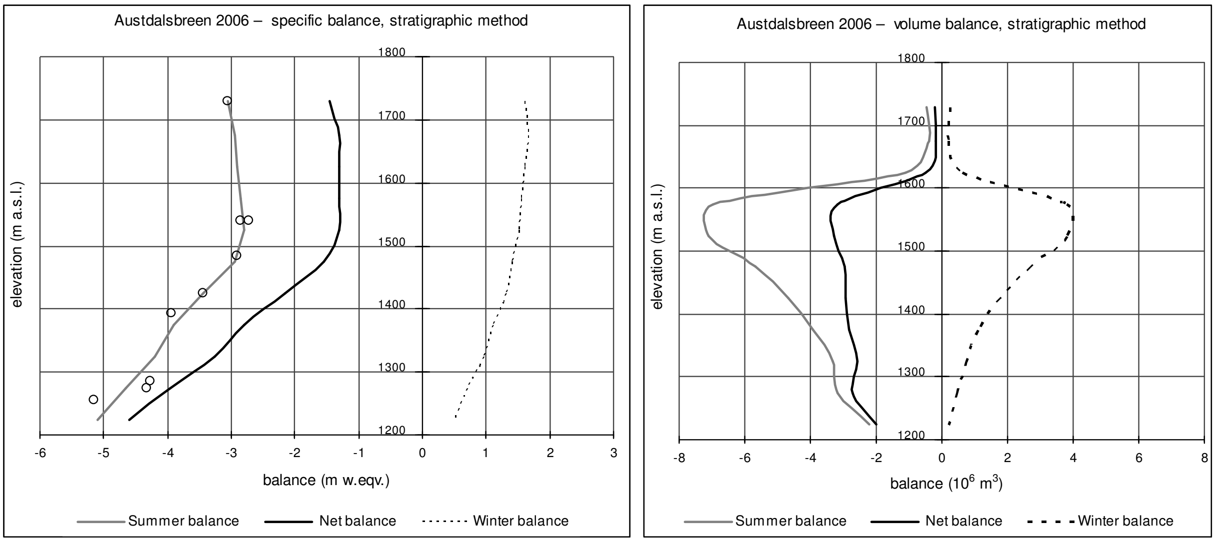



**Figure 5-3**
**Altitudinal distribution of winter-, summer- and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2006. Specific summer balance at ten stakes in seven locations is shown (o).**

**Table 5-1**
**Altitudinal distribution of winter-, summer- and net balances at Austdalsbreen in 2006.**

**Mass balance Austdalsbreen 2005/06 – stratigraphic method**

| Altitude (m a.s.l.) | Area ($km^2$) | Winter balance Measured 5th May 2006 | | Summer balance Measured 11th Oct 2006 | | Net balance Summer surface 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| | | Specific (m w.eqv.) | Volume ($10^6$ $m^3$) | Specific (m w.eqv.) | Volume ($10^6$ $m^3$) | Specific (m w.eqv.) | Volume ($10^6$ $m^3$) |
| 1700 - 1757 | 0.16 | 1.60 | 0.25 | -3.05 | -0.48 | -1.45 | -0.23 |
| 1650 - 1700 | 0.13 | 1.65 | 0.21 | -2.95 | -0.38 | -1.30 | -0.17 |
| 1600 - 1650 | 0.38 | 1.60 | 0.60 | -2.90 | -1.09 | -1.30 | -0.49 |
| 1550 - 1600 | 2.45 | 1.55 | 3.79 | -2.85 | -6.98 | -1.30 | -3.18 |
| 1500 - 1550 | 2.54 | 1.50 | 3.81 | -2.80 | -7.11 | -1.30 | -3.30 |
| 1450 - 1500 | 1.92 | 1.40 | 2.69 | -2.95 | -5.67 | -1.55 | -2.98 |
| 1400 - 1450 | 1.36 | 1.30 | 1.76 | -3.45 | -4.67 | -2.15 | -2.91 |
| 1350 - 1400 | 1.01 | 1.10 | 1.11 | -3.90 | -3.94 | -2.80 | -2.83 |
| 1300 - 1350 | 0.79 | 0.95 | 0.75 | -4.20 | -3.31 | -3.25 | -2.56 |
| 1250 - 1300 | 0.69 | 0.70 | 0.48 | -4.65 | -3.19 | -3.95 | -2.71 |
| 1200 - 1250 | 0.44 | 0.50 | 0.22 | -5.10 | -2.22 | -4.60 | -2.00 |
| Calving | | | | | -1.0 | | -1.0 |
| **1200 - 1757** | **11.84** | **1.32** | **15.7** | **-3.38** | **-40.1** | **-2.06** | **-24.4** |

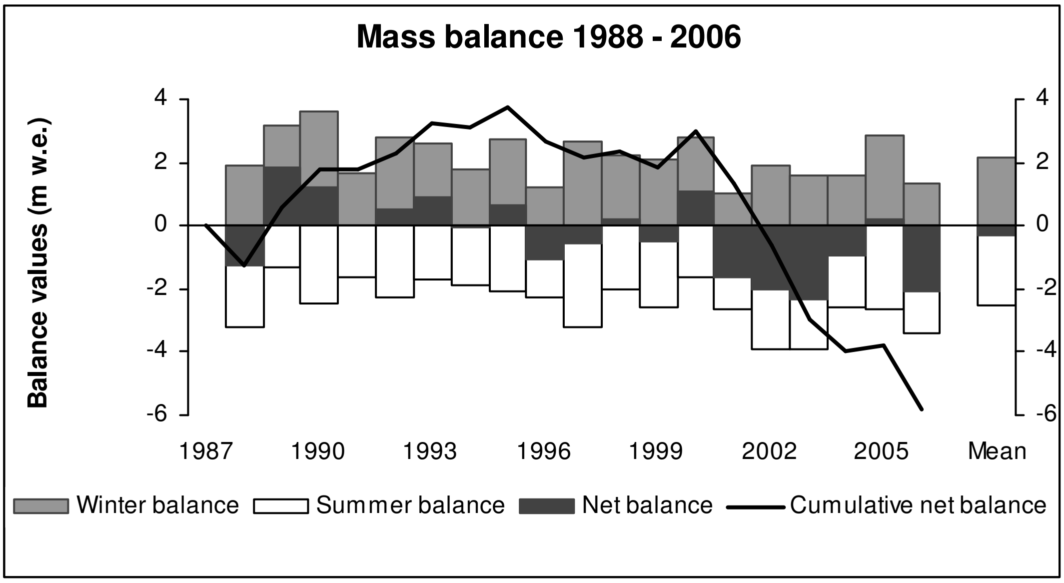



**Figure 5-4**
**Winter, summer and net balances at Austdalsbreen during the period 1988-2006. Mean winter, summer and net balance is 2.19, –2.49 and –0.30 m w.e., respectively. Cumulative net balance in this period was –5.9 m w.e.**

## 5.2 Front position change

Eight points along the calving terminus were surveyed on 11th October 2006. Between 17th October 2005 and 10th October 2006 the mean front position change was +24 ±5 m (Fig. 5-5). This is the first recorded advance since measurements began in 1988. The advance, or the lack of summer retreat, was caused by the unusually low lake levels in Styggevatnet during summer and autumn 2006 (Fig. 5-6). Comparison of surveyed stake positions and terminus positions on 4th July and 11th October show that hardly any calving took place at this part of the terminus during the summer. Previously, low annual lake levels have coincided with reduced calving and retreat (as in 1994, see Fig. 5-7). Since 1988 the glacier terminus has retreated 396 metres, whilst the glacier area has decreased by approximately 0.41 $km^2$ (Fig. 5-5).

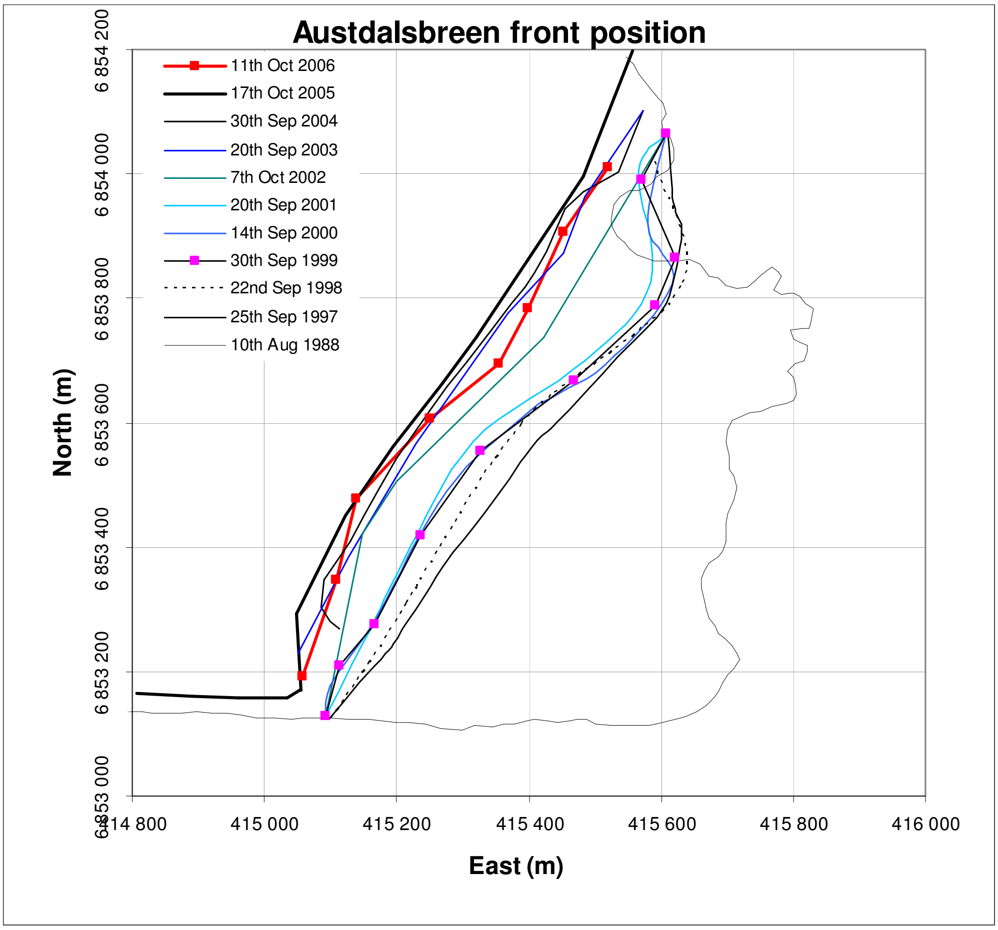



**Figure 5-5**
**Surveyed front position of Austdalsbreen in 1988 when the lake was regulated, and autumn position in 1997-2006. Mean front position change between 17th October 2005 and 11th October 2006 was +24 m.**

Due to large variations in calving, the variation in front position throughout the year is large compared with the net change from year to year. Figure 5-6 illustrates how the front position at a central flow line has varied over the last 19 years. As a consequence of lake regulation it was expected that the glacier terminus would retreat. Modelling predicted a future change in front position that is shown as a broken line in Figure 5-7. The predicted mean annual net balance used in the model was –0.47 m w.e., whilst the actual mass balance has been –0.30 m w.e.

**Figure 5-6**
**Austdalsbreen photographed 11th October 2006 (top – photo Miriam Jackson), 4th July 2006 (middle – photo Hallgeir Elvehøy) and 17th October 2005 (bottom – photo Ole Magnus Tønsberg). The lake level was 1175 m a.s.l. on 11th October 2006 and 1198 m a.s.l. on 17th October 2005.**

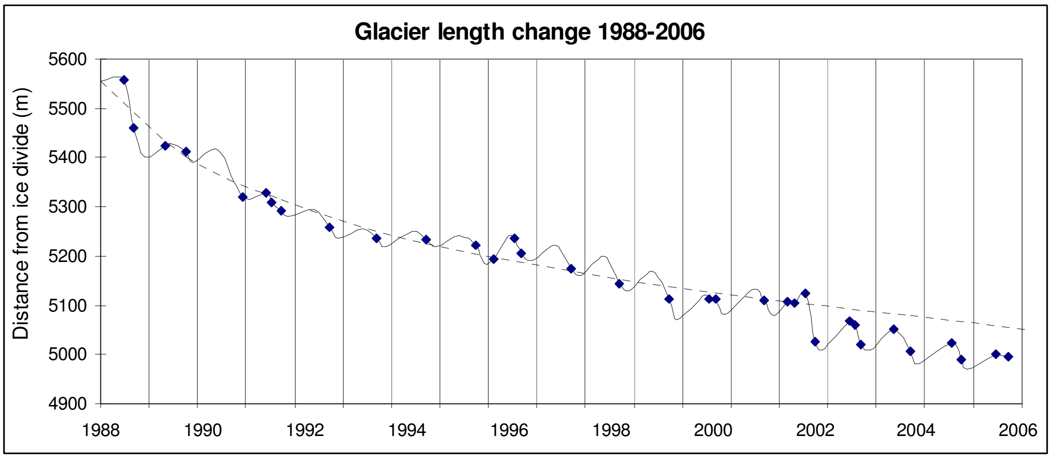



**Figure 5-7**
**Surveyed glacier front position along a central flow line, shown as change in glacier length along this flow line (dots). The solid line indicates annual variation in front position. The glacier terminus advances from December to July when the lake is frozen, and retreats during July-December due to calving. In 1988, lake Austdalsvatnet/Styggevatnet was regulated as a reservoir for the first time. The broken line shows predicted glacier length change based on expected annual lake level variations due to regulation and an annual net balance of –0.47 m w.eqv. (Laumann & Wold, 1992).**

# 5.3 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 10th August and 17th October 2005, and 4th July, 11th August and 11th October 2006.

Annual velocities were calculated for four stake locations (stake 92 – 47 m/a, stake 90 – 31 m/a, stake 24 – 23 m/a and stake 60 – 16 m/a). At stake 5, located 200 m up-glacier from the terminus, the mean summer velocity was 0.14 m/d corresponding to an annual velocity of 53 m/a. The stake velocities are slightly lower than in 2005.

The glacier velocity averaged across the front width and thickness had to be estimated in order to calculate the calving volume (chap. 5.1). The surface centre line velocity at the terminus was calculated from summer measurements at stake 5 (53 m/a), average distance from the stake to terminus (200 m), and an average strain rate from previous years (0.1 1/a) to 70 m/a. 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. The resulting terminus cross-sectional averaged glacier velocity is 50 ±10 m/a.

# 6. Hardangerjøkulen (Hallgeir Elvehøy)

Hardangerjøkulen (60°32'N, 7°22'E) is the sixth largest (73 km$^2$) glacier in Norway. The glacier is situated on the main water divide between Hardangerfjorden and Hallingdalen valley. In 1963 the Norwegian Polar Institute began mass balance measurements on the south-western outlet glacier Rembesdalsskåka (17 km$^2$), which drains towards Simadalen valley and Hardangerfjorden. In the past Simadalen has been flooded by jökulhlaups (outburst floods) from the glacier-dammed lake Demmevatnet, the most recent occurring in 1937 and 1938.

The Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations at Rembesdalsskåka since 1985. The investigated basin covers the altitudinal range between 1020 and 1865 m a.s.l. At Rembesdalsskåka, glacier length observations were initiated in 1917 by Johan Rekstad at Bergen Museum. Observations were conducted in several periods during the 20$^{th}$ century. Statkraft Energy AS re-initiated the observations at Rembesdalsskåka in 1995. At Midtdalsbreen, glacier length observations were started by Prof. Atle Nesje at the University of Bergen in 1982. Glacier length observations are described in chapter 14. The University of Utrecht, Netherlands, operates an automatic weather station (AWS) close to the terminus of Midtdalsbreen.

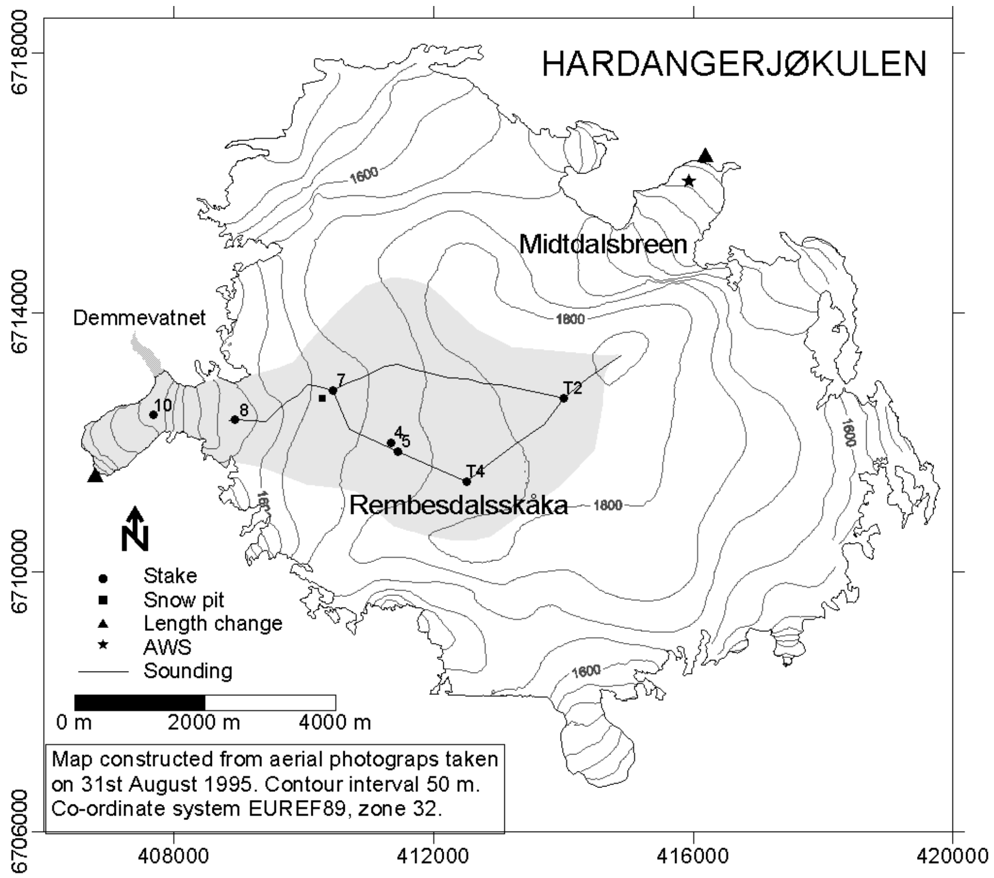



**Figure 6-1**
**Location of sounding profiles, stakes and snow pit at Rembesdalsskåka (shaded), glacier length observations at Rembesdalsskåka and Midtdalsbreen, and an automatic weather station (AWS) at Midtdalsbreen.**

# 6.1 Mass balance at Rembesdalsskåka in 2006

## Fieldwork

The stake network was checked on 28th November, 2nd January and 20th February. Stakes in five out of six locations were maintained throughout the winter. Snow depth soundings and stake measurements on 28th November showed the amount of late-autumn melting at five locations. At stakes 10 and 8, 0.65 and 0.35 m ice, respectively had melted. Stakes 7, T4 and T2 had become 0.40, 0.30 and 0.15 m longer, respectively due to melting and compaction.

The winter balance measurements were carried out on 9th May. The calculation of winter balance is based on the following data (see fig. 6-1 for locations):

- Snow depth measurements at stakes 10 (1270 m a.s.l.), 8 (1510 m a.s.l.), 7 (1660 m a.s.l.), 5 (1720 m a.s.l.), T4 (1770 m a.s.l.) and T2 (1830 m a.s.l.) showing snow depths of 0.95, 0.95, 2.05, 3.25, 2.75 and 2.75 m, respectively.
- Snow density down to the summer surface (SS) at 2.05 m depth at stake 7 (1660 m a.s.l.). The mean snow density of the snow pack was 0.50 g/cm$^3$. Below the SS there was firn from 2005.
- 67 snow depth soundings along 12 km of profiles on the glacier plateau above 1500 m a.s.l. Between 1500 and 1700 m a.s.l. the snow depth was1.5 to 2.5 metres. Above 1700 m a.s.l. the snow depth was 2.5 to 3.0 m. The SS was easy to detect.

Between 12th June and 22nd September stakes 10 and 8 had melted out, and all the winter snow on the glacier had melted.

Summer and net balance was measured on 10th October. Measurements at the stakes showed up to 0.35 m of new snow at stakes above 1600 m a.s.l. At stakes T2 (1830 m a.s.l.), T4 (1775 m a.s.l.), 5 (1725 m a.s.l.), and 4 (1720 m a.s.l.), 1.85- 2.15 - 1.45 and 2.15 m of firn from 2005, respectively, had melted. At stake 7 1.7 metres of firn from 2005 and 1.3 m of firn older than 2001 had melted. At stakes 8 (1510 m a.s.l.) and 10 (1270 m a.s.l.), 0.50 and 0.65 m of ice, respectively had melted since 22nd September.

## 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

The winter balance was calculated as the sum of late autumn ablation measured on 28th November 2005 and winter snow accumulation measured on 9th May 2006.

The altitudinal distribution of the late autumn ablation was determined from measurements at stakes 10, 8, 7, T4 and T2. The density of melted snow (from the winter of 2005) and ice was set to 0.60 and 0.90 g/cm$^3$, respectively. The total late autumn ablation equalled 4 mill. m$^3$ water or 0.2 m w.e. distributed equally over Rembesdalsskåka.

The snow accumulation was calculated from snow depth and snow density measurements taken on 9th May 2006.

A snow depth-water equivalent profile for 9th May 2006 was calculated based on snow density measurements in a pit at stake 7 (1660 m a.s.l.). Using the calculated profile, the mean density of 2.5 m of snow was 0.50 g/cm$^3$. The snow depth measurements were transformed to water equivalent values using this profile.

The calculated water equivalent values were plotted against altitude. From these points, an altitudinal winter accumulation curve was drawn (Fig. 6-2). Below 1510 m a.s.l. the only snow depth measurement was at stake 10, and the snow accumulation curve had to be extrapolated from the measurements at stakes 8 and 10. From this curve a mean value for each 50 m elevation interval was determined.

The winter balance was calculated as the sum of late autumn ablation and snow accumulation in each altitudinal interval. The resulting winter balance was 0.9 ±0.2 m w.e. or 15 ±3 mill. m$^3$ water. This is 43 % of the 1963-2005 average of 2.11 m w.e., and 48 % of the 2001-2005 average of 1.89 m w.e. This is the smallest winter balance since the measurements started in 1963. The altitudinal distribution of the winter balance is shown in Figure 6-2 and Table 6-1.

### Summer balance

The summer balance was calculated directly at four locations between 1660 and 1830 m a.s.l. The density of firn from 2005 is set as 0.7 g/cm$^3$, and the density of firn older than 2001 at stake 7 is set as 0.75 g/cm$^3$. The snow and ice melting between 12th June and 22nd September at stake 8 and 10 was estimated from stake measurements and the melt record at the AWS at Midtdalsbreen. On 12th June, 0.85 m of snow remained at the AWS. The snow pack had melted around 3rd July, and 3.5 m of ice had melted by 8th September. The melt rate of snow and ice was 4.0 cm/d and 5.2 cm/d, respectively. Stake 10 is located 170 m lower than the AWS, and stake 8 is located 70 m higher than the AWS. The melt rate for snow was estimated as 5.0 and 4.0 cm/d at stakes 10 and 8, respectively, while the melt rate for ice was estimated as 6.0 and 5.0 cm/d, respectively. The resulting ice melt until 22nd September (after the remaining snow had melted) at stake 10 and 8 was 5.65 and 4.40 metres, respectively. The density of the ice at stakes 8 and 10 is set as 0.9 g/cm$^3$.

From these six point values the summer balance curve in Figure 6-2 was drawn. The summer balance was calculated as −3.1 ±0.2 m w.e., corresponding to −35 ±3 mill. m$^3$ of water. This is 158 % of the 1963-2005 average, which is −1.98 m w.e., and 135 % of the 2001-2005 average of −2.31 m w.e.

### Net balance

The net balance at Rembesdalsskåka was calculated as −2.2 ±0.3 m w.e. or −38 ±5 mill. m$^3$ water. The 1963-2005 average is +0.08 m w.e., and the 2001-2005 average is −0.42 m w.e. The altitudinal distribution of winter, summer and net balances is shown in Figure 6-2 and Table 6-1. Since all the winter snow melted, the ELA was above the top of the glacier at 1860 m a.s.l., and the accumulation area ratio (AAR) was 0 %. Results from 1963-2006 are shown in Figure 6-3. The cumulative net balance is +3.4 m w.e.

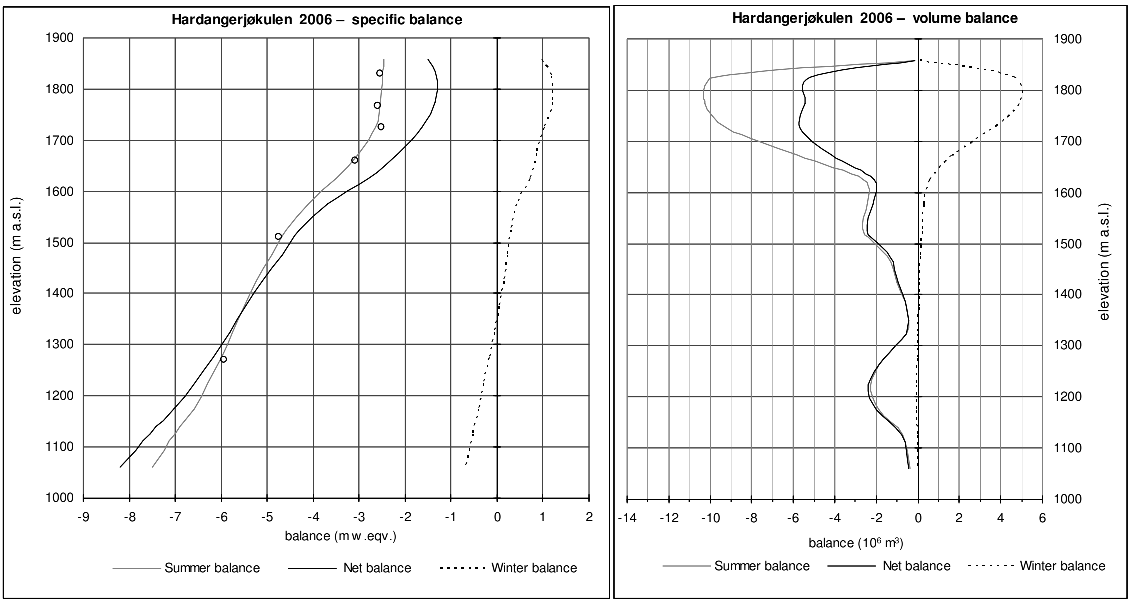



**Figure 6-2**
**Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalsskåka, Hardangerjøkulen in 2006. Specific summer balance at six stakes is shown (o).**

**Table 6-1**
**Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka in 2006.**

**Mass balance Hardangerjøkulen 2005/06 – traditional method**

| | | Winter balance | | Summer balance | | Net balance | |
|---|---|---|---|---|---|---|---|
| | | Measured 9th May 2006 | | Measured 10th Oct 2006 | | Summer surface 2005 - 2006 | |
| 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 ($10^6$ $m^3$) |
| 1850 - 1865 | 0.09 | 0.95 | 0.1 | -2.45 | -0.2 | -1.50 | -0.1 |
| 1800 - 1850 | 3.93 | 1.18 | 4.6 | -2.50 | -9.8 | -1.32 | -5.2 |
| 1750 - 1800 | 4.03 | 1.20 | 4.8 | -2.55 | -10.3 | -1.35 | -5.4 |
| 1700 - 1750 | 3.46 | 1.02 | 3.5 | -2.65 | -9.2 | -1.63 | -5.6 |
| 1650 - 1700 | 1.94 | 0.84 | 1.6 | -3.00 | -5.8 | -2.16 | -4.2 |
| 1600 - 1650 | 0.75 | 0.71 | 0.5 | -3.50 | -2.6 | -2.79 | -2.1 |
| 1550 - 1600 | 0.59 | 0.43 | 0.3 | -4.10 | -2.4 | -3.67 | -2.2 |
| 1500 - 1550 | 0.57 | 0.30 | 0.2 | -4.60 | -2.6 | -4.30 | -2.4 |
| 1450 - 1500 | 0.29 | 0.22 | 0.1 | -4.90 | -1.4 | -4.68 | -1.4 |
| 1400 - 1450 | 0.19 | 0.13 | 0.0 | -5.25 | -1.0 | -5.12 | -1.0 |
| 1350 - 1400 | 0.10 | 0.03 | 0.0 | -5.50 | -0.6 | -5.47 | -0.6 |
| 1300 - 1350 | 0.10 | -0.07 | 0.0 | -5.75 | -0.6 | -5.82 | -0.6 |
| 1250 - 1300 | 0.27 | -0.18 | 0.0 | -6.00 | -1.6 | -6.18 | -1.7 |
| 1200 - 1250 | 0.36 | -0.30 | -0.1 | -6.30 | -2.3 | -6.60 | -2.4 |
| 1150 - 1200 | 0.28 | -0.42 | -0.1 | -6.60 | -1.9 | -7.02 | -2.0 |
| 1100 - 1150 | 0.11 | -0.54 | -0.1 | -7.00 | -0.7 | -7.54 | -0.8 |
| 1020 - 1100 | 0.05 | -0.70 | 0.0 | -7.50 | -0.4 | -8.20 | -0.4 |
| 1020 - 1865 | 17.1 | 0.90 | 15.4 | -3.12 | -53.4 | -2.22 | -38.0 |

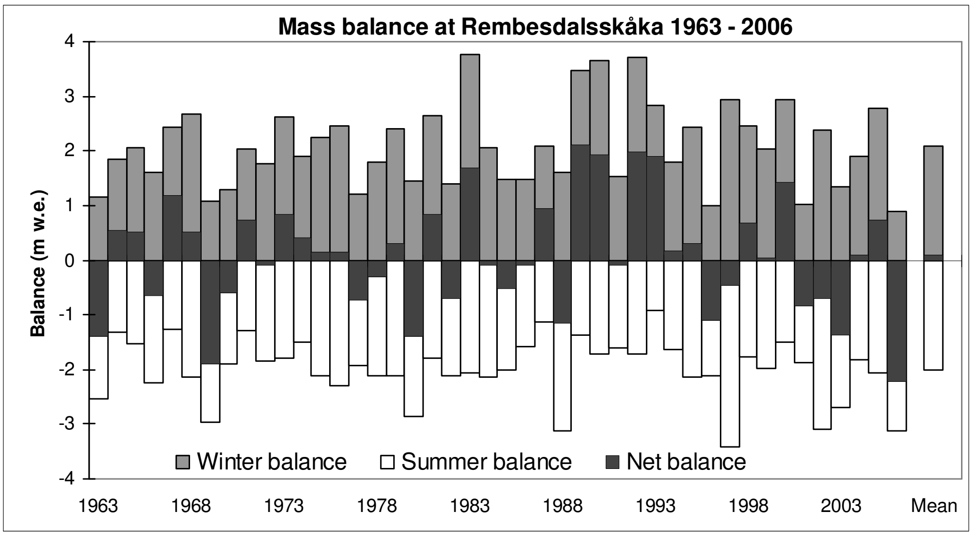



**Figure 6-3**
**Winter, summer and net balances at Hardangerjøkulen during the period 1963-2006. Mean values for the period are $b_w$=2.08 m, $b_s$=−2.00 m and $b_n$=+0.08 m water equivalents.**

# 6.2 Meteorological measurements on Hardangerjøkulen (Rianne H. Giesen, Utrecht University)

Since October 2000, an automatic weather station (AWS) has been operating on Midtdalsbreen, a north-easterly outlet glacier of Hardangerjøkulen. The station (Fig. 1) is owned and maintained by the Institute of Marine and Atmospheric research Utrecht (IMAU), Utrecht University (contact: J.Oerlemans@phys.uu.nl). The station records air temperature, relative humidity, wind speed and direction, distance to the surface, shortwave and longwave radiation and air pressure. Sampling is done every few minutes (depending on the sensor) and 30-minute averages are stored.
The measurements are used to study the local microclimate at Hardangerjøkulen and to calibrate a mass balance model for the glacier. Here, we present a selection of data collected between 1st October 2005 and 8th September 2006.

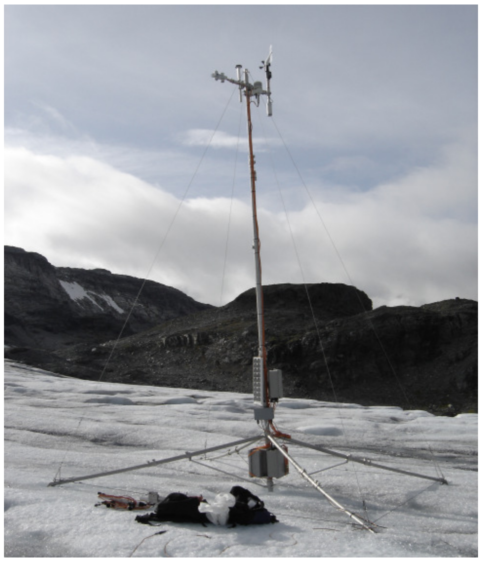


**Figure 6-4**
**The AWS on Midtdalsbreen on 8th September 2006. Photo: R.H. Giesen**

## Surface height

The change in surface height as monitored by the station is shown in Figure 6-5. For some periods, surface height had to be estimated by calculating surface melt from the other parameters. There was some snowfall in October, but the build-up of the winter snow pack started in early November. The maximum snow depth was less than 2 m, which is small compared to other years. At the end of June, all winter snow had melted at the AWS site. From then until 8th September about 3.3 m of ice melted.

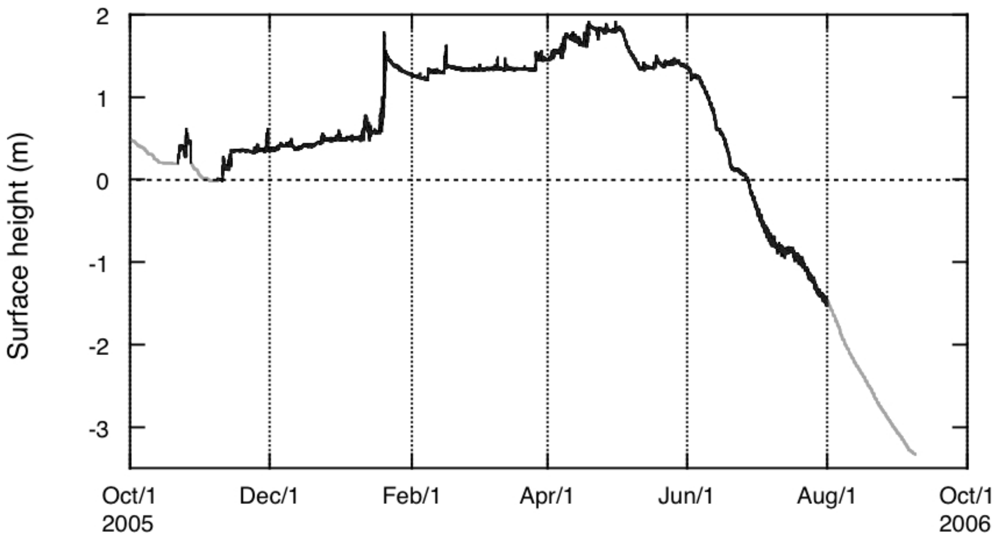



**Figure 6-5**
**Surface height measured by the AWS (black) and estimated from calculated surface melt (gray).**

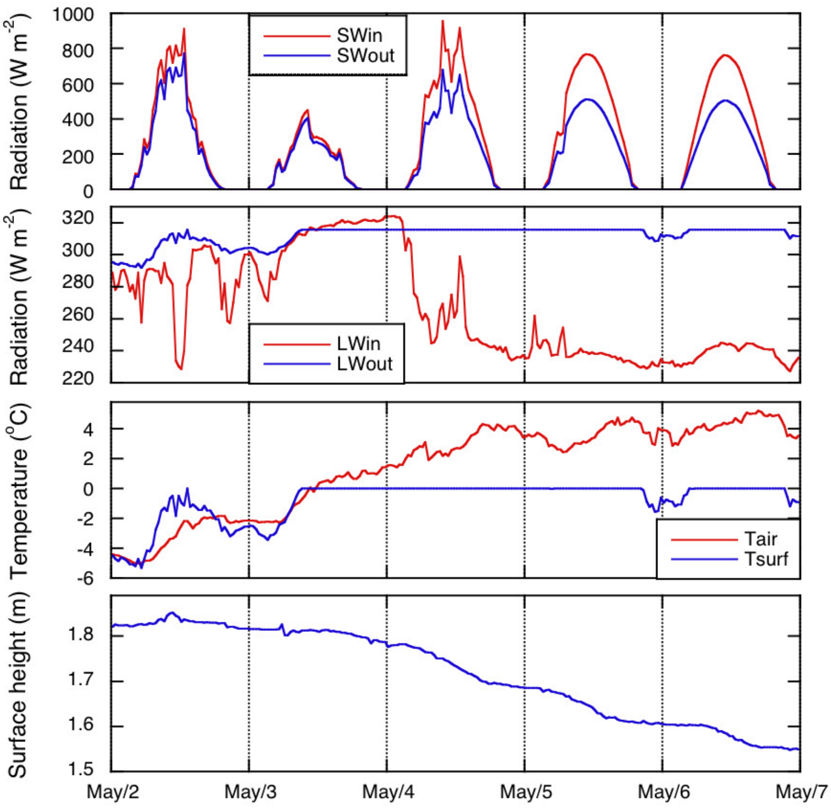



**Figure 6-6**
**Measured incoming and reflected shortwave radiation (SWin and SWout), incoming and outgoing longwave radiation (LWin and LWout), air and surface temperature (Tair and Tsurf) and surface height (= snow pack thickness) for a 5-day period in May 2006.**

## Daily cycles

Figure 6-6 shows 30-minute values of several parameters measured by the AWS for a 5-day period in May 2006. This period was chosen because of interesting differences between the days.

The fluctuations in the shortwave radiation on the first three days indicate cloudy conditions. Almost no clouds were present on the last two days. On two cloudy days, 2nd and 3rd May, maximum incoming solar radiation is higher than on the cloudless days. This occurs when solar radiation directly reaches the sensor and is further increased by multiple reflections between clouds and the snow surface. On 3rd May, the reflected solar radiation is almost equal to the incoming solar radiation, indicating a high surface albedo. This is likely caused by snowfall on 2nd May, which is seen as an increase in the surface height (fourth panel).

The second panel illustrates that clouds emit considerably more long wave radiation (LWin) than the clear sky. Outgoing long wave radiation reaches a maximum value of 315.6 $Wm^{-2}$ on 2nd May, implying that the surface has reached the melting point temperature, which can also been seen in the third panel. Air temperature is not restricted and increases beyond the melting point temperature. On the clear sky days, a daily cycle is visible with a maximum in the afternoon. When the surface has reached the melting point temperature, snow starts to melt and the surface height decreases. Melting mainly occurs during the day, when solar radiation is available and the air temperature is highest. Within four days, snow depth decreased by almost 25 cm.

# 7. Aurland Mountains

(Arve M. Tvede and Tron Laumann)

## 7.1 Recent glacial changes in the Aurland Mountains

### Introduction

The Aurland Mountains are located in the inner part of the Sognefjord area, close to the main water divide. The area is a mountain plateau complex, mainly at 1200 – 1400 m a.s.l., but with some isolated plateaux as high as 1600 – 1700 m a.s.l. The highest plateaux are composed of hard Precambrium rocks, which were pushed over the softer Cambrium rocks during the time of the Caledonian mountain formation. The plates often end in escarpments. These high plateaux contain some glaciers, the largest of which is Storskavlen, which in September 1969 covered 7.45 km$^2$ (Østrem and others, 1988). The other glaciers are all smaller than 1 km$^2$ (see Fig. 7-1).

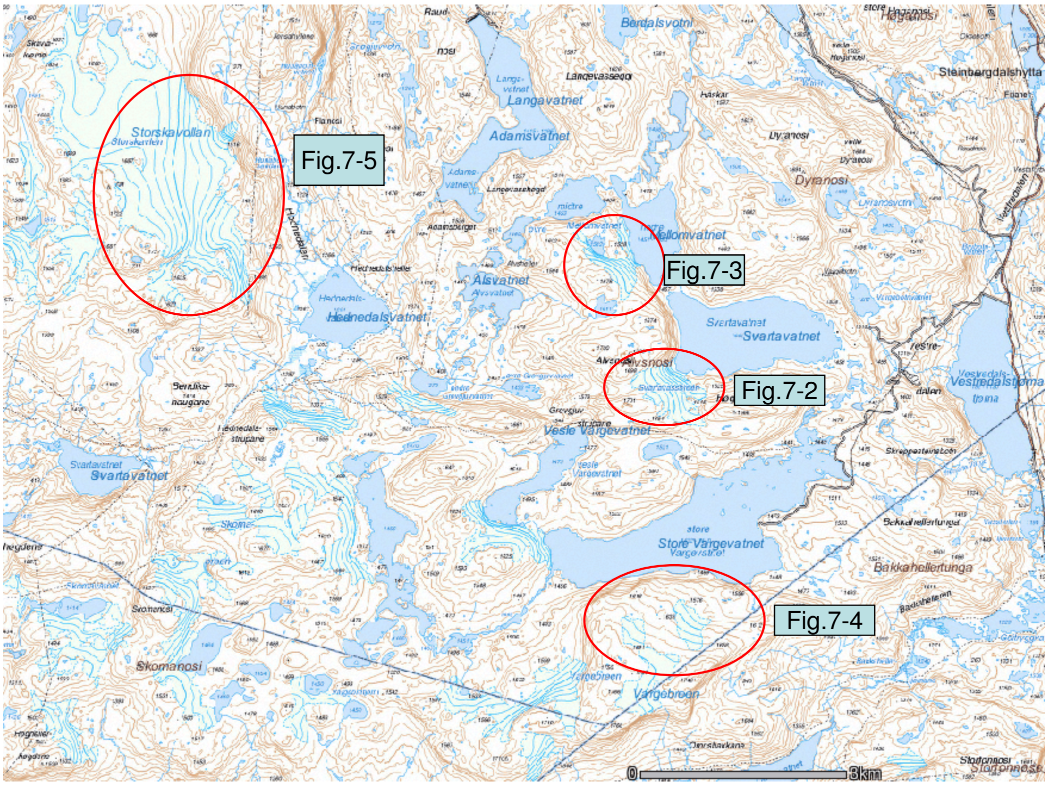



**Figure 7-1**
**Map of the area, showing glaciers described in the text and in photos.**

In the 1990s it was found that some of the glaciers had changed their size and volume somewhat differently during the last 50 years (see Tvede and Laumann, 1997).

The glaciers were revisited in September 2006 and photos were taken from the same points that were used by the National Geographical Survey in 1941 and by the authors in 1995.

## Comparison of 1941 and 2006

Comparable photos from these two years are presented below for Svartavassbreen, Alsnosibreen and Vargebreen glaciers. The exact date of the 1941 photos is unknown, but they were probably taken in the late summer as there is little snow left on the glaciers. The photos from 2006 were all taken on 10th September.

**Figure 7-2**
**Svartavassbreen glacier. The upper photo is from late summer 1941 (photo by Kvistgård) and the lower is from 10th September 2006 (photo by A. M. Tvede). Lake Svartavatn is in the foreground. The lake is regulated and the water level was lowered about 5 metres in 2006.**

**Figure 7-3**
**The Alsnosibreen glacier. The upper photo is from late summer 1941 (photo by Kvistgård) and the lower is from 10th September 2006 (photo by A. M. Tvede). Lake Mellomvatn is in the foreground. The lake is regulated and the water level was lowered about 5 metres in 2006. The glacier Storskavlen is seen in the background.**

**Figure 7-4**
**Vargebreen glacier. The upper photo is from late summer 1941 (photo by Kvistgård) and the lower is from 10th September 2006 (photo by A.M. Tvede). Lake Store Vargevatn is in the foreground. The lake is regulated, but the water level was approximately the same in both photos.**

Both photos show the glaciers in a state with little or no snow left from the preceding winter. In 1941 there were no measurements of glacier mass balance in Norway. Instead we have studied weather data from Bergen in 1941. The winter of 1940-41 was very dry with only 56 % of the normal precipitation in the accumulation period from October to May. The summer of 1941 was warm with a mean temperature for June, July and August 0.6 °C above normal. I would thus be expected that the glacier on the west side of the watershed would have a strong negative mass balance in 1941. Tvede (1982) presented a calculation of the mass balance for Folgefonna glacier based on the weather data from Bergen. For 1941 the calculation resulted in a negative balance of 1.99 m w.e. Liestøl

(1967) presented similar calculations for the Storbreen glacier in Jotunheimen with a negative balance of 1.04 m w.e.

In 2006 the weather conditions were similar to 1941 with a dry winter preceding a warm summer. As documented earlier in this report, the mass balances in 2006 were negative for all glaciers in Southern Norway. The results for Folgefonna, Hardangerjøkulen and Storbreen glaciers were −3.0, −2.2 and −2.15 m w.e. Hence, the photos in Figures 7-2, 7-3 and 7-4 were taken in glaciologically quite comparable situations, with no remaining snow cover to complicate the interpretation. This is an important premise when comparing the size of the glaciers from photos.

Figure 7-5 shows Storskavlen glacier from a distance. There are no photos from 1941 from the same location.

**Figure 7-5**
**Storskavlen glacier from the southeast on 10th September 2006. Photo: Arve M. Tvede.**

## Changes between 1941 and 2006

The Svartavassbreen glacier (Fig. 7-2) had little net change during the past 65 years. The glacier front terminated in the lake in 1941, and in 2006 the front was on dry land, 5-20 m from the water. However, had the water stage been the same in 2006 as in 1941, then the glacier front would had ended in the water also in 2006. The glacier increased its thickness by 5.8 m between 1969 and 1989 (Tvede and Laumann, 1997). The increase in thickness and in size continued until the mid 1990s, but is not quantified. From 1995 to 2006 there has evidently been a substantial decrease in size as seen on photos (the 1995 photo is not presented here).

The Alsnosibreen glacier (Fig. 7-3) also had little net change. In fact, there are signs of a net thickening in the central part of the glacier where a small rock was visible in 1941, but not in 2006. Like Svartavassbreen glacier, the glacier front ended in a lake in 1941, and on dry land in 2006, but would have terminated in water if the lake level had been the same. The glacier was not visited in the 1990s, but it is thought that the mass balance history was similar to that of Svartavassbreen glacier.

The Vargebreen glacier (Fig. 7-4) covered 2 $km^2$ in 1941 and had a length of 2.5 km. In 2006 this glacier had nearly disappeared. Pictures taken in September 1995 (see Tvede and Laumann, 1997) showed that the area covered by the glacier in 1941, was to a large extent covered by snow fields. Air photos from September 1969, another year with very little snow left, showed that only small patches of ice were left. Hence, it seems that Vargebreen must have lost most of its mass between 1941 and 1969.

The changes on Storskavlen glacier (Fig. 7-5) can not be quantified by comparable photos as for the other glaciers. However, the glacier was crossed on foot on 9th September 2006 and observations made indicate that a substantial down-melting has occurred on this glacier, too. On the glacier plateau several rocks outcrops have appeared, that were not visible in 1941. Between 1969 and 1989 the glacier had on average lost 4.2 m of thickness. The changes were, however, very unevenly distributed, from a loss of more than 20 m to an increase of up to 10 m.

### Discussion

Of the four glaciers visited in the Aurland Mountains, one glacier has almost disappeared, one glacier has lost much of its mass and two glaciers are more or less unchanged. The possible reasons for the differences between glaciers situated so close to another, were discussed by Tvede and Laumann, 1997.The main reason seemed to be changes in the local snow accumulation due to wind drift. Weather data indicate that there has been an increase in the frequency of strong wind from the west from the 1950s onwards. This will bring relatively more snow drifting from glacier free terrain on to glaciers in sheltered positions.

# 8. Storbreen (Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the Jotunheimen mountain massif in central southern Norway (Fig. 8-1). The glacier has a total area of 5.4 $km^2$ and ranges in altitude from 1390 to 2090 m a.s.l. (Fig. 8-2). Mass balance measurements were initiated in 1949 and 2006 is the 58th year of continuous measurements. An automatic weather station (AWS) has been operating on the glacier since September 2001 and data from 2005/2006 are described in section 8.2. Results of ice velocity measurements are reported in section 8.3.

**Figure 8-1**
**The upper part of Storbreen photographed on 5th August 2006. Most of the winter snow had already melted away at this time. Photo: Liss M. Andreassen.**

## 8.1 Mass balance 2006

### Fieldwork

Accumulation measurements were performed on 9th May and the calculation of winter balance is based on:

- Measurements of stakes in 12 different positions. Both stake readings and data from the sonic ranger at the AWS (see chapter 8.2) showed additional melting on the lowest stakes after the final measurements on 30th September 2005.
- Soundings of snow depth in 157 positions (15.5 km of profiles) between 1450 and 1950 m a.s.l., covering most of the altitudinal range of the glacier. The summer

surface was easy to identify over the whole glacier. The snow depth varied between 0.6 and 3.9 m, the mean being 2.1 m.

- Snow density was measured down to the summer surface at two positions, at the AWS on the glacier (to 1.7 m depth at 1570 m a.s.l.) and at stake 4 (to 1.7 m depth at 1725 m a.s.l.).

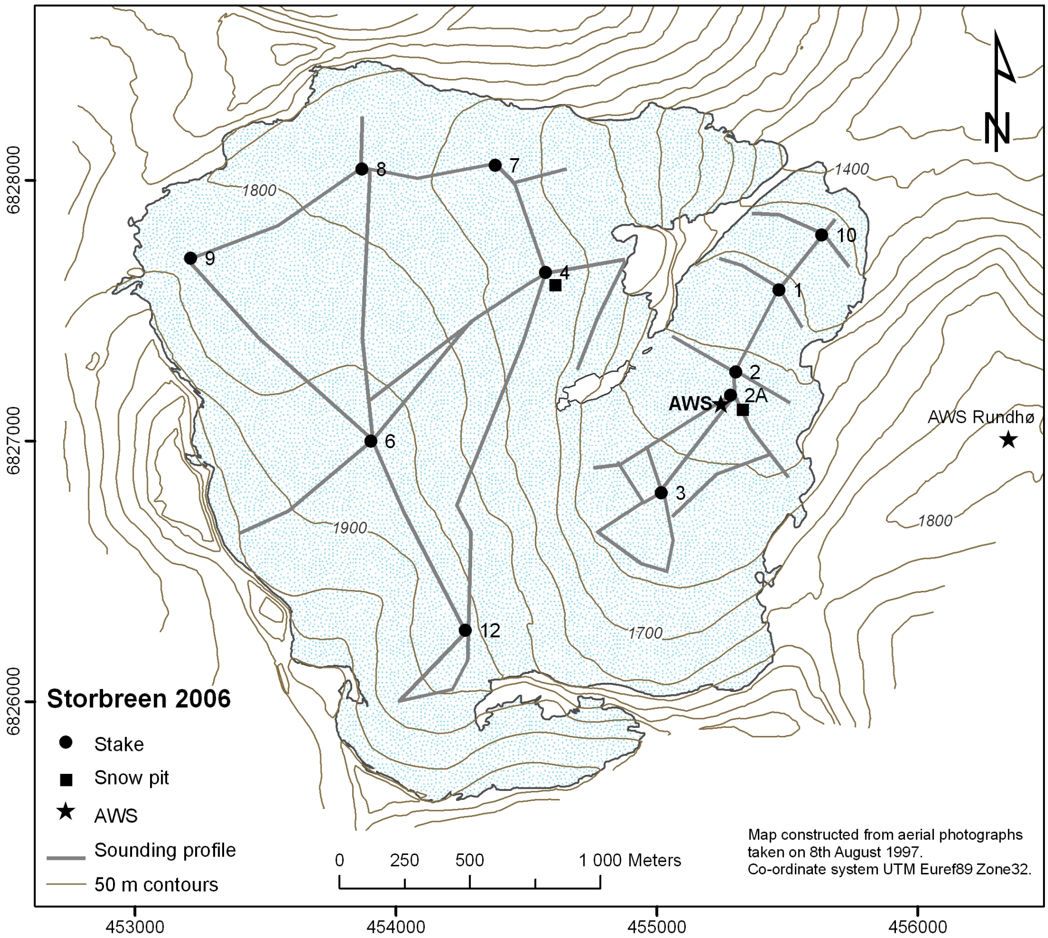



**Figure 8-2**
**Location of stakes, density pits and the automatic weather stations (AWS).**

Ablation measurements were performed on 9th September on stakes in 10 locations from 1512 to 1866 m a.s.l. The locations of stakes, density pits and soundings are shown in Figure 8-2.

## Results

The mass balance results are shown in Table 8-1 and Figure 8-3.

### Winter balance

Winter accumulation was calculated from soundings and the snow density measurements. The mean measured snow density was 0.39 $g/cm^3$ (0.36 $g/cm^3$ at the AWS and 0.41 $g/cm^3$

at stake 4). The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval.

The specific winter accumulation was calculated to be 0.9 ±0.2 m w.e. This is only 56 % of the mean for 1971-2000 and 60 % of the mean for the observation period 1949-2005.

In order to account for the additional summer melt in the cumulative balance, the winter balance was calculated as the winter accumulation subtracted by the additional melt. This gave a winter balance of 0.86 ±0.2 m w.e.

### Summer balance

Summer balance was calculated directly from stakes at 10 locations. There was between 0.15 and 2.2 m remaining snow at the five highest stake locations. The density of the remaining snow was assumed to be 0.6 g/cm$^3$. The density of the melted ice was assumed to be 0.9 g/cm$^3$. The summer balance was calculated to be –3.0 ±0.3 m w.e., which is 185 % of the mean period 1971-2000 and 177 % of the mean for the observation period 1949-2004.

### Net balance

The net balance of Storbreen in 2006 was –2.1 ±0.3 m w.e., which is equivalent to a volume of 11.5 ±1.6 $10^6$ m$^3$ of water. There was no remaining snow at the glacier and the large mass deficit resulted in an ELA above the highest point of the glacier, and hence an accumulation area ratio (AAR) of 0 %. The total deficit of the glacier since 1949 amounts to –16.9 m w.e., giving a mean annual net balance of –0.26 m w.e. for the 58 years of measurements (Fig. 8-4).

**Table 8-1**
**The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2006.**

**Mass balance Storbreen 2005/06 – traditional method**

| Altitude (m a.s.l.) | Area (km$^2$) | Winter balance, Measured 9 May 2006: Specific (m w.e.) | Winter balance: Volume ($10^6$ m$^3$) | Summer balance, Measured 9 Sep 2006: Specific (m w.e.) | Summer balance: Volume ($10^6$ m$^3$) | Net balance, Summer surfaces 2005 - 2006: Specific (m w.e.) | Net balance: Volume ($10^6$ m$^3$) |
|---|---|---|---|---|---|---|---|
| 2050 - 2100 | 0.04 | 1.30 | 0.05 | -2.00 | -0.08 | -0.70 | -0.03 |
| 2000 - 2050 | 0.15 | 1.30 | 0.20 | -2.20 | -0.33 | -0.90 | -0.14 |
| 1950 - 2000 | 0.23 | 1.32 | 0.30 | -2.40 | -0.55 | -1.08 | -0.25 |
| 1900 - 1950 | 0.36 | 1.34 | 0.48 | -2.60 | -0.94 | -1.26 | -0.45 |
| 1850 - 1900 | 0.57 | 1.09 | 0.62 | -2.70 | -1.54 | -1.61 | -0.92 |
| 1800 - 1850 | 0.92 | 0.90 | 0.83 | -2.90 | -2.67 | -2.00 | -1.84 |
| 1750 - 1800 | 0.75 | 0.93 | 0.70 | -3.00 | -2.25 | -2.07 | -1.55 |
| 1700 - 1750 | 0.64 | 0.76 | 0.49 | -3.15 | -2.02 | -2.39 | -1.53 |
| 1650 - 1700 | 0.40 | 0.82 | 0.33 | -3.20 | -1.28 | -2.38 | -0.95 |
| 1600 - 1650 | 0.49 | 0.82 | 0.40 | -3.30 | -1.62 | -2.48 | -1.22 |
| 1550 - 1600 | 0.35 | 0.55 | 0.19 | -3.40 | -1.19 | -2.85 | -1.00 |
| 1500 - 1550 | 0.21 | 0.17 | 0.04 | -3.60 | -0.76 | -3.43 | -0.72 |
| 1450 - 1500 | 0.18 | 0.00 | 0.00 | -3.70 | -0.67 | -3.70 | -0.67 |
| 1390 - 1450 | 0.06 | 0.00 | 0.00 | -3.80 | -0.23 | -3.80 | -0.23 |
| **1390 - 2100** | **5.35** | **0.86** | **4.63** | **-3.01** | **-16.11** | **-2.15** | **-11.48** |

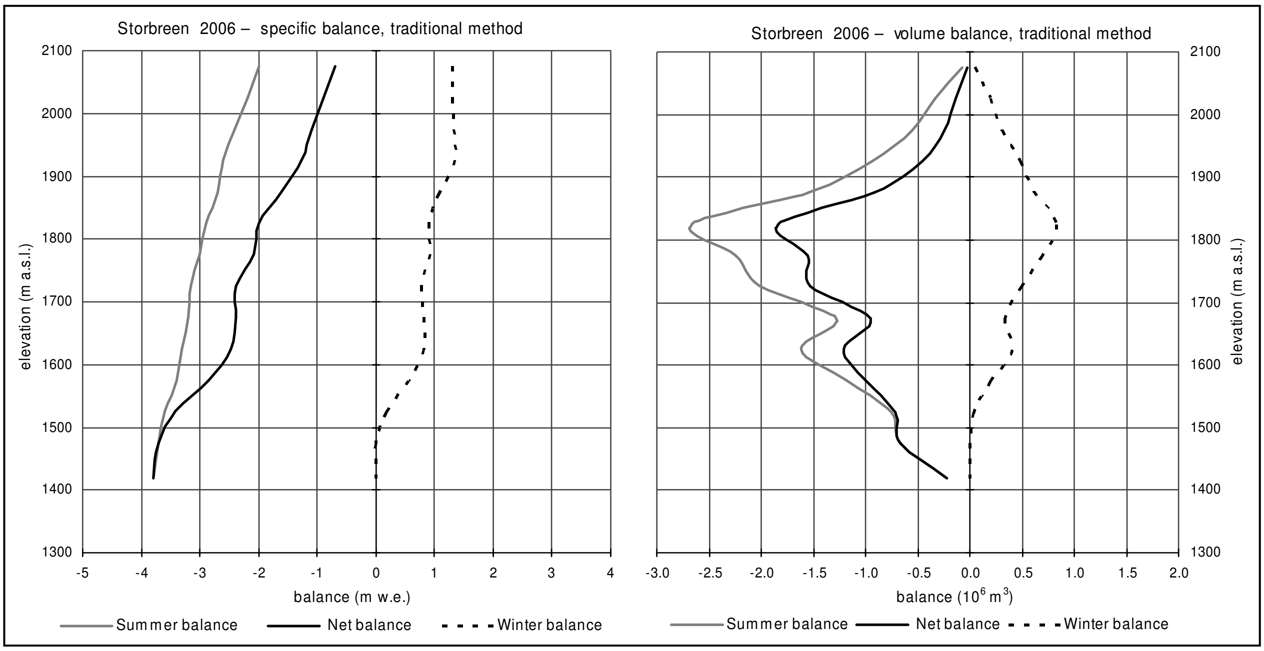



**Figure 8-3**
**Mass balance diagram for Storbreen 2006, showing specific balance on the left and volume balance on the right.**

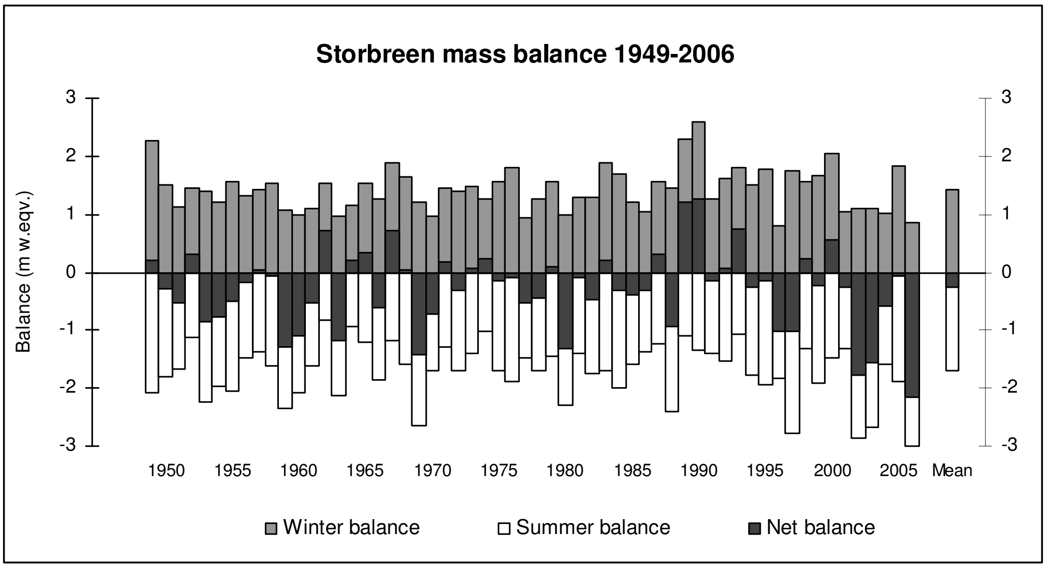



**Figure 8-4**
**Winter, summer and net balance at Storbreen for the period 1949-2006.**

## 8.2 Meteorological measurements

An automatic weather station (AWS) has been operating in the ablation zone of Storbreen, at about 1580 m a.s.l. (Fig. 8-2), since September 2001. The station is part of the Institute of Marine and Atmospheric Research (IMAU) network of AWS on glaciers (http://www.phys.uu.nl/~wwwimau/research/ice_climate/aws/, contact: J.Oerlemans@phys.uu.nl). The station records air temperature, wind speed, wind direction, shortwave and longwave radiation, humidity and instrument height above the surface. Measurements of humidity, temperature and wind are done at two levels, 2 m and 6 m, above the ice surface. Measurements are done every few minutes (depending on the sensor) and 30-minute mean values are recorded. The results from the AWS are used to monitor the micro-climate and study the surface energy balance of Storbreen. Here we present some of the data from the 2005/2006 season.

In September 2005 NVE installed an automatic weather station at Rundhø, a ridge east of the glacier (Fig. 8-2). The station is located at 1805 m asl. and measures temperature, humidity, wind speed and, wind direction. Data are transferred to NVE via telemonitoring.

### Temperature

The measured daily mean temperatures at the AWS at Storbreen and the AWS outside the glacier at Rundhø are shown in Figure 8-5. The temperatures measured at the two stations are well correlated ($r^2 = 0.97$). The temperature observed at Rundhø is −1.7 °C lower than the 6 m temperature at Storbreen. The lowest daily mean values were observed in the beginning of March with temperatures reaching as low as −21.8 °C at Storbreen.

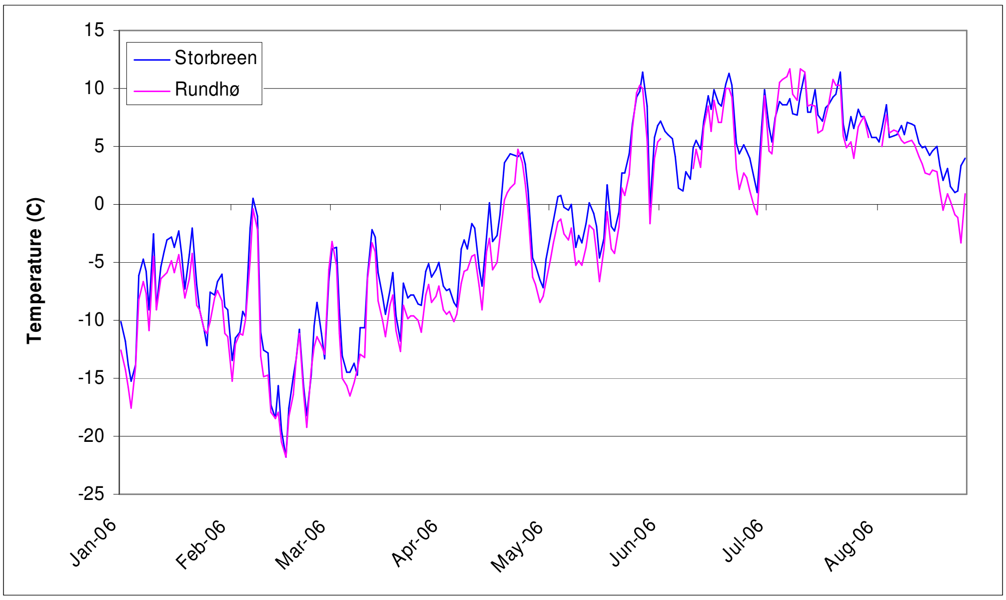
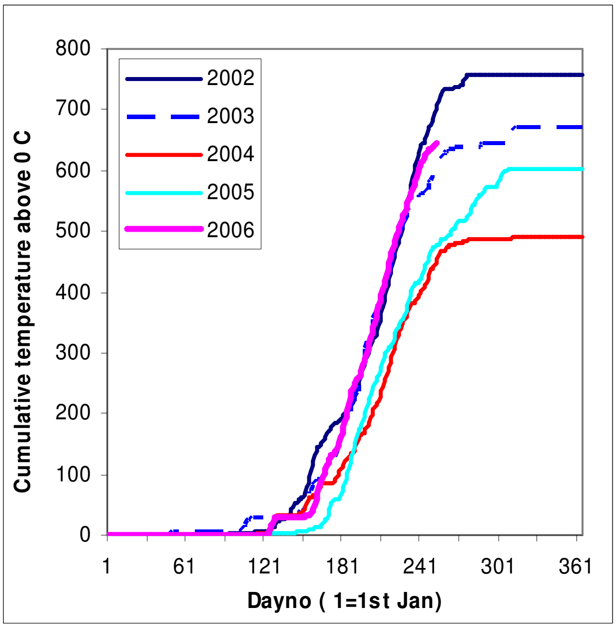



**Figure 8-5**
**Mean daily temperatures at the AWS at Storbreen (1570 m a.s.l.) and at Rundhø (1805 m a.s.l.) in the period 1st January – 9th September. See Figure 8-2 for location.**

This is the lowest daily mean value recorded for Storbreen during the five years of observations. This minimum record occurred shortly after a warm period at the end of




February when air temperatures reached just above 0 °C. The highest daily mean temperature occurred as early as 12th June with 11.4 °C. Comparison of the cumulative daily positive temperatures for the five years of AWS observations reveals that the summer season 2006 was the second warmest of the five years (Fig. 8-6).

**Figure 8-6**
**Cumulative daily air temperature (when daily temp above 0 °C) at 6 m level at the AWS at Storbreen for the years 2002-2006. Measurements were available until 11th September in 2006.**

## Surface height

The sonic ranger recordings of surface height and the derived snow height are shown in Figure 8-7. After the ablation measurements on September 30th 2005 a shallow layer of fresh snow melted away and further melting of the ice surface occurred. A new snowfall took place in mid-October but melted away. From the beginning of November the winter snow pack gradually built up reaching a maximum of 2.0 m mid-April. This is lower than the mean snow thickness of about 3 m for the reference period 1971-2000. The snow pack melted rapidly from the beginning of June and the surface was snow free by 4th July.

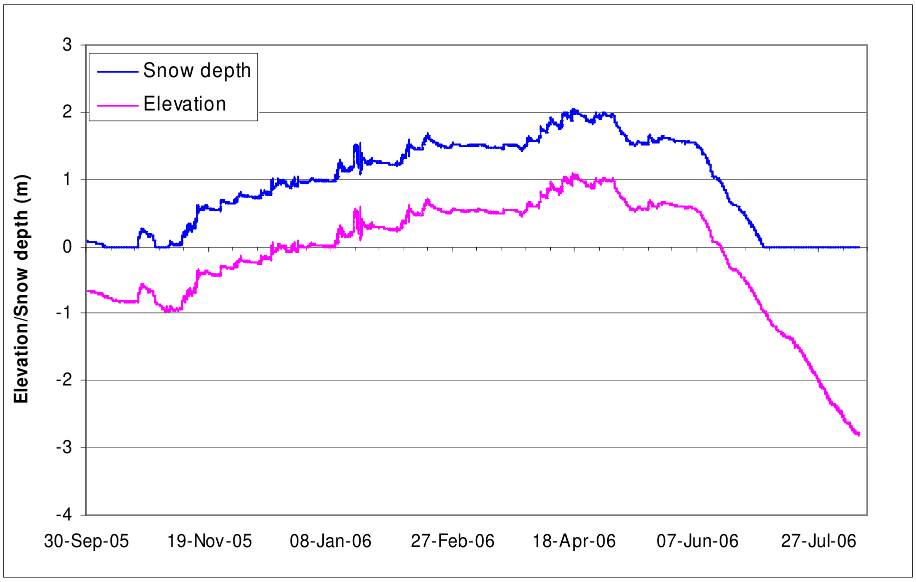



**Figure 8-7**
**Surface elevation measured from the sonic rangers for the period 30th September 2005 -12th August 2006.**

## Surface energy balance

The AWS-data have been used to calculate the surface energy budget of Storbreen. The surface energy balance, $Q_{tot}$, can be expressed as:

$$Q_{tot} = SW_{net} + LW_{net} + Q_{sen} + Q_{lat}$$

where $SW_{net}$ is shortwave net radiative flux, $LW_{net}$ is longwave net radiative flux, $Q_{sen}$ is sensible heat flux and $Q_{lat}$is latent heat flux.

The radiative fluxes are measured at the AWS. The turbulent fluxes were calculated by applying the bulk method. Figure 8-8 show daily cycles in the surface energy balance fluxes for 15 days in July 2006 when the glacier surface is snow free at the AWS. The figure illustrates clearly the strong daily cycle in shortwave net radiation in contrast with the other fluxes. The longwave net radiative flux is generally negative. Figure 8-9 summarises the mean values of the surface energy fluxes during melt in 2006 (until 11th September). The shortwave net radiation is the most important contributor to the melt, while the sensible heat flux is the second most important. The longwave radiative flux is negative, while the latent heat flux is the smallest positive flux.

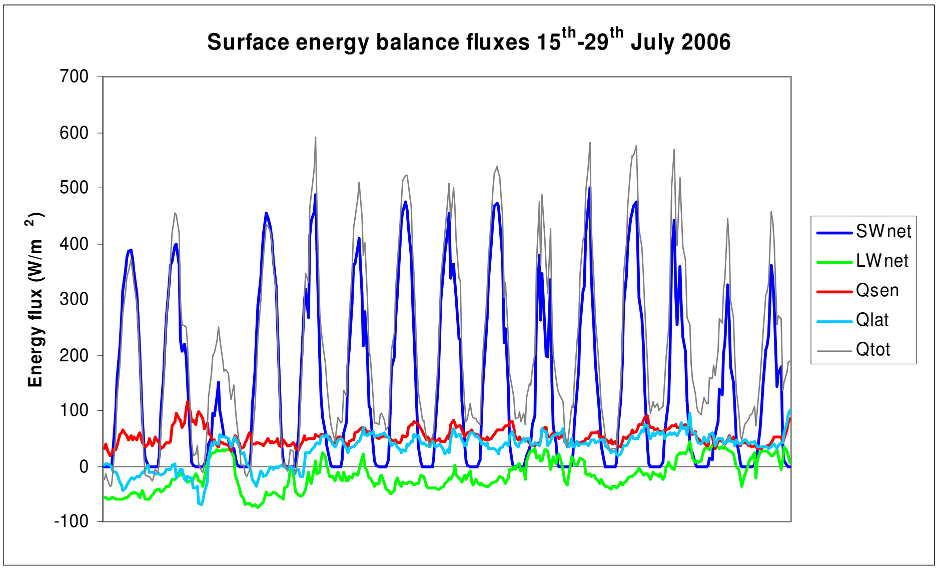



**Figure 8-8**
**Surface energy fluxes at the AWS at Storbreen for the period 15th to 29th July 2006 (1 hour values). SWnet is the shortwave net flux, LWnet is the longwave net flux, Qsen is the sensible heat flux and Qlat is the latent heat flux. Qtot is the total surface energy balance.**

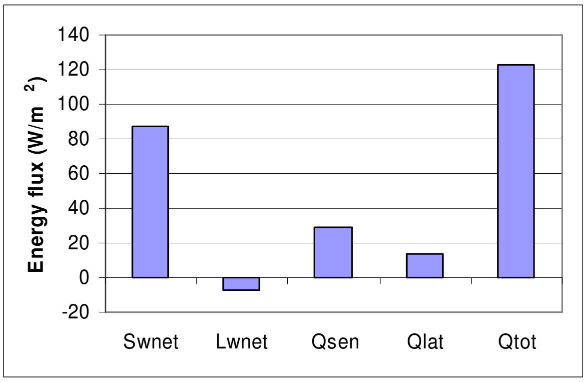



**Figure 8-9**
**Mean surface energy fluxes at the AWS at Storbreen during melt in 2006 (until 11th September). See text of Figure 8-8 for explanation of terms.**

## 8.3 Ice velocity

### Measurements

Measurements of stake positions were carried out on 30th September 2005, 10th May 2006, 2nd August 2006 and 9th September 2006 using differential GPS (dGPS), with one receiver at the base station and one at the stake. Stakes in nine different locations were measured.

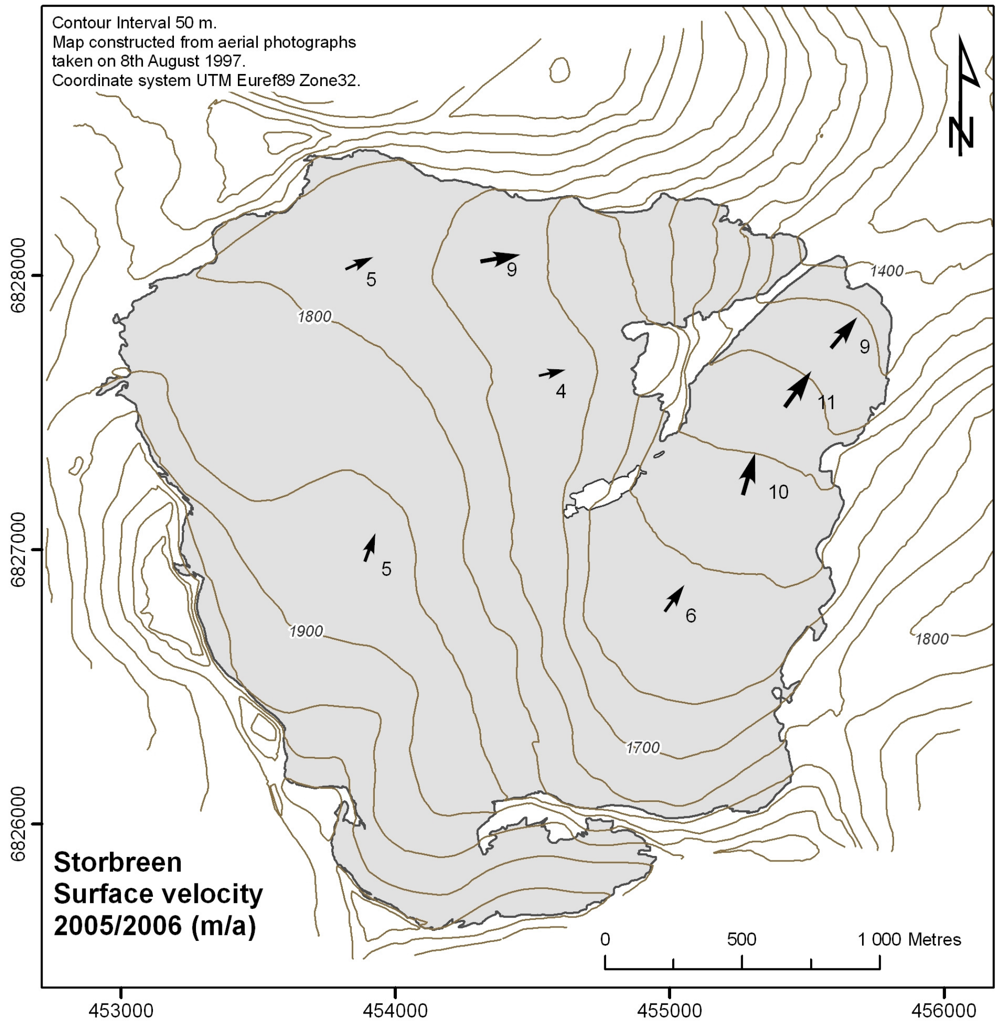



**Figure 8-10**
**Map of annual surface ice velocity vectors at Storbreen based on measurements in 2005 and 2006. The arrows shows the direction and the number shows the surface velocity in m/a. The length of the arrow is proportional to the velocity.**

### Results

The calculated annual surface velocities for eight stake locations are shown in Figure 8-10. The measurements reveal velocities of about 10 m/a on the lower part of the glacier and velocities of 5-10 m/a on the upper part.

# 9. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61º34`N, 8º 26`E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 9-1). It ranges in elevation from 1480 to 2210 m a.s.l. and has an area of 3.0 km$^2$ (Fig. 9-2). Mass balance investigations have been carried out annually since 1962 and 2006 is the 45$^{th}$ year of continuous measurements.

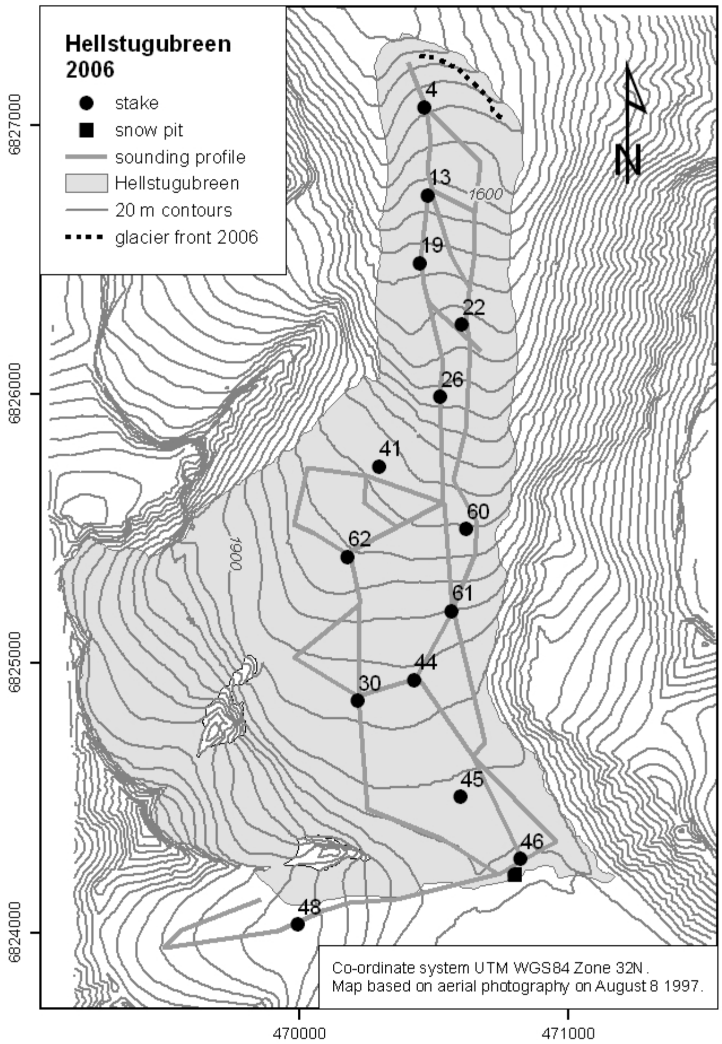
**Figure 9-1**
**Approaching a snow-covered Hellstugubreen for the winter accumulation measurements on May 30$^{th}$ 2006. Photo: Håkon Dreyer Sæter.**

## 9.1 Mass balance 2006

### Fieldwork

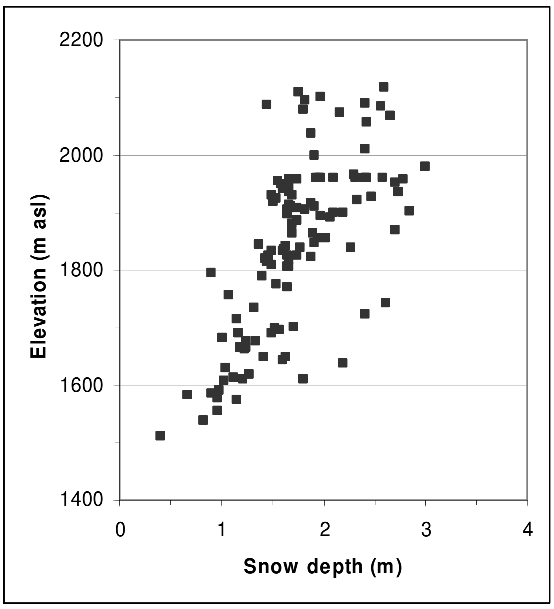
Accumulation measurements were performed on 30$^{th}$ May and the calculation of winter balance is based on:

- Measurements of stakes in 11 different positions. Stake readings showed significant melting only at the lowermost stake (stake 4, see Fig. 9-2) after the ablation measurements on 30$^{th}$ September 2005.
- Soundings of snow depth in 121 positions (13 km of profiles) between 1510 and 2120 m a.s.l. covering most of the altitudinal range of the glacier (Fig. 9-3). The snow depth varied between 0.4 and 3.0 m, the mean being 1.7 m.
- The snow density was measured by sampling in a pit at 1960 m a.s.l. where the total snow depth was 2.0 m.




Ablation measurements were carried out on 22nd September on nine stakes. Due to very high melting, two of the other stakes had melted out. The location of stakes, density pit and sounding profiles are shown in Figure 9-2.

**Figure 9-2**
**Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pit in 2006. The map is from 1997. The position of the eastern part of the glacier front in 2006 (measured by handheld GPS) is also indicated. The western part was not measured.**




## Results

The mass balance results of 2006 are presented in Table 9-1 and Figures 9-3 and 9-4.

### Winter balance

The winter balance was calculated from the soundings (Fig. 9-3) and the snow density measurement, which was considered to be representative for the whole glacier. The density was 0.41 g/cm$^3$.

**Figure 9-3**
**Snow depth soundings on Hellstugubreen in 2006.**

The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The mean winter accumulation was 0.7 ±0.2 m w.e. This is 64 % of the mean for the period 1971-2000, or 66 % of the mean for the observation period 1962-2005. No adjustment for autumn melt was calculated in 2006.

### Summer balance

Direct summer balance was calculated from stakes in six locations. There was no now remaining at any of the stakes. The density of the melted ice was assumed to be 0.9 g/cm$^3$ and the density of melted firn to be between 0.7 and 0.8 m w.e. The summer balance was calculated to be –2.7 ±0.3 m w.e., which is 194 % of the mean value of –1.41 m w.e. for the period 1971-2000. The summer balance calculated for 2006 is the second greatest summer balance calculated for Hellstugubreen, only in 1997 was the summer balance more negative (–2.8 m w.e.).

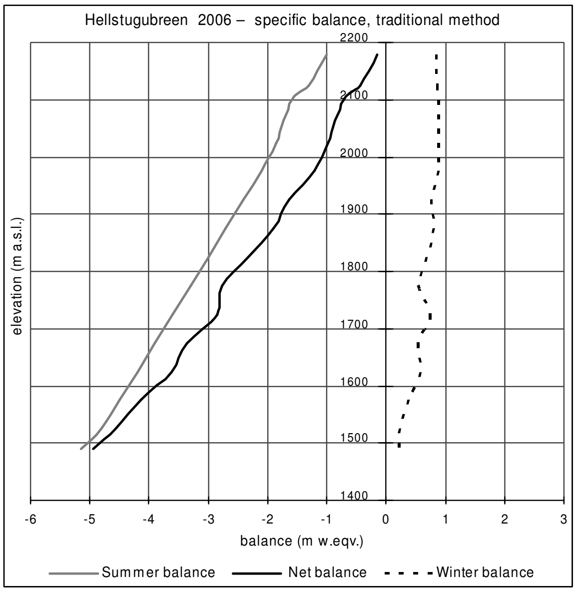
### Net balance

A winter balance well below normal, and a very negative summer balance resulted in the largest deficit recorded for Hellstugubreen. The net balance of Hellstugubreen in 2006 was –2.0 ±0.3 m w.e., which amounts to a volume loss of –6.1 ±0.9 mill. m$^3$ water. The equilibrium line altitude (ELA) was above the glacier resulting in an accumulation area ratio (AAR) of 0 % (Fig. 9-4). Hellstugubreen has had a cumulative mass loss of –16.7 m w.e. since 1962, giving a mean annual deficit of 0.37 m w.e. per year (Fig. 9-5). 2006 is the sixth year in row with a negative net balance, amounting to a cumulative deficit of –6.4 m w.e. for the period 2001-2006.

**Table 9-1**
**The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2006.**

**Mass balance Hellstugubreen 2005/06 – traditional method**

| | | Winter balance<br>Measured 30th May 2006 | | Summer balance<br>Measured 22nd Sep 2006 | | Net balance<br>Summer surfaces 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| 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$^3$) |
| 2150 - 2210 | 0.02 | 0.85 | 0.02 | -1.00 | -0.02 | -0.15 | 0.00 |
| 2100 - 2150 | 0.09 | 0.86 | 0.08 | -1.30 | -0.12 | -0.44 | -0.04 |
| 2050 - 2150 | 0.28 | 0.88 | 0.25 | -1.60 | -0.45 | -0.72 | -0.20 |
| 2000 - 2050 | 0.18 | 0.88 | 0.16 | -1.85 | -0.34 | -0.97 | -0.18 |
| 1950 - 2000 | 0.38 | 0.89 | 0.34 | -2.10 | -0.79 | -1.21 | -0.46 |
| 1900 - 1950 | 0.61 | 0.76 | 0.47 | -2.40 | -1.47 | -1.64 | -1.00 |
| 1850 - 1900 | 0.35 | 0.80 | 0.28 | -2.70 | -0.94 | -1.90 | -0.66 |
| 1800 - 1850 | 0.33 | 0.68 | 0.22 | -3.00 | -0.98 | -2.32 | -0.76 |
| 1750 - 1800 | 0.13 | 0.54 | 0.07 | -3.30 | -0.44 | -2.76 | -0.37 |
| 1700 - 1750 | 0.10 | 0.75 | 0.08 | -3.60 | -0.38 | -2.85 | -0.30 |
| 1650 - 1700 | 0.17 | 0.53 | 0.09 | -3.90 | -0.66 | -3.37 | -0.57 |
| 1600 - 1650 | 0.13 | 0.59 | 0.07 | -4.20 | -0.53 | -3.61 | -0.46 |
| 1550 - 1600 | 0.16 | 0.38 | 0.06 | -4.50 | -0.72 | -4.12 | -0.66 |
| 1500 - 1550 | 0.08 | 0.23 | 0.02 | -4.80 | -0.37 | -4.57 | -0.36 |
| 1480 - 1500 | 0.02 | 0.21 | 0.00 | -5.15 | -0.09 | -4.94 | -0.09 |
| **1480 - 2210** | **3.03** | **0.73** | **2.20** | **-2.74** | **-8.30** | **-2.01** | **-6.09** |



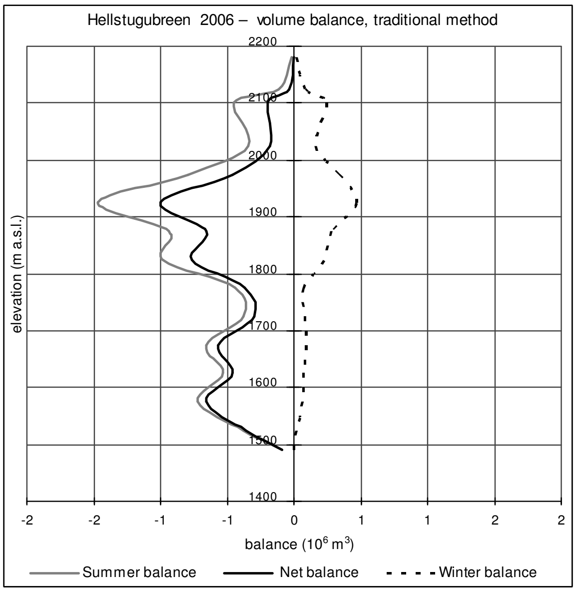




**Figure 9-4**
**Mass balance diagram for Hellstugubreen in 2006, showing specific balance on the left and volume balance on the right.**

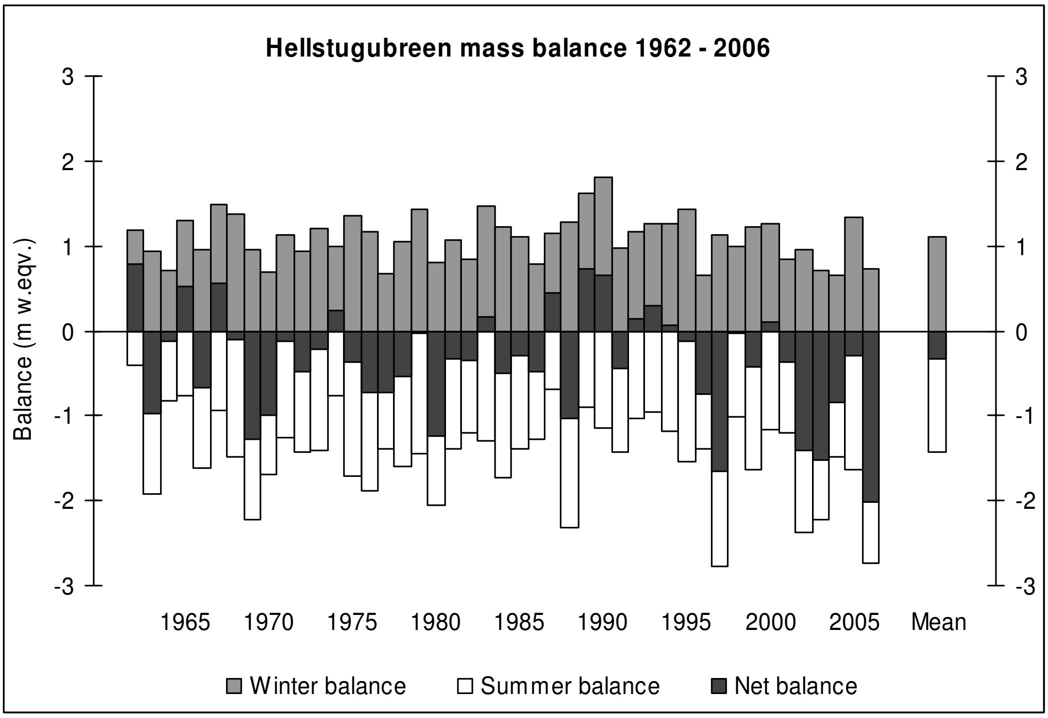



**Figure 9-5**
**Winter, summer and net balance at Hellstugubreen for the period 1962-2006.**

# 10. 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. 10-1). The glacier covers an area of 2.2 km$^2$ and ranges in elevation from 1830 to 2290 m a.s.l. (Fig. 10-2). 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.

**Figure 10-1**
**The lower part of Gråsubreen photographed from Veodalen on 13th September. The glacier ice looks thin and dirty and there was no remaining snow from the previous winter. Photo: Miriam Jackson.**

## 10.1 Mass balance 2006

### Fieldwork

Accumulation measurements were performed on 30th May and the calculation of winter balance is based on:

- Measurements of stakes in 13 different positions. Stake readings did not indicate any significant melting after the final measurements on 30th September 2005.
- Soundings of snow depth in 100 positions along 9.6 km of profiles, between 1847 and 2267 m a.s.l., covering most of the altitudinal range of the glacier. The summer

surface was easy to identify over the whole glacier. The snow depth varied between 0.43 and 3.70 m, the mean being 1.21 m.

Ablation measurements were carried out on 12th and 13th September, when stakes in eight locations were measured (Fig. 10-2). Several other stakes had melted out due to high melting. There was no fresh snow covering the glacier at the time of the ablation measurements (Fig. 10-1).

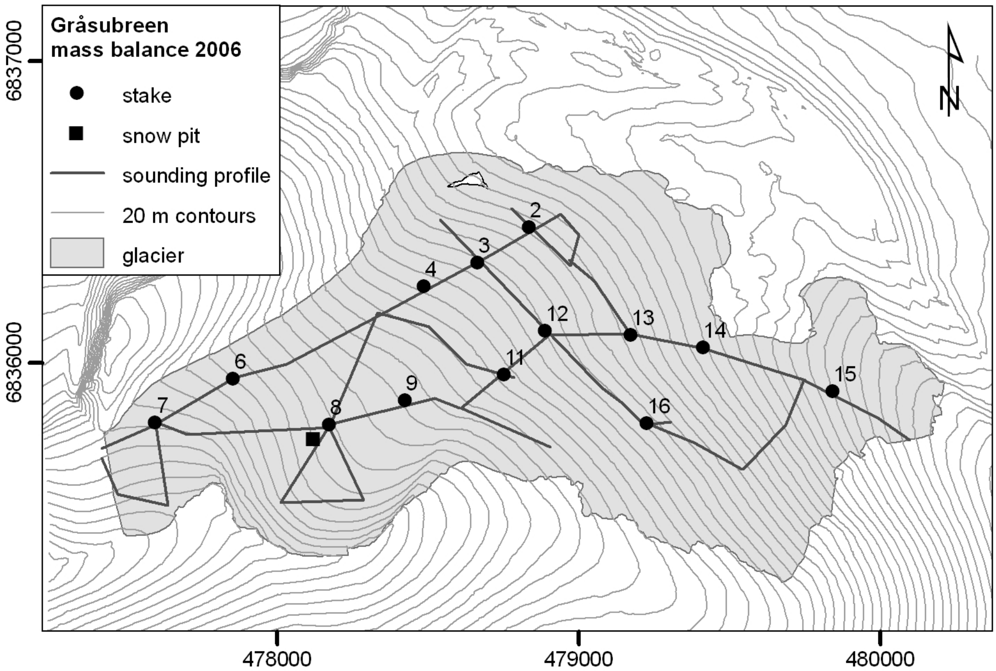



**Figure 10-2**
**Map of Gråsubreen (shaded in grey) showing the location of stakes, snow pit and sounding profiles in 2006.**

## Results

The mass balance results are presented in Table 10-1 and Figure 10-3.

### Winter balance

Winter accumulation was calculated from the soundings and the snow density measurement, which was considered representative for the whole glacier. The mean measured snow density was only 0.36 g/cm$^3$. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter balance of 0.5 ±0.2 m w.e., which is 65 % of the mean for the period 1971-2000.

The stake recordings showed neither significant additional melting after the previous year's ablation measurements, nor any significant formation of superimposed ice. Therefore, the winter balance was not adjusted for these factors.

### Summer balance

Summer balance was calculated from direct measurements of stakes in eight locations. The density of the melted ice was estimated to be 0.90 g/cm$^3$. The resulting summer balance was −2.6 ±0.3 m w.e. This is the highest summer balance measured at Gråsubreen. The specific summer balance is 242 % of the mean for the period 1971-2000.

### Net balance

A winter balance well below normal, and the record high summer balance resulted in the largest deficit ever recorded for Gråsubreen, a net balance of −2.1 ±0.3 m w.e. There was no remaining snow from the winter left at the glacier, thus the equilibrium line altitude (ELA) was above the highest point of the glacier. Accordingly, the accumulation area ratio (AAR) was 0 % (Fig. 10-3).

**Table 10-1**
**The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2006.**

**Mass balance Gråsubreen 2005/06 – traditional method**

| | | Winter balance Measured 31 May 2006 | | Summer balance Measured 12 Sep 2006 | | Net balance Summer surfaces 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| Altitude (m a.s.l.) | Area ($km^2$) | Specific (m w.e.) | Volume ($10^6$ $m^3$) | Specific (m w.e.) | Volume ($10^6$ $m^3$) | Specific (m w.e.) | Volume ($10^6$ $m^3$) |
| 2250 - 2290 | 0.04 | 0.48 | 0.02 | -2.50 | -0.11 | -2.02 | -0.09 |
| 2200 - 2250 | 0.17 | 0.31 | 0.05 | -2.55 | -0.42 | -2.24 | -0.37 |
| 2150 - 2200 | 0.26 | 0.48 | 0.13 | -2.60 | -0.68 | -2.12 | -0.56 |
| 2100 - 2150 | 0.34 | 0.33 | 0.11 | -2.55 | -0.86 | -2.22 | -0.75 |
| 2050 - 2100 | 0.37 | 0.39 | 0.15 | -2.55 | -0.95 | -2.16 | -0.80 |
| 2000 - 2050 | 0.42 | 0.57 | 0.24 | -2.55 | -1.07 | -1.98 | -0.83 |
| 1950 - 2000 | 0.36 | 0.66 | 0.24 | -2.60 | -0.93 | -1.94 | -0.69 |
| 1900 - 1950 | 0.14 | 0.73 | 0.10 | -2.70 | -0.39 | -1.97 | -0.28 |
| 1830 - 1900 | 0.15 | 0.71 | 0.11 | -2.75 | -0.42 | -2.04 | -0.31 |
| **1830 - 2290** | **2.25** | **0.51** | **1.14** | **-2.59** | **-5.83** | **-2.08** | **-4.68** |

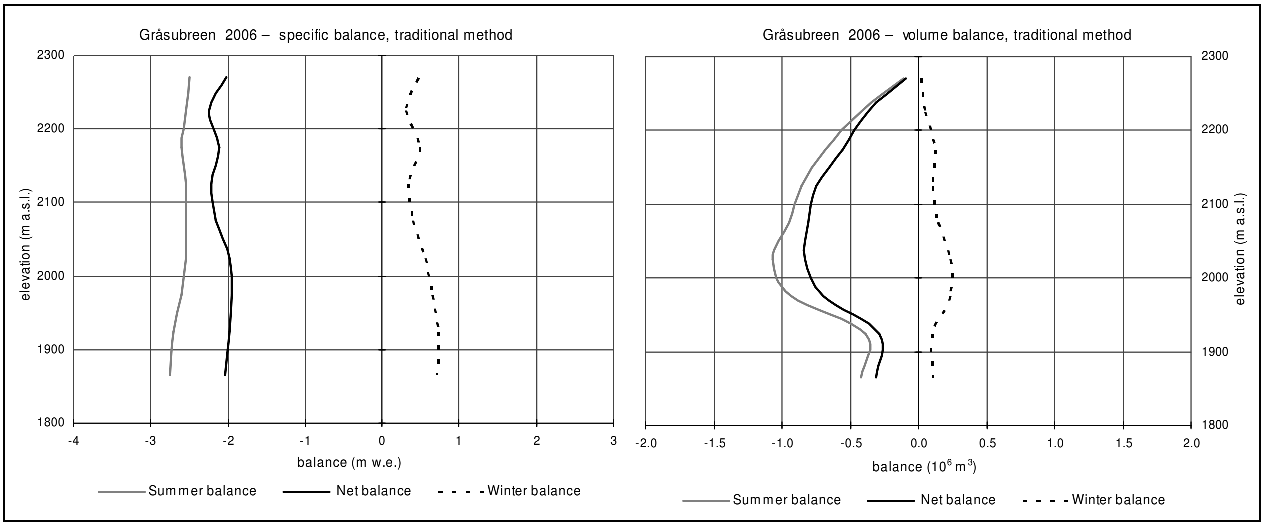



**Figure 10-3**
**Mass balance diagram for Gråsubreen in 2006, showing specific balance on the left and volume balance on the right.**

Since 1962 Gråsubreen has had a cumulative mass loss of −15.7 m w.e., or −0.31 m w.e. per year. Most of this mass loss occurred in the 1970s and 1980s, and since 2001. During the past five years Gråsubreen has lost −5.9 m w.e., over a third of the net deficit since 1962.

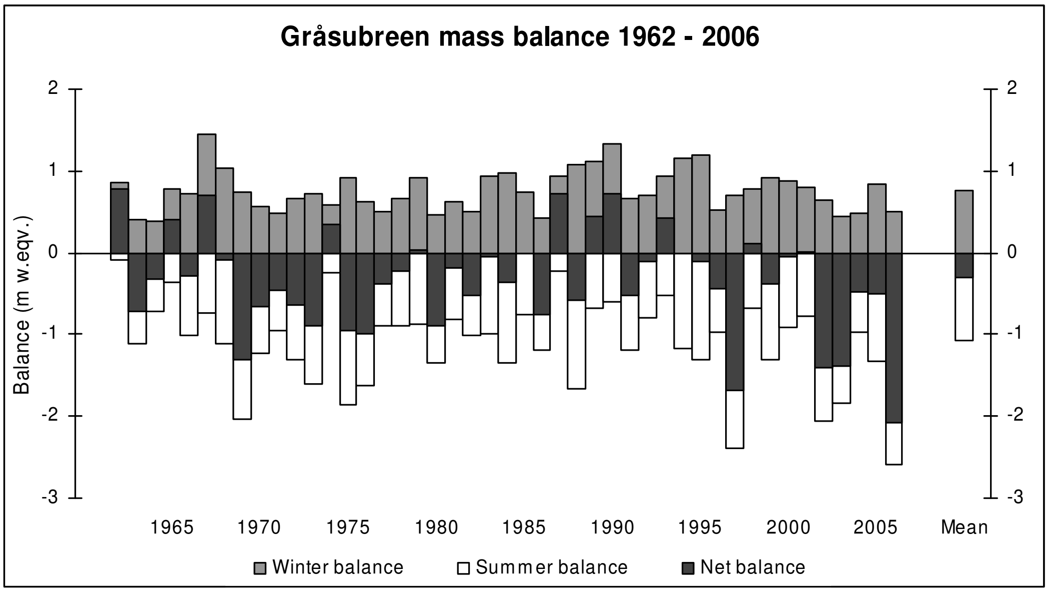



**Figure 10-4**
**Winter, summer and net balance at Gråsubreen during the period 1962-2006.**

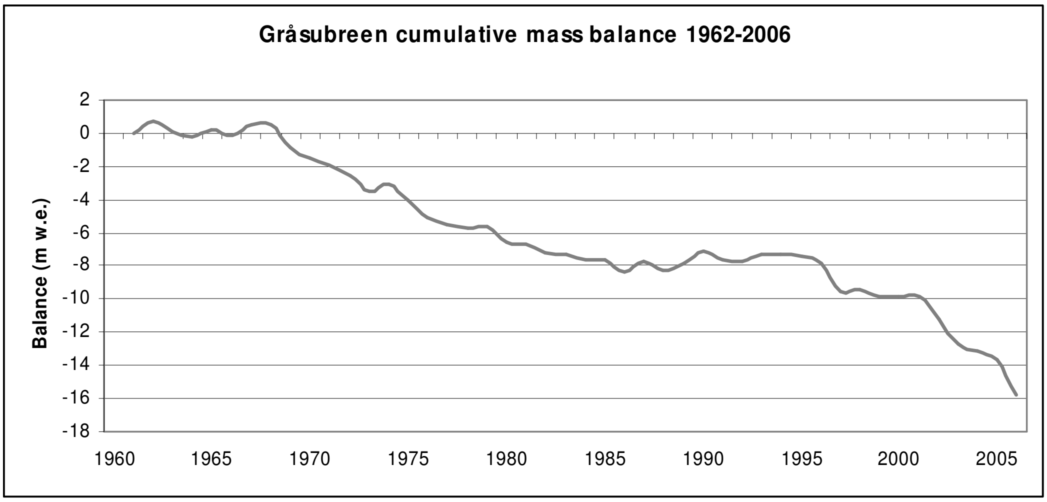



**Figure 10-5**
**Cumulative net balance at Gråsubreen during the period 1962-2006.**

# 11. Engabreen (Hallgeir Elvehøy and Miriam Jackson)

Engabreen (66°40'N, 13°45'E) is a 40 km$^2$ north-western outlet from the western Svartisen ice cap. It covers an altitude range from 1575 m a.s.l. (at Snøtind) down to 10 m a.s.l. (at Engabrevatnet), as shown in Figure 11-1. Mass balance measurements have been performed annually since 1970, and length change observations started in 1903. A meteorological station has been operated at the nunatak Skjæret (1364 m a.s.l.) since 1995.

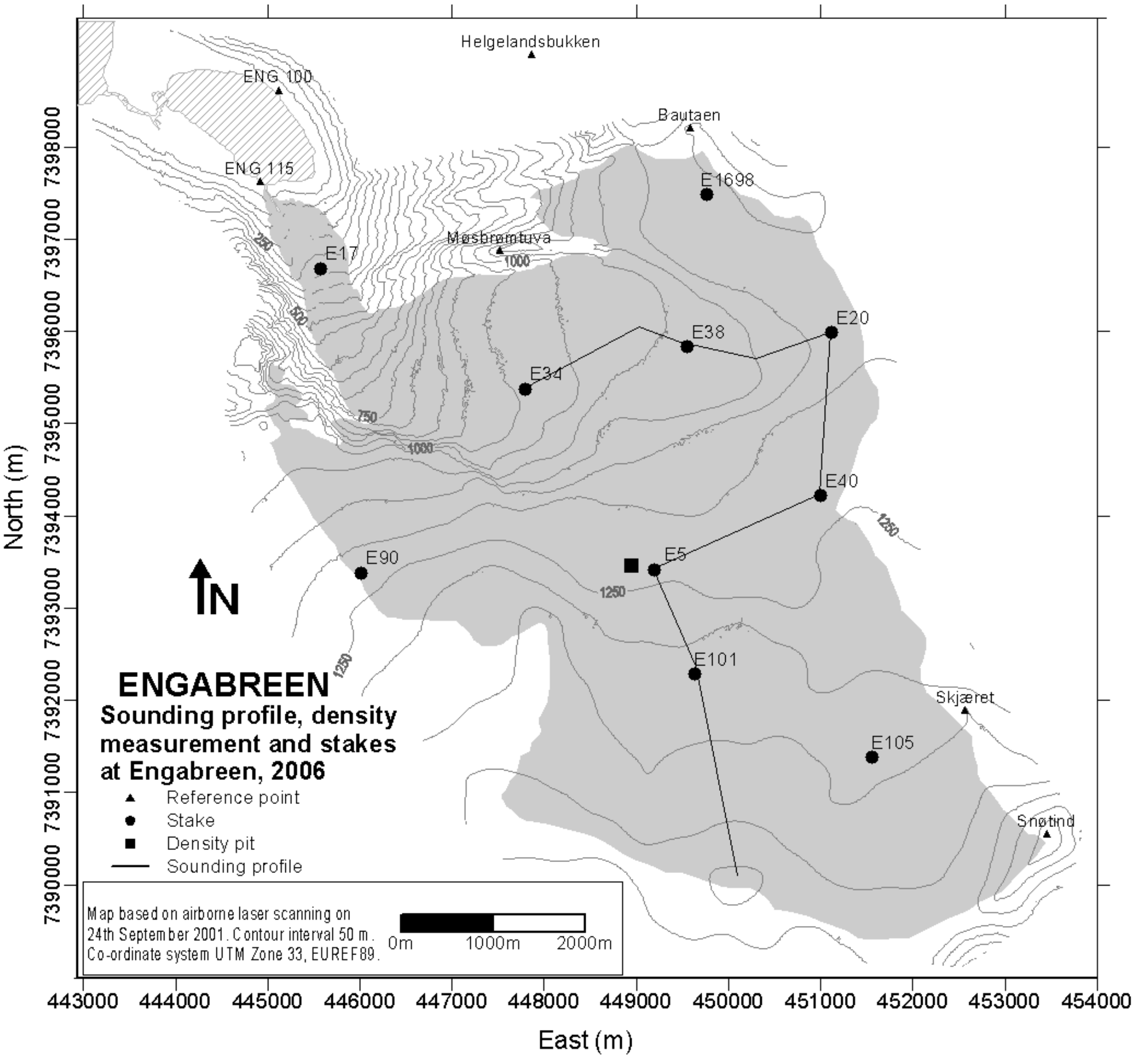



**Figure 11-1**
**Location of stakes, density pit and sounding profiles on Engabreen in 2006.**

## 11.1 Mass balance 2006

The amount of snow depth soundings has been reduced due to financial concerns. The length of sounding profiles was reduced from about 30 km of profiles to 11 km in 2006.

## Fieldwork

Engabreen was visited on 9th March. Stakes in positions E105, E101, E20, E38 and E17 were measured. The snow depth at the stakes on the plateau was 3 to 5 metres. The glacier tongue was snow-free, and approximately 1.5 m of ice had melted since 29th September. On 20th April stakes in locations E17 and E34 were measured, showing a small amount of additional melting at the tongue. On 1st May stake E20 was measured showing a modest increase in snow depth since 9th March.

Due to unfavourable weather conditions the snow accumulation measurements were not carried out until 13th June. At locations E20 and E34, a decrease of 1.1 and 1.4 m respectively of snow depth, was recorded since 1st May. At location E17 on the glacier tongue, 1.7 m of ice had melted since 27th April. At locations E105 and E101 a decrease in snow depth of 0.5 m since the 9th March was measured, but the snow depth decrease after the 1st May was probably somewhat larger.

The locations of stakes and towers, density pit, core samples and sounding profiles are shown in Figure 11-1. The calculation of winter balance is based on the following measurements on 13th June:

- Direct measurement of snow depth at locations E105 (4.5 m), E101 (3.7 m), E90 (2 stakes - 3.2 and 2.7 m), E40 (2 stakes - 3.9 and 4.1 m), E16 (3.7 m), E20 (2.7 m), E38 (2 stakes - 2.8 and 2.3 m) and E34 (2 stakes - 0.1 and 0.2 m).
- Snow depth from coring at stake E5, showing 3.8 m of snow.
- 40 snow depth soundings along 11 km of profiles. The snow depth was between 3.5 and 4.4 m at most of the observation points above 1200 m a.s.l., and mainly between 1.3 and 3.3 m between 950 and 1200 m a.s.l.
- Direct measurement of ice melt at location E17, showing 3.3 m of melt.
- The transient snow line altitude at approximately 950 m a.s.l.
- Snow density measured down to the summer surface (SS) at 3.8 m depth at stake E5. Mean snow density was 0.57 g/cm$^3$.

When the glacier was re-visited on 28th June, an additional half metre of snow had melted on the plateau. Between 28th June and 3rd August the stakes in positions E34 and E17 melted out. Approximately 2 m of snow melted on the plateau in this period.

Between 3rd August and 4th October stake E17 melted out again. At location E34, 3.1 m of ice melted in this period, while at E105 2.3 m of snow melted.

The net and summer balance measurements were carried out on 4th October. At this time, there was no new snow on the glacier. From stake measurements the transient snow line altitude was about 1320 m a.s.l. The net balance was observed directly at eight stakes in eight locations between 1050 and 1350 m a.s.l. Some winter snow remained only at E105 (0.5 m). At stakes E16, E40, E5, E90 and E101 all the winter snow and around 1 metre of old firn had melted. At stakes E38 and E20 more than 2 m of firn had melted. At location E34, at 960 m a.s.l. the stakes melted out between 13th June and 3rd August. Between 3rd August and 4th October 3.1 m of ice melted (0.05 m/d). At the glacier tongue (300 m a.s.l.), the stakes melted out twice, implying at least 6.0 m of ice melt between 28th June and 4th October.

## Results

The mass balance is calculated using the stratigraphic method, which reports the balance between two successive "summer surfaces", excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements.

### Winter balance

The date of maximum snow-water-equivalents (SWE) was probably around 1st May. Between 3rd and 10th May the air temperature at Skjæret was positive even at night. Even though there may have been some refreezing in the snow pack, some run-off probably took place before 13th June, especially on the lower part of the glacier. This volume has not been calculated.

The calculation of winter balance was based on point measurements of snow depth (stake readings, coring and snow depth soundings) and on snow density measurement (Fig. 11-1). A water equivalent profile was modelled from the snow density measured at stake E5 (1240 m a.s.l.). This model was then used to calculate the water equivalent value of the snow depth measurements.

Point values of the snow water equivalent (SWE) were plotted against altitude, and a curve was drawn based on visual evaluation (Fig. 11-2). Below 960 m a.s.l. the winter balance curve was interpolated based on the observed snow depth around stake E34 and the observed negative winter balance at stake E17. Based on this altitudinal distribution curve, the winter balance was calculated as 1.7 ±0.2 m w.e., which corresponds to a volume of 68 ±8 mill. $m^3$ of water. This is 58 % of the mean value for the period 1970-2005 (2.98 m w.e.), and 66 % of the mean value for the 5-year period 2001-2005 (2.62 m w.e.). This is the third smallest winter balance after 1985 (1.5 m w.e.) and 2001 (1.6 m w.e.).

### Summer balance

The summer balance was measured directly at stakes E105, E101, E20 and E38, and was calculated from snow depth sounding and stake measurements at stakes E5, E40 and E90. At locations E34 and E17 some of the summer melting had to be estimated. An altitudinal distribution curve was drawn based on the calculated summer balance in nine locations between 300 and 1350 m a.s.l (Fig. 11-2). The summer balance was calculated as −3.2 ±0.2 m w.e., which equals a volume of −125 ±8 mill. $m^3$ water. This is 138 % of the average for the period 1970-2005 (−2.29 m w.e.), and 116 % of the average for the 5-year period 2001-2005 (-2.72 m w.e.). The summer balance was smaller than in 1988 and 2002 (−4.0 and −3.5 m w.e., respectively), but comparable with the summer balances in 1972, 1979, 1980 and 1997.

### Net balance

The net balance of Engabreen for 2006 was calculated as −1.4 ±0.3 m w.e., which corresponds to a volume loss of 60 ±10 mill. $m^3$ water. The mean value for the period 1970-2005 is +0.69 m w.e., but only −0.10 m w.e for 2001-2005. The equilibrium line altitude (ELA) was determined as 1325 m a.s.l. from the net balance curve in Figure 11-2.

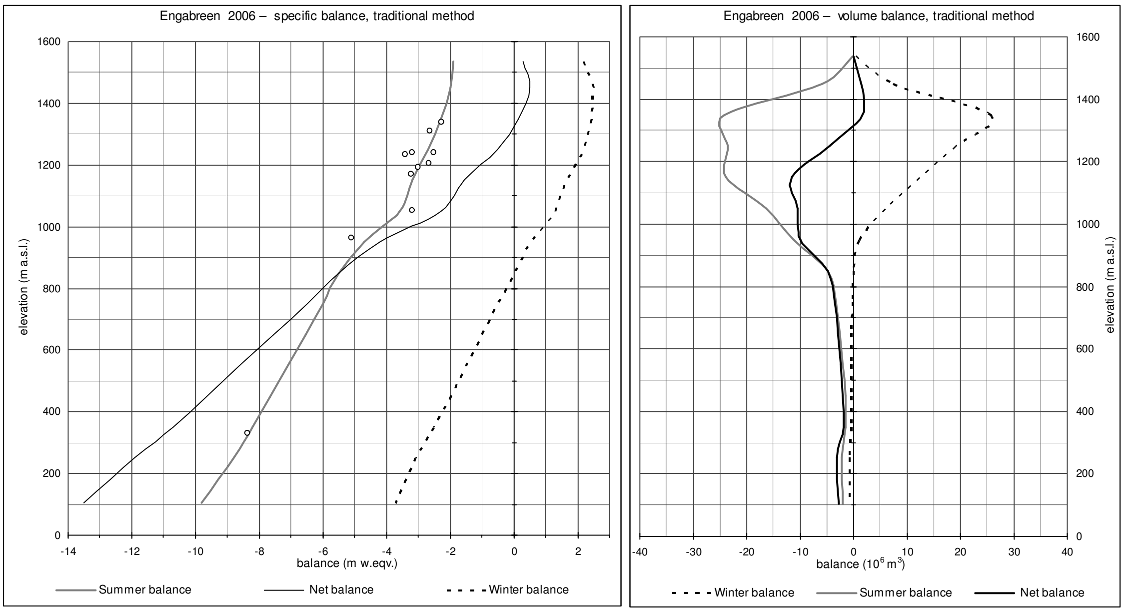



**Figure 11-2**
**Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2006. Summer balance at stakes and towers is shown as circles (○).**

**Table 11-1**
**Specific and volume winter, summer and net balance calculated for 100 m elevation intervals at Engabreen in 2006.**

**Mass balance Engabreen 2005/06 – traditional method**

| | | Winter balance Measured 13th Jun 2006 | | Summer balance Measured 4th Oct 2006 | | Net balance Summer surface 2005 - 2006 | |
|---|---|---|---|---|---|---|---|
| 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 ($10^6$ $m^3$) |
| 1500 - 1575 | 0.13 | 2.20 | 0.3 | -1.90 | -0.2 | 0.30 | 0.0 |
| 1400 - 1500 | 2.94 | 2.50 | 7.4 | -2.00 | -5.9 | 0.50 | 1.5 |
| 1300 - 1400 | 10.52 | 2.45 | 25.8 | -2.30 | -24.2 | 0.15 | 1.6 |
| 1200 - 1300 | 8.68 | 2.20 | 19.1 | -2.70 | -23.4 | -0.50 | -4.3 |
| 1100 - 1200 | 7.47 | 1.65 | 12.3 | -3.20 | -23.9 | -1.55 | -11.6 |
| 1000 - 1100 | 4.52 | 1.30 | 5.9 | -3.60 | -16.3 | -2.30 | -10.4 |
| 900 - 1000 | 2.38 | 0.50 | 1.2 | -4.70 | -11.2 | -4.20 | -10.0 |
| 800 - 900 | 0.87 | 0.00 | 0.0 | -5.50 | -4.8 | -5.50 | -4.8 |
| 700 - 800 | 0.54 | -0.50 | -0.3 | -6.00 | -3.2 | -6.50 | -3.5 |
| 600 - 700 | 0.38 | -1.00 | -0.4 | -6.55 | -2.5 | -7.55 | -2.9 |
| 500 - 600 | 0.28 | -1.50 | -0.4 | -7.10 | -2.0 | -8.60 | -2.4 |
| 400 - 500 | 0.20 | -2.00 | -0.4 | -7.65 | -1.5 | -9.65 | -1.9 |
| 300 - 400 | 0.17 | -2.50 | -0.4 | -8.20 | -1.4 | -10.70 | -1.8 |
| 200 - 300 | 0.26 | -3.10 | -0.8 | -8.80 | -2.3 | -11.90 | -3.1 |
| 10 - 200 | 0.21 | -3.70 | -0.8 | -9.80 | -2.1 | -13.50 | -2.8 |
| 10 - 1575 | 39.6 | 1.73 | 68.4 | -3.16 | -124.9 | -1.43 | -56.5 |

This corresponds to an accumulation area ratio (AAR) of 26 %. The mass balance results are shown in Figure 11-2 and Table 11-1. The results from 2006 are compared with mass balance results for the period 1970-2006 in Figure 11-3. Engabreen had its second-most negative year, only 1988 being more negative (–1.8 m w.e.).

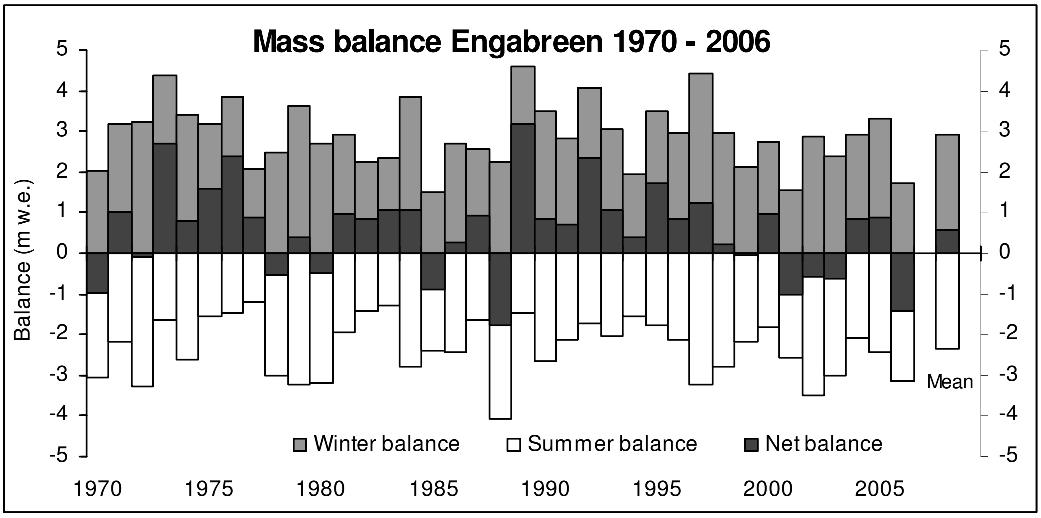



**Figure 11-3**
**Mass balance at Engabreen during the period 1970-2006. The accumulated surplus amounts to 22 m water equivalents. The average winter, summer and net balances are $b_w$ =2.92 m w.e., $b_s$ =–2.33 m w.e. and $b_n$ =0.59 m w.e.**

# 11.2 Elevation changes

Elevation profiles were measured on Engabreen on 28th June and 4th October 2006 using dGPS. The elevation profiles have been compared to DEMs generated from data collected using Airborne Laser Scanning (ALS) by TopScan GmbH in Germany (Geist et al, 2005). The DEMs are generated from point elevations collected with an average distance of 1.4 m. The vertical precision is better than 0.1 m, and comparable with that achieved using dGPS.

On 28th June 2006, 45 km of elevation profiles were measured on Engabreen (Fig. 11-4). The surface elevation of 5167 points was compared with a 5x5 m DEM constructed from ALS-data obtained on 30th June 2003. The average elevation change over 3 years is −1.2 m. Above 1300 m a.s.l the average elevation changes was −0.46 m, while below 1100 m a.s.l. the elevation change was about −2.8 m w.e. Figure 11-4 shows that the elevation change is smaller at higher than at lower altitudes. The largest elevation changes (> 4 m) were recorded along the wind scoop at Helgelandsbukken.

On 4th October 2006, 1280 point elevations along a total of 4.4 km of profiles in three areas were measured. The measured elevations were compared with a 20 x 20 m DEM produced from airborne laser scanning (ALS) on 21st September 2001. The elevation changes are shown in Fig 11-5. Around stake E17 on the glacier tongue at between 310 and 330 m a.s.l. the elevation changes in 132 points were between −16.0 and −18.5 m. Above the ice fall around stake E34, between 950 and 960 m a.s.l., the elevation changes in 165 points were between −3.6 and −4.8 m. Between stakes E40 and E105, between 1260 and 1340 m a.s.l., the elevation changes in 817 points were between −0.2 and −3.1 m.

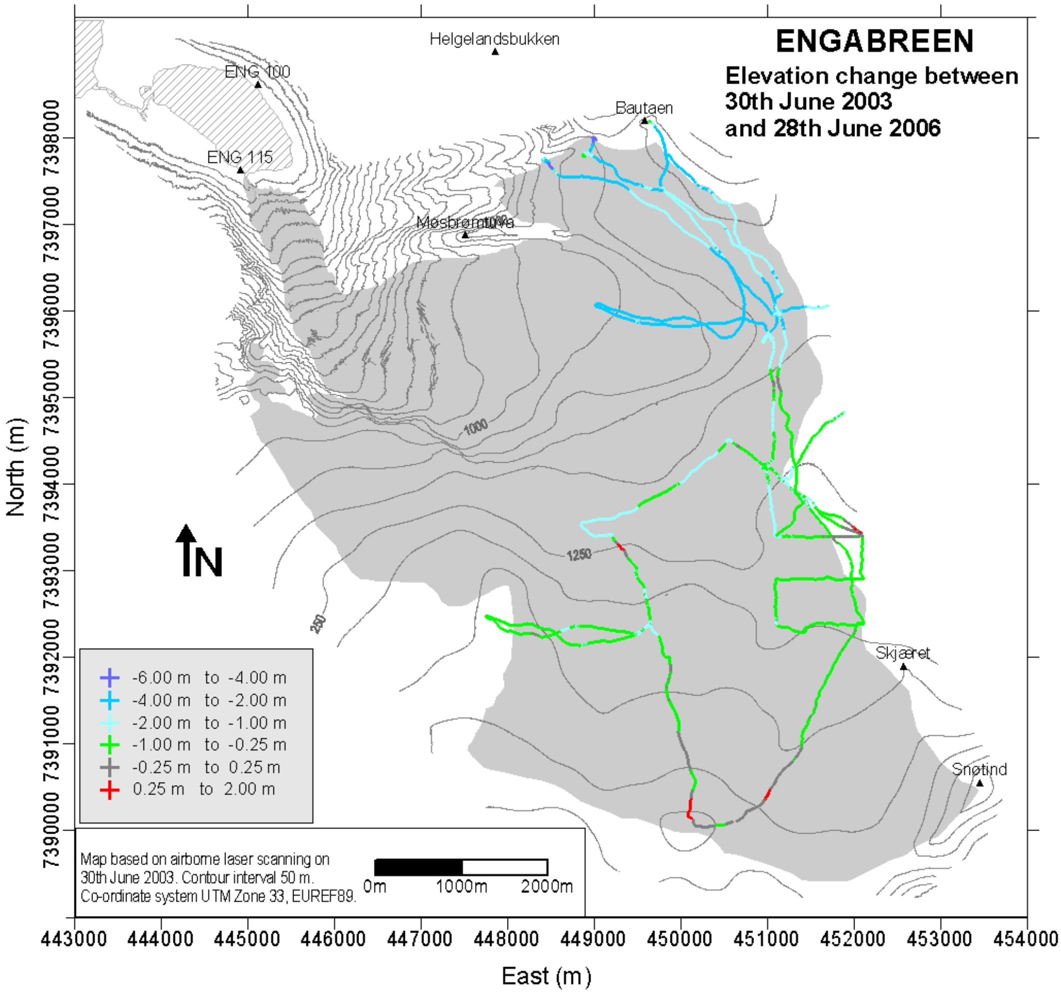



**Figure 11-4**

**Surface elevation change between 30th June 2003 and 28th June 2006 on Engabreen.**

If the density profile of the upper part of the glacier depth is considered unchanged, the elevation change corresponds with −15.7 ± 0.4 m w.e. around E17, −3.8 ± 0.3 m w.e. around E34, and −1.4 ± 0.5 m w.e. between E40 and E105.

The corresponding, calculated mass balance between spring 2003 and spring 2006 is +0.4 m w.e., and the calculated mass balance between the autumn 2001 and autumn 2006 is −0.9 m w.e. These results imply that the calculated mass balance is too positive. Note that this simple analysis does not take into consideration mass redistribution due to glacier movement.

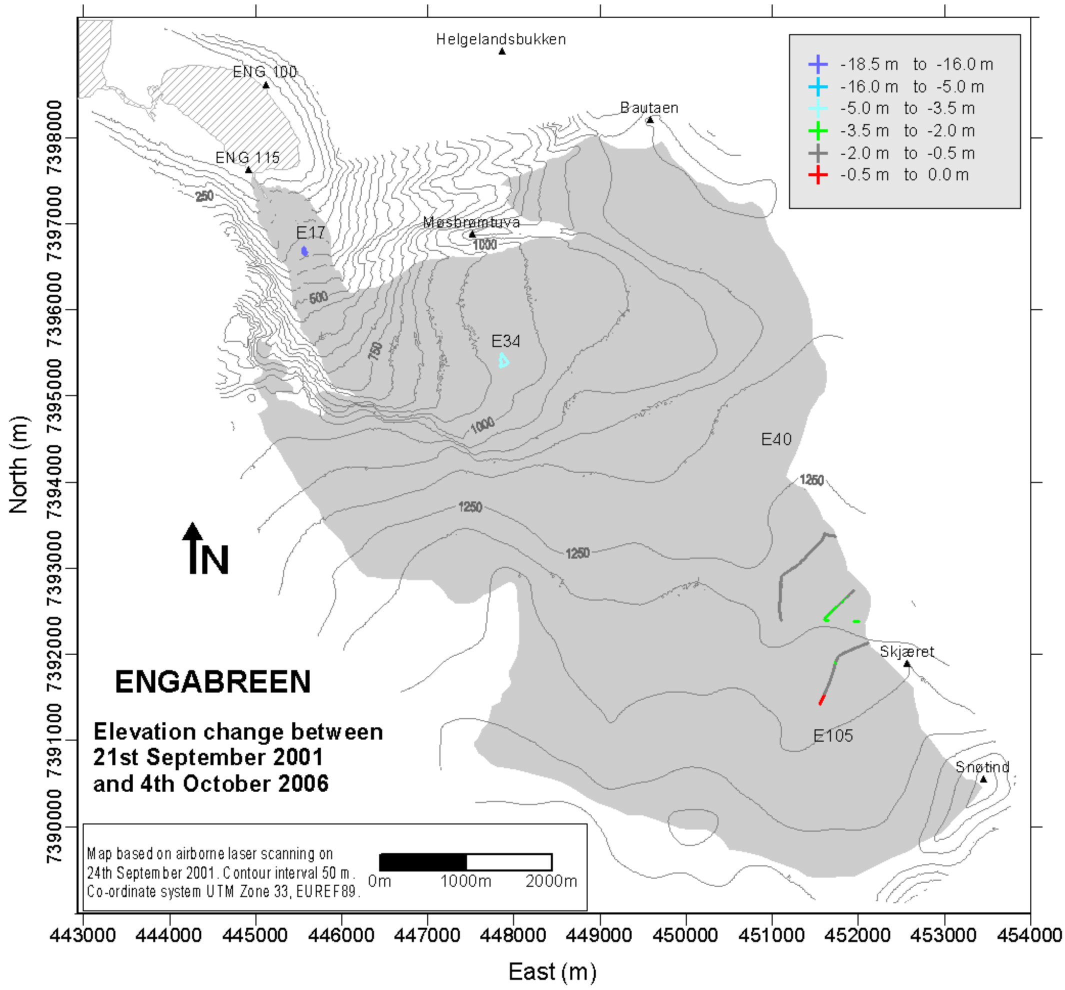



**Figure 11-5**
**Surface elevation change between 21st September 2001 and 4th October 2006 on Engabreen.**

# 11.3 Meteorological observations

A meteorological station recording air temperature and global radiation is located on the nunatak Skjæret (1364 m a.s.l.) close to the drainage divide between Engabreen and Storglombreen (Fig. 11-1). The station has recorded data since 1995 with some gaps. The nearest meteorological station is 80700 Glomfjord (39 m a.s.l.), 19 km north of Skjæret. This station has been operated by the Norwegian Meteorological Institute (DNMI) since 1916.

In 2006, data was collected at Skjæret until 3rd October with no gaps (Fig 11-6). After the autumn measurements on 29th September 2005 the air temperature was close to or above freezing during the first half of October, and then again between 28th October and 4th November. The coldest period this winter was during the eastern storm “Narve” between 17th and 22nd January when the daily mean temperature was below –20 °C (19th January). “Narve” caused substantial damages all over northern Norway. The first period in spring having mid-day temperatures above 0 °C was from 4th to 10th May, and following this the temperature was at or below freezing until 11th June. The snow measurements were done on 13th June. This coincided with the start of the melting season on the upper part of the glacier. The maximum day temperature was measured on

2nd August (16.8 °C). Fairly high daily temperatures in Glomfjord until 16th October and again between 16th November and 12th December suggest that melting occurred after the ablation measurements on 4th October, especially on the lower part of the glacier.

At Glomfjord the mean annual temperature in 2006 was 6.4 °C, which is 1.4 °C above the 1961-90 average. The summer temperature (15th May-15th September, 12.2 °C) was 2.0 °C lower than in 2002, but similar to the summer temperature in 2003. At Skjæret the summer temperature (15th May-15th September) was 3.5 °C which is 1.1 °C lower than in the warm summer of 2002.

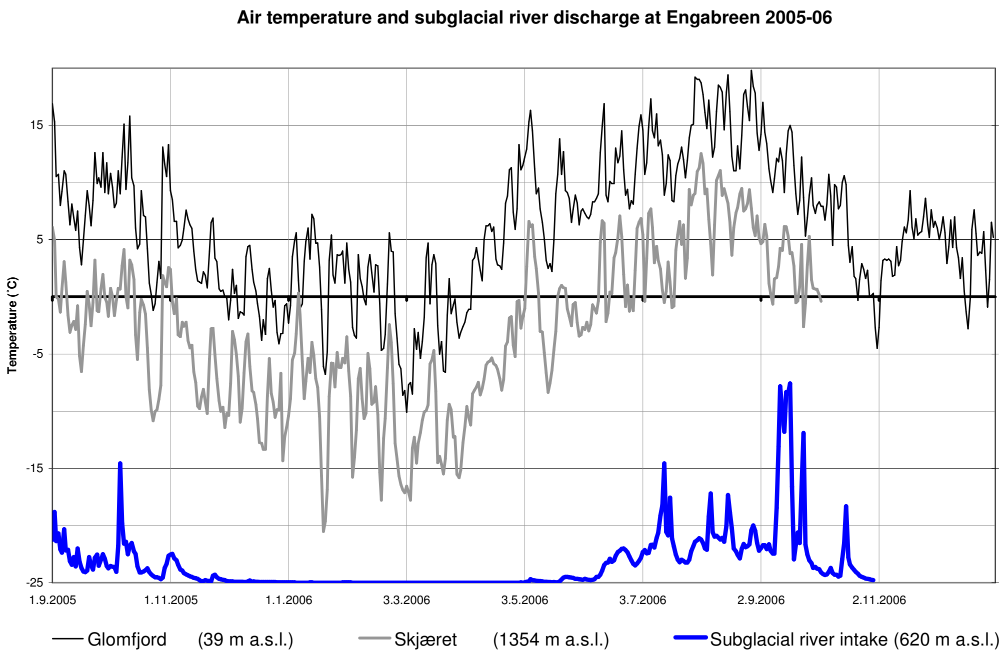



**Figure 11-6**
**Daily mean air temperature at Skjæret (159.20) and Glomfjord (80700), and discharge in the subglacial river intake beneath Engabreen between 1st September 2005 and 31st December 2006.**

Precipitation data from Glomfjord have not been available since 2004. A precipitation station 80740 Reipå (9 m a.s.l.) is located 28 km north of Engabreen, and has been recording since July 1995. The 1961-90 annual mean is estimated as 1452 mm (71 % of Glomfjord). Comparison of winter precipitation sums (1/10-31/5) from 1997-2002 indicates that Reipå gets 67 % of the precipitation in Glomfjord. The winter precipitation in 2006 was 936 mm, which is considerably more than in 2001 and 2003, suggesting that winter precipitation was also higher on Engabreen.

## 11.4 Svartisen subglacial laboratory

Svartisen Subglacial Laboratory is a unique facility situated under Engabreen. It allows direct access to the bed of the glacier for the purposes of measuring sub-glacial parameters and performing experiments on the ice. Further general information about the laboratory is available in report number 14 in NVE's document series for 2000, entitled 'Svartisen Subglacial Laboratory' (Jackson, 2000).

### Pressure measurements

Six load cells were installed at the bed of the glacier in December 1992 in order to measure variations in subglacial pressure. Four of these were still operating in 2006. A further two load cells were installed in November 1997 and were also still operating in 2006 (Fig. 11-7). The load cells are Geonor P-105 Earth Pressure Cells. Readings are recorded from the load cells at 15 minute intervals (more frequently when experiments are being performed). The load cells recorded data successfully from 1st January to 31st December in 2006. Data from 29th September 2005 to year end 2005 is also included here, as these were not available at the time of writing the last report. Note that the following graphs presenting the pressure data have different axes. A seventh load cell (number 7, Fig 11-7), has recorded intermittently since installation in November 2003, hence these results are not included here.

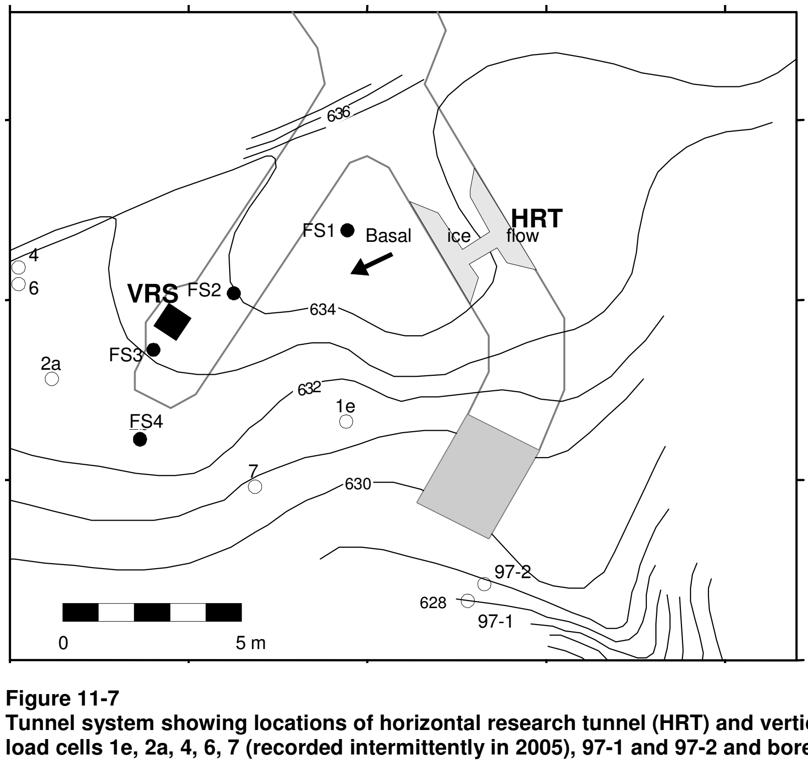



**Figure 11-7**
**Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 7 (recorded intermittently in 2005), 97-1 and 97-2 and boreholes, marked FS.**

Pressure sensor records for 29th September 2005 to 31st December 2005 are shown in Figure 11-8. There is more variation in the pressure than is usual for the time of year. This is a direct result of the subglacial discharge being much higher than is usual (see Figure 11-6). Average pressures are slightly lower at all sensors, except for 1e, compared with the previous year. As usual, sensors 97-1 and 97-2 show the most variation and are more likely to be connected to the drainage system, but sensors 4, 6 and 1e are a more representative indication of pressure at the glacier bed. There are several obvious events shown in the pressure records. The first of these occurs on about 4th October (day 277) and is the result of heavy rainfall in this period that led to discharges in the subglacial tunnel of almost 80 $m^3/s$. The next occurs on 29th October (day 302). Although the measured discharge is smaller, it shows a sharp increase on the previous days which suggests that the subglacial drainage system had started to close down when this happened. This event led to extremely low pressures recorded at sensors 97-1 and 97-2, which lasted for several days. The event on 9th November (day 313) appears to be unrelated to the subglacial discharge. The next event occurs on 20th November (day 324) when heavy rain and slightly warmer temperatures initiated subglacial discharge of 7 $m^3/s$, an increase in magnitude of more than 5. The final event occurs on 11th December (day 345), when heavy rain and slightly warmer temperatures caused a minor increase in subglacial flow that had a major effect on the pressure at the bed.

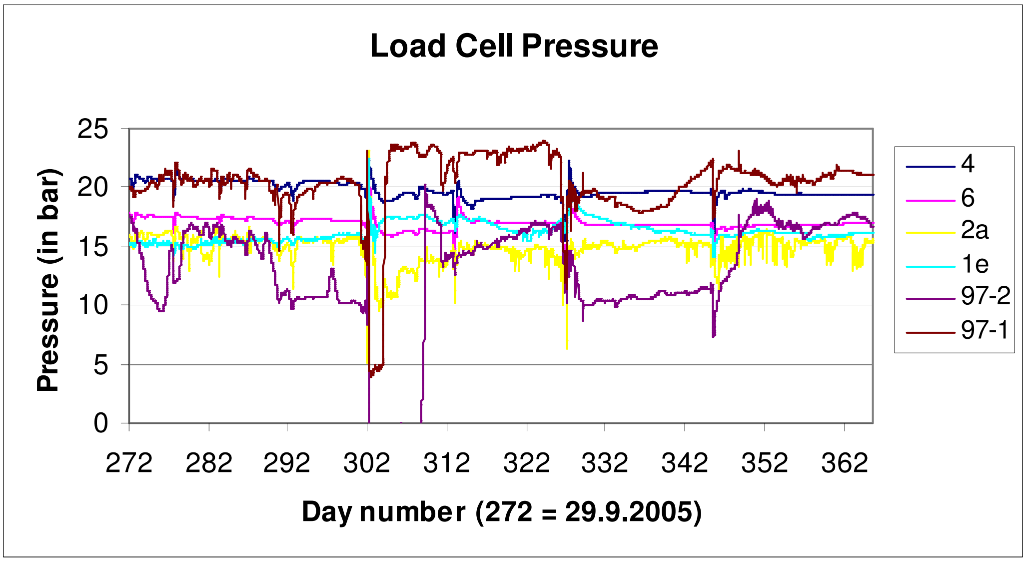



**Figure 11-8**
**Pressure records for the period 29th September to 31st December 2005.**

Pressure sensor records for winter 2006 from 1st January to 30th April are shown in Figure 11-9. In the period from 20th to 27th April (days 110 to 117) experimental work was performed in the subglacial laboratory and the records from this time are somewhat noisy. The results from these experiments will be published elsewhere.

The records for winter 2006 are typical for the winter period - relatively quiet and stable, corresponding with very low flow measured in the subglacial tunnel. It is interesting to note that the pressure measured at several sensors is lower than for the corresponding period in 2005, especially sensors 4 and 6 that are 1 to 2.5 bars lower than the previous year.

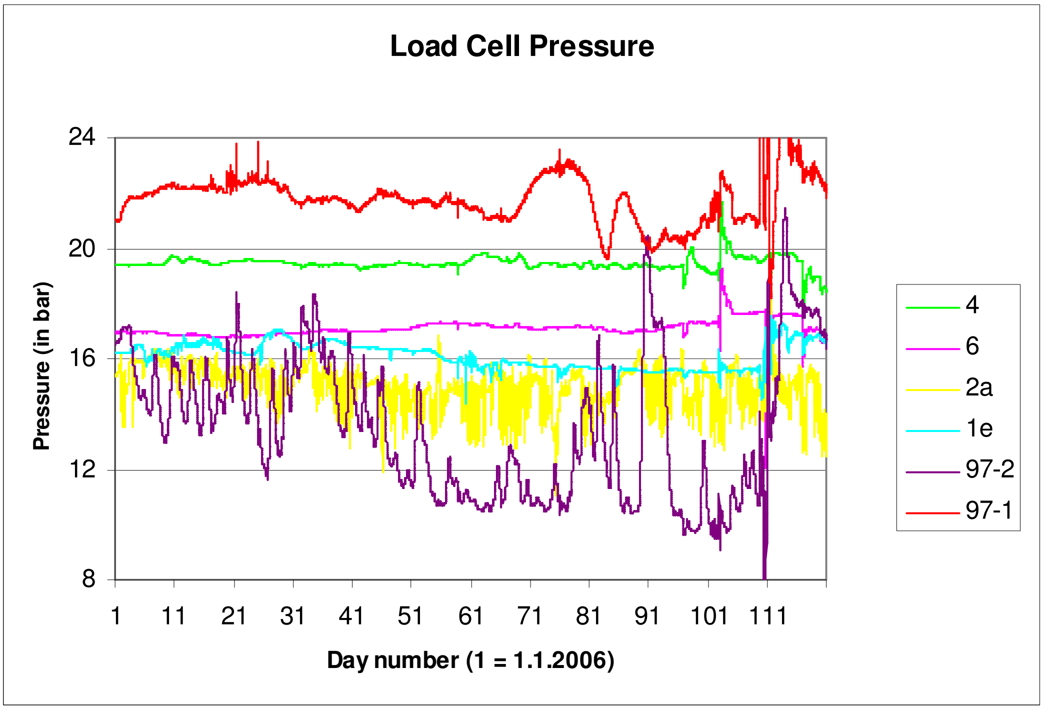



**Figure 11-9**
**Pressure records for 1st January to 30th April.**

Pressure sensor records for the spring and summer, from 1st May to 31st August, are shown in Figure 11-10. These are fairly typical for the summer period. Sensors 97-1 and 97-2, which tend to show a lot of variation, were moderately quiet except for the end of June and beginning of July. This is when the summer subglacial drainage system is becoming established and channel position tends to migrate. Generally, the amount of activity in the pressure records suggests a well-developed drainage system at the glacier base, as is usual at this time of year. Pressures recorded were lower than in 2005, except for sensor 1e. The difference was greatest at sensors 4 and 6, and most distinct in May and June. There was a warm, stable period of weather at the end of August, and diurnal fluctuations in glacier run-off are reflected in diurnal variations in measured pressure.

Pressure sensor records for the autumn and early winter, from 1st September to 31st December, are shown in Figure 11-11. These are fairly typical for the transition from the summer period with high run-off to the winter period with a closed drainage system. The records show a similar pattern to those for 2005 (compare with Fig 11-8). The subglacial discharge was unusually high in September, almost 100 $m^3/s$ from 12th to 17th September (days 255 to 260) and also 24th September (day 267), and this is clearly seen in the pressure records. Another unusually high peak of 40 $m^3/s$ occurred on 16th October (day 289), and is registered at all the sensors. There were several distinct peaks in pressure recorded after this, but unfortunately records of subglacial discharge are not available after 1st November.

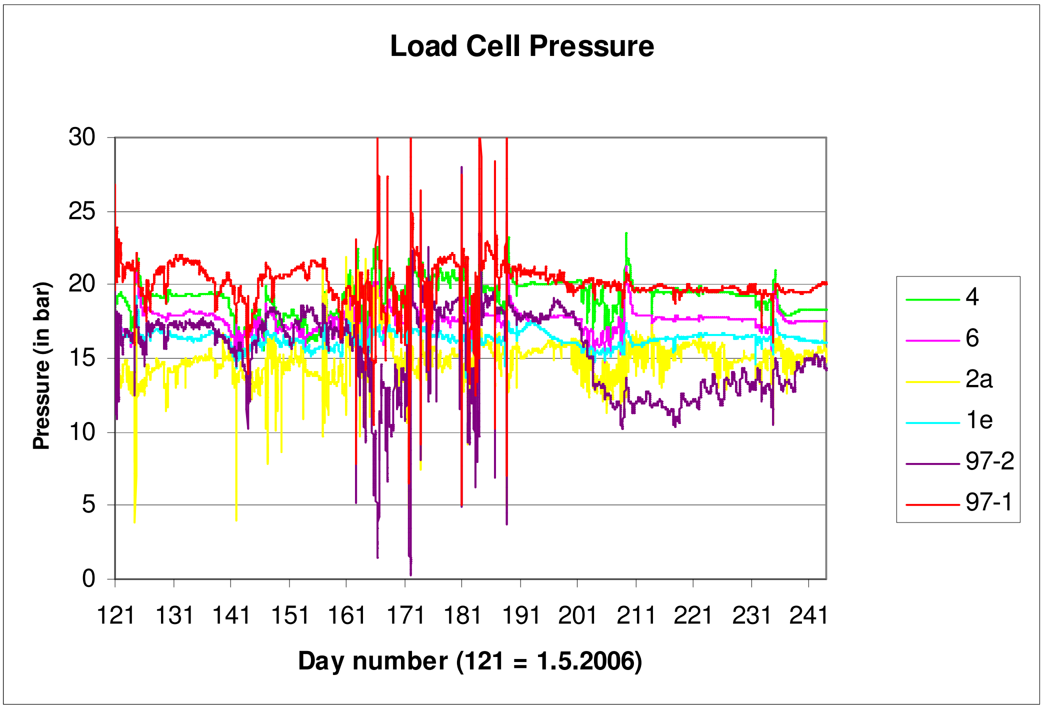



**Figure 11-10**
**Pressure records for the period 1st May to 31st August.**

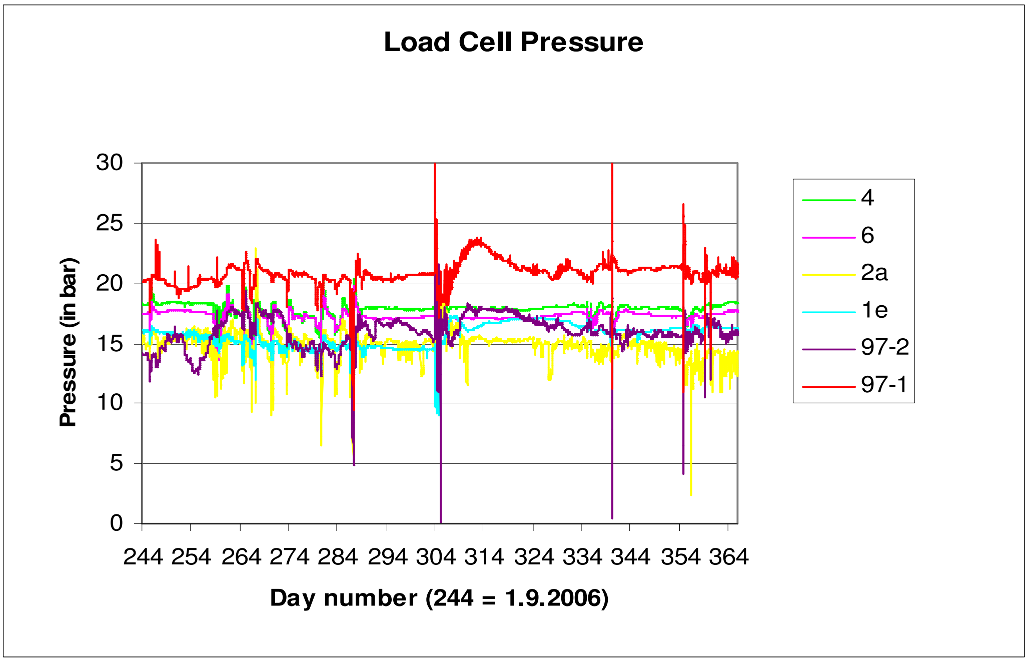



**Figure 11-11**
**Pressure records for the period 1st September to 31st December 2006.**

## 11.5 Svartisheibreen

Svartisheibreen (5.5 $km^2$, 774-1530 m a.s.l., 66°35'N, 13°45'E) is located 10 km south-west of Engabreen. The glacier has been monitored since 1987 in connection with a planned hydropower development. The monitoring program included mass balance (1988 – 1994), bed topography, glacier velocity, volume change, and lake level recording in the proglacial lake Heiavatnet. The lake has been subject to jökulhlaups at least three times between 1991 and 1999. The glacier was not visited during 2006.

The net balance of Svartisheibreen in 2006 was calculated from a linear regression model between net balance at Engabreen and net balance at Svartisheibreen. Using this model, the specific net balance of Svartisheibreen was −1.3 m w.e., which corresponds to a mass deficit of −7 mill. $m^3$ water (Fig. 11-12). The cumulative net balance at Svartisheibreen since 1969 equals +10 m w.e. The cumulative net balance at Engabreen in the same period is +22 m w.e.

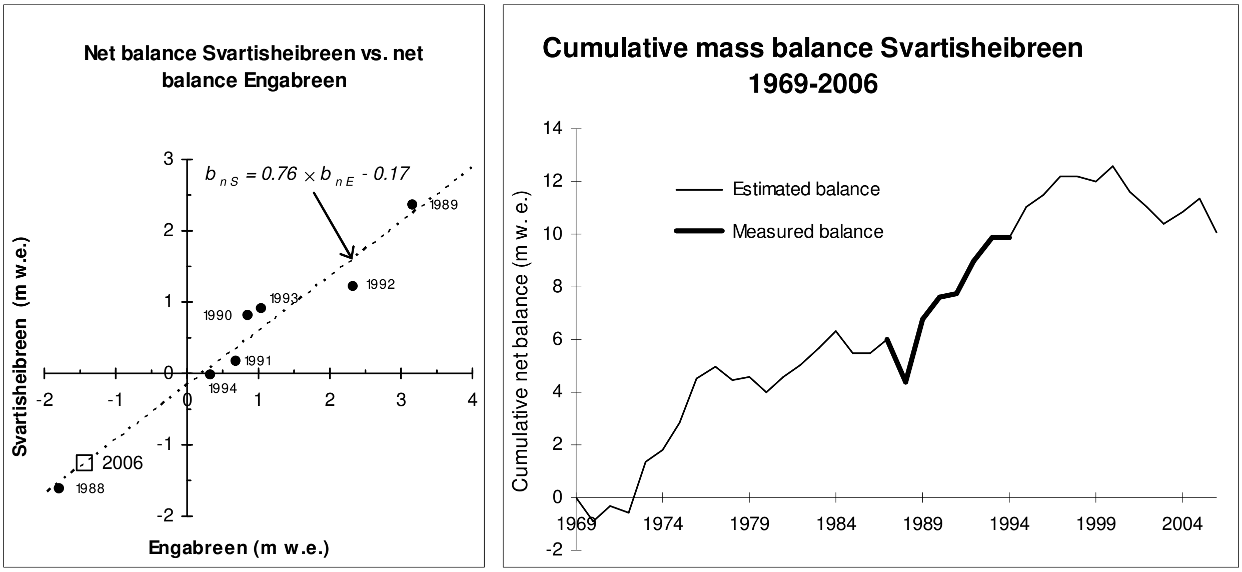



**Figure 11-12**
**Net balance at Svartisheibreen modelled from measured net balance at Engabreen and Svartisheibreen in 1988-94 (left), and cumulative specific net balance at Svartisheibreen for the period 1969-2006 (right).**

# 12. Langfjordjøkelen (Bjarne Kjøllmoen)

Langfjordjøkelen (70º10'N, 21º45'E) is a plateau glacier situated on the border of Troms and Finnmark counties, approximately 60 km northwest of the city of Alta. It has an area of about 8.4 $km^2$ (1994), and of this 3.7 $km^2$ drains eastward. The investigations are performed on this east-facing part, ranging from 280 to 1050 m a.s.l.

The glaciological investigations in 2006 include mass balance and change in glacier length (chap. 13). Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995.

## 12.1 Mass balance 2006

### Fieldwork

#### Snow accumulation measurements

Snow accumulation was measured on 25$^{th}$ April and the calculation of winter balance is based on (Fig. 12-2):

- Measurements of stakes in positions 10 (485 m a.s.l.), 25 (730 m a.s.l.), 30 (890 m a.s.l.) and 40 (1050 m a.s.l.) showing snow depths of 2.1, 3.2, 3.3 and 3.3 m respectively.
- Core sample at position 20 showing snow depth of 3.1 m.
- 69 snow depth soundings between 346 and 1052 m elevation. The summer surface (SS) was distinct over whole the glacier. In general the snow depth varied between 2.5 and 4.5 m.
- Snow density was measured down to 3.1 m depth (SS at 3.3 m) at stake position 30.

**Figure 12-1**
**Drilling of substitute stake in April at position 20. Photo: Hallgeir Elvehøy.**

Location of stakes, density pit and sounding profiles at Langfjordjøkelen in 2006 are shown in Figure 12-2.

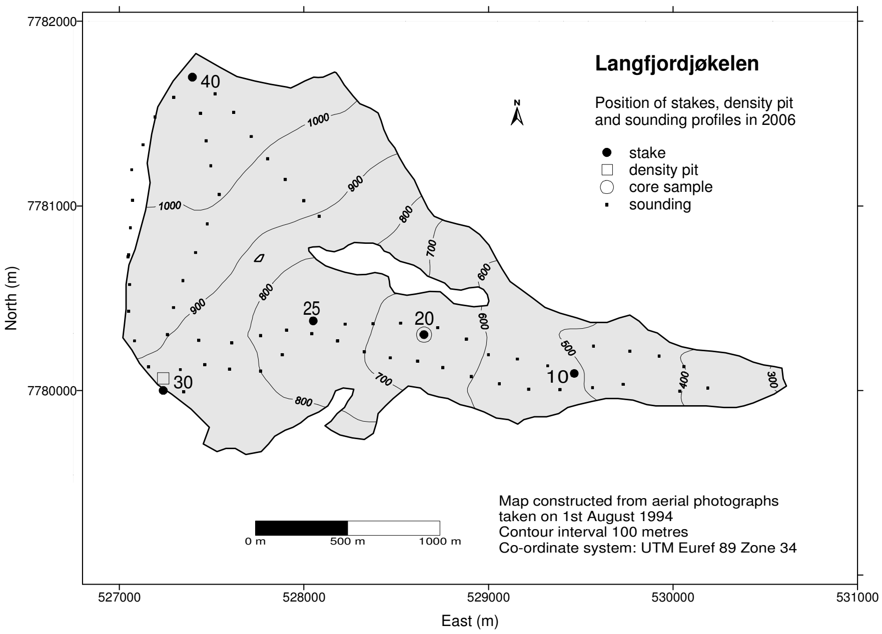



**Figure 12-2**
**Location of stakes, soundings and snow pit at Langfjordjøkelen in 2006.**

### Ablation measurements

Ablation was measured on 6th October. The net balance was measured at seven stakes in all five locations between 480 and 1052 m a.s.l. The stakes had increased in length between 4.5 m (1052 m a.s.l.) and 6.9 m (480 m a.s.l.) since snow measurements in late April. There was no snow remaining on the glacier surface from the winter season 2005/2006. At the time of measurements between 25 and 60 cm of fresh snow had fallen.

## Results

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, core sample and soundings) and on one snow density measurement.

There was no melting after the final measurements in October 2005. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measurement at 890 m altitude. The mean density of 3.3 m snow was 0.406 g/cm$^3$. The density model was used to convert all measured snow depths to water equivalent.

The winter balance calculations were performed by plotting the measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 12-4) and a mean value for each 100 m height interval was estimated (Tab. 12-1).

The winter balance was calculated as 1.4 ±0.2 m w.eqv., corresponding to a water volume of 5 ±1 mill. m$^3$. The result is 65 % of the mean value for the periods 1989-1993 and

1996-2005. Only two years have shown a lower winter balance on Langfjordjøkelen, with the lowest in 1999 (1.3 m eqv.).

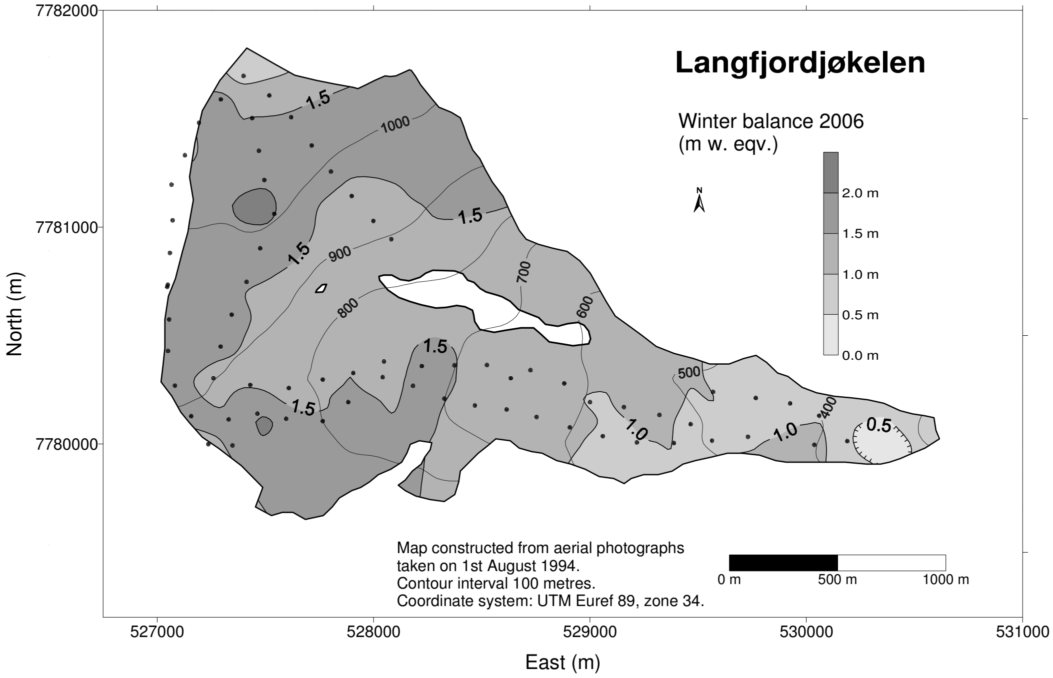



**Figure 12-3**
**Winter balance at Langfjordjøkelen in 2006 interpolated from 69 snow depth measurements (•).**

The winter balance was also calculated using different gridding methods and different spacing based on the aerial distribution of the snow depth measurements (Fig. 12-3). Water equivalent for each cell in the grid was calculated and summarised. The calculations gave an average of 1.4 m w.eqv., too.

## Summer balance

When calculating the summer balance the density of melted firn was estimated as between 0.70 and 0.80 g/cm$^3$, while the density of melted ice was taken as 0.90 g/cm$^3$.

The summer balance was calculated at stakes at all five elevations. The summer balance increased from −2.2 m w.eqv. at position 40 (1050 m a.s.l.) to −5.1 m w.eqv. at position 10 (485 m a.s.l.). Based on estimated density and stake measurements, the summer balance was calculated to be −3.8 ±0.3 m w.eqv., which is −14 ±1 mill. m$^3$ of water. The result is 126 % of the average for the periods 1989-1993 and 1996-2005. This is the greatest summer balance measured at Langfjordjøkelen.

## Net balance

The net balance at Langfjordjøkelen for 2006 was −2.4 ±0.3 m w.eqv., which equals a volume loss of −9 ±1 mill. m$^3$ of water (Tab. 12-1). The mean value for the measurement periods 1989-93 and 1996-2005 is −0.86 m w.eqv. (Fig. 12-5), while the average over the 5-year period 2001-2005 is −1.6 m w.eqv. This is the greatest deficit measured at Langfjordjøkelen since 1989.

There was net ablation over the entire glacier surface and accordingly, the equilibrium line altitude (ELA) lies *above* the summit (Fig. 12-4). Consequently, the AAR is 0 %.

The mass balance results are shown in Table 12-1. The corresponding curves for specific and volume balance are shown in Figure 12-4. The historical mass balance results are presented in Figure 12-5.

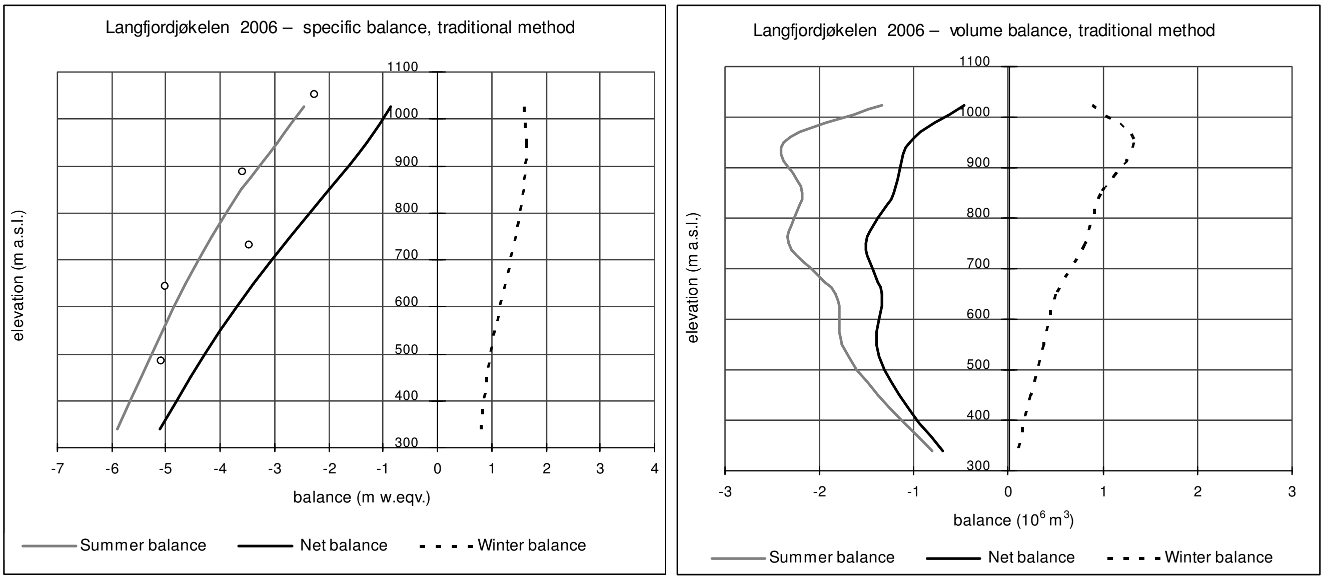



**Figure 12-4**
**Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2006. Summer balance for stakes at three different sites is shown (o).**

**Table 12-1**
**Winter, summer and net balance for Langfjordjøkelen in 2006. Mean values for the periods 1989-93 and 1996-2006 are $b_w$ = 2,14 m, $b_s$ = –3,09 m and $b_n$ = –0,95 m w.eqv.**

**Mass balance Langfjordjøkelen 2005/06 – traditional method**

| Altitude (m a.s.l.) | Area (km$^2$) | Winter balance Measured 25th April 2006 Specific (m w.eq.) | Winter balance Volume ($10^6$ m$^3$) | Summer balance Measured 6th Oct 2006 Specific (m w.eq.) | Summer balance Volume ($10^6$ m$^3$) | Net balance Summer surface 2005 - 2006 Specific (m w.eq.) | Net balance Volume ($10^6$ m$^3$) |
|---|---|---|---|---|---|---|---|
| 1000 - 1050 | 0.55 | 1.60 | 0.9 | -2.45 | -1.3 | -0.85 | -0.5 |
| 900 - 1000 | 0.81 | 1.65 | 1.3 | -2.95 | -2.4 | -1.30 | -1.0 |
| 800 - 900 | 0.61 | 1.60 | 1.0 | -3.60 | -2.2 | -2.00 | -1.2 |
| 700 - 800 | 0.56 | 1.45 | 0.8 | -4.15 | -2.3 | -2.70 | -1.5 |
| 600 - 700 | 0.39 | 1.25 | 0.5 | -4.65 | -1.8 | -3.40 | -1.3 |
| 500 - 600 | 0.35 | 1.05 | 0.4 | -5.05 | -1.8 | -4.00 | -1.4 |
| 400 - 500 | 0.25 | 0.90 | 0.2 | -5.45 | -1.4 | -4.55 | -1.2 |
| 280 - 400 | 0.14 | 0.80 | 0.1 | -5.90 | -0.8 | -5.10 | -0.7 |
| **280 - 1050** | **3.65** | **1.42** | **5.2** | **-3.83** | **-14.0** | **-2.41** | **-8.8** |

The balance year 2005/2006 is the tenth successive year with significant negative net balance at Langfjordjøkelen. The cumulative net balance for the period 1989-2006 (estimated values for 1994 and 1995 included) is −16 m w.eqv. Most of this mass loss (94 %) has occurred over the last ten years (1997-2006).

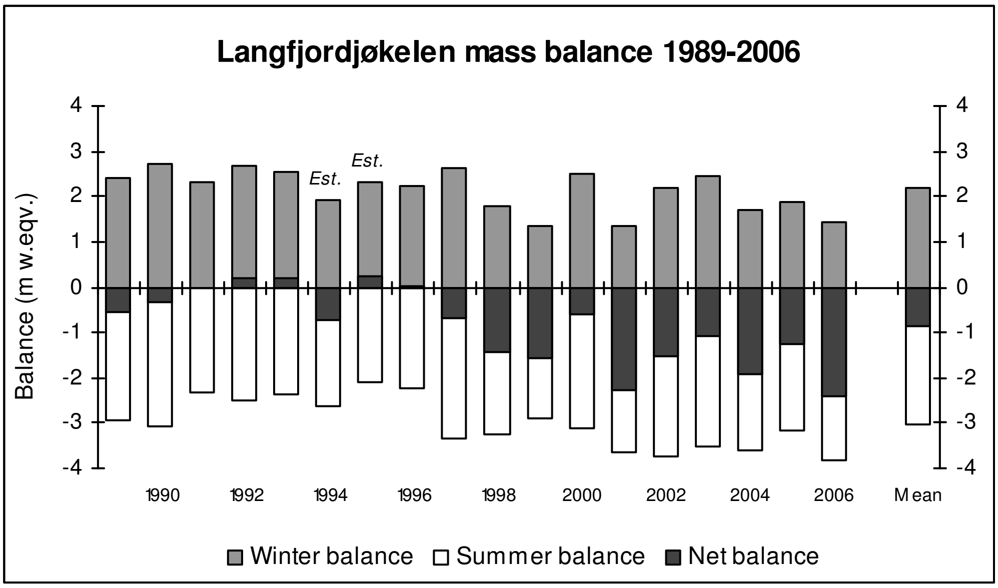



**Figure 12-5**
**Mass balance at Langfjordjøkelen during the period 1989-2006. The total accumulated deficit over 1989-2006 is 16 m w.eqv. (includes estimated values for 1994 and 1995).**

# 13. Glacier monitoring

(Hallgeir Elvehøy and Miriam Jackson)

## 13.1 Glacier length change

Observations of glacier length change at Norwegian glaciers started around 1900. In 2006, glacier length change was measured for 28 glaciers, 24 in southern Norway and four glaciers in northern Norway (Fig. 13-2). One glacier in Skjomen and two glaciers in Okstindan in Nordland are included in the monitoring network. At one of the glaciers, Austre Okstindbreen (Fig. 13-1), glacier length changes were monitored between 1906 and 1945 by Professor Werenskiold and colleagues at the University of Oslo (Hoel & Werenskiold, 1962). Both glaciers in Okstindan have been studied by English and Danish universities since the 1960s (i.e. Worsley, 1974; Knudsen & Theakstone, 1980). The mass balance of Austre Okstindbreen was measured between 1987 and 1996 by the University of Århus, Denmark, on contract from NVE and Statkraft (Kjøllmoen, 1998). At Storsteinsfjellbreen in Skjomen the mass balance was measured in 1964-68 and 1991-95, and the volume change between 1960 and 1993 was mapped (Andreassen, 2000).

**Figure 13-1**
**Austre Okstindbreen, a northern outlet from Okstindbreen in Nordland, photographed on 20th September 2006. Photo: Hallgeir Elvehøy.**

### Methods

The distance to the glacier terminus is measured from one or several established cairns or painted marks on rocks in defined directions, usually in September or October each year. Change in distance gives a rough estimate of the length change of the glacier. These measurements have a fairly high degree of uncertainty as to what extent the measurement is representative for the entire glacier tongue. Nevertheless, the measurements give valuable information about glacier fluctuations, and regional tendencies and variations when longer time periods are considered (Andreassen et al., 2005).

### Results 2006

Twenty-eight glaciers were measured in 2006, four in northern Norway, and 24 glaciers in southern Norway. The glacier retreat observed in previous years continued at the highest rate observed since the 1940s. The glacier length changes at the observed glaciers are listed in Table 13-1.

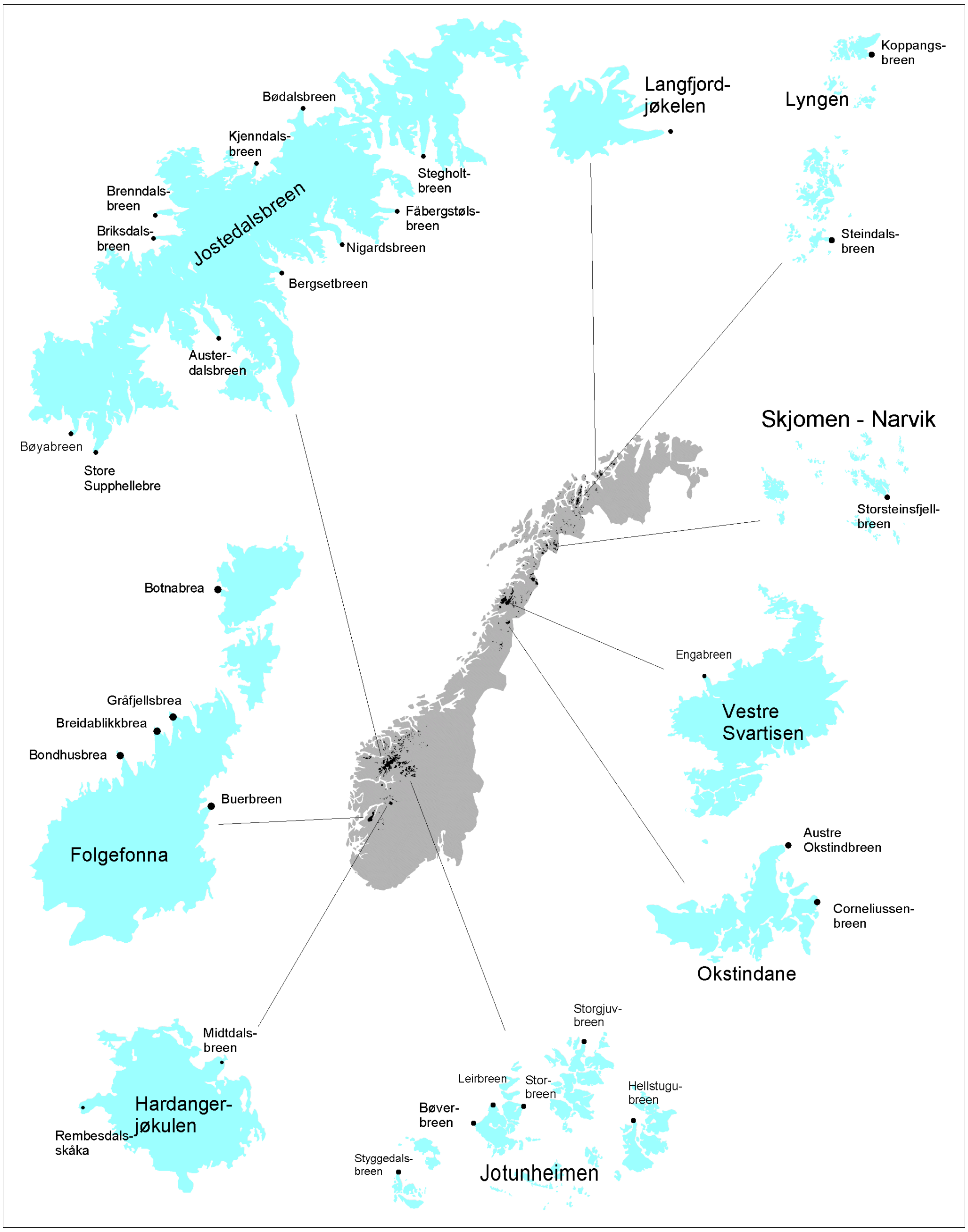



**Figure 13-2**
**Location map showing glaciers where length change observations were performed in 2006. Note that the different glacier areas are not to the same scale.**

At Jostedalsbreen, Brenndalsbreen and Kjenndalsbreen retreated 160 m, and Briksdalsbreen and Bergsetbreen retreated 120 metres. Eight out of eleven measured glacier tongues retreated more than 30 metres. At Brenndalsbreen there was a major change in the drainage system this summer which coincided with the collapse of the lowermost part of the glacier. At Bergsetbreen the lowermost tongue is detached from the rest of the glacier and is melting away. The reported retreat this year refers to the remnant of the glacier tongue. If the lower tongue is ignored, Bergsetbreen has become about 800 m shorter. Next year the measurement will refer to the active tongue. Briksdalsbreen has retreated to the upper part of the pro-glacial lake and appears similar to how it was in photos from 1953 when the previous, major retreat ended. Due to inconsistencies between cumulative measured length changes, and maps and photos, the length change series has been re-calculated (chapter 13-2).

**Table 13-1**
**Glacier length change between autumn 2005 and autumn 2006 for 28 glaciers . See Figure 13-2 for locations.**

| Region | Glacier | Change (m) | Measured by |
|---|---|---|---|
| Jostedalsbreen | Austerdalsbreen | –21 | NVE |
| | Bergsetbreen | –122 | NVE |
| | Brenndalsbreen | –160 | Dr. S. Winkler, Germany |
| | Briksdalsbreen | –122 | NVE/Prof. A. Nesje, Univ. Bergen |
| | Bødalsbreen | –72 | Dr. S. Winkler, Germany |
| | Fåbergstølsbreen | –46 | NVE |
| | Kjenndalsbreen | –161 | Dr. S. Winkler, Germany |
| | Nigardsbreen | –32 | Statkraft |
| | Stegholtbreen | 5 | NVE |
| | Bøyabreen | –47 | Norsk Bremuseum |
| | Store Supphellebreen | –8 | Norsk Bremuseum |
| Folgefonna | Bondhusbrea | –48 | Statkraft |
| | Botnabrea | –24 | Geir Knutsen, Tyssedal |
| | Breidablikkbrea | –2 | Statkraft |
| | Buerbreen | –9 | NVE |
| | Gråfjellsbrea | –97 | Statkraft |
| Hardangerjøkulen | Midtdalsbreen | –10 | Prof. A. Nesje, Univ. Bergen |
| | Rembesdalsskåka | –34 | Statkraft |
| Jotunheimen | Bøverbreen | –5 | Dr. S. Winkler, Germany |
| | Hellstugubreen | –15 | NVE |
| | Leirbreen | –16 | NVE |
| | Storbreen* | –16 | NVE |
| | Storgjuvbreen | –8 | Dr. S. Winkler, Germany |
| | Styggedalsbreen | –8 | NVE |
| Okstindane | Austre Okstindbreen | x | NVE |
| | Corneliussen-breen | x | NVE |
| Svartisen | Engabreen | –5 | Statkraft |
| Skjomen | Storsteinsfjellbreen | x | NVE |
| Lyngen | Koppangsbreen | –38 | NVE |
| | Steindalsbreen | –34 | NVE |
| Finnmark | Langfjordjøkelen | –35 | NVE |

x measurements started in 2006
* not measured in 2005 due to snow cover

At Folgefonna, Gråfjellsbrea retreated 97 metres. An 800 m long pro-glacial lake has appeared during 25 years of retreat. Bondhusbrea retreated 48 m in 2006 and has retreated 188 m since 1996 when measurements resumed. The most recent advance at Bondhusbrea started about 1985. The glacier advanced approximately 30 metres between 1974 and 1982, and another 60 m from about 1985 until about 1996. Bondhusbrea has retreated

188 m since 1996, and has not been this short for several hundred years. At Hardanger-jøkulen, Rembesdalsskåka retreated 34 metres, and has retreated 263 m since 1997.

In Jotunheimen, all six glaciers retreated. Styggedalsbreen, Bøverbreen and Storgjuvbreen advanced slightly in the years preceding 2000 as did several other glaciers, while the other three glaciers have been retreating continually as did most glaciers in Jotunheimen. For example, Hellstugubreen and Leirbreen have retreated 110 m since 1990 (–7 m/a).

In Nordland, Engabreen retreated slightly, and has retreated 189 m since the last advance ended in 1999. The glaciers in Skjomen and Okstindane are also retreating. Corneliussen-breen advanced during the 1970s, 80s and 90s, but had retreated 180 metres from its most recent end moraine which was formed late in the 1990s. Austre Okstindbreen has retreated about 1750 m since 1908. Storsteinsfjellbreen in Skjomen has retreated 470 m between 1963 and 2006 (–11 m/a).

In Troms and Finnmark the glaciers have retreated continually. Langfjordjøkelen has retreated 360 m since 1994 (–20 m/a), whilst Steindalsbreen and Koppangsbreen in Lyngen have retreated about 150 m since 1998 (–18 m/a).

## Changes since 1982

In the 1980s, most of the observed glaciers retreated slowly (Fig. 13-3). Many outlet glaciers from coastal ice caps started to advance late in the 1980s. This advance ended before the turn of the century. At Stegholtbreen the advance didn't begin until 1996 and lasted four years. The more continental glaciers such as Hellstugubreen have been retreating slowly for decades.

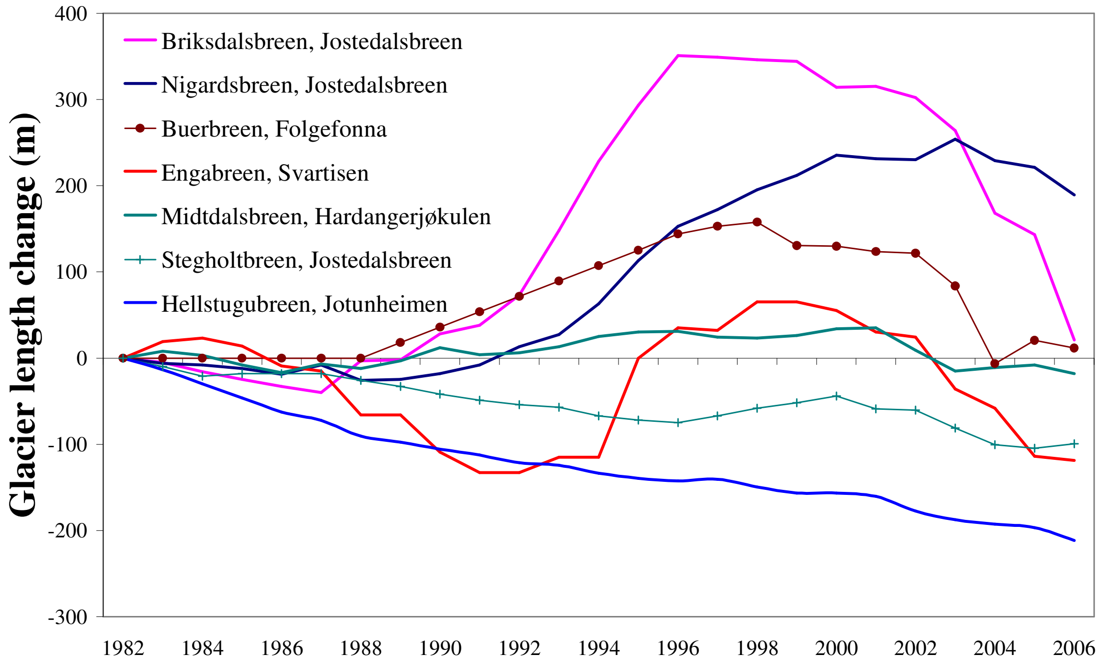



**Figure 13-3**
**Cumulative glacier length change since 1982 at seven glaciers. See Figure 13-2 for locations.**

# 13.2 Briksdalsbreen - revised glacier length record 1900-2006

## Background

Briksdalsbreen (11.9 $km^2$) is a western outlet of Jostedalsbreen. The glacier is short and steep and reacts quickly to changes in the mass balance. Glacier length change measurements at Briksdalsbreen started in 1900 (Rekstad 1902; 1904). Briksdalsbreen has had several periods of advances and retreats with advances prior to 1910, 1925, 1961, 1969, 1980 and 1997 (Andreassen et al., 2005). Between 1932 and 1951 the terminus retreated more than 800 metres and uncovered lake Briksdalsvatnet. The last advance started in 1987 and covered the lake entirely in 1997. Since 1999, the glacier has retreated rapidly, and the lake is again exposed. By the end of 2006 the glacier was near its 1951 position at the upstream end of the lake (Fig. 13-4).

In addition to length-change observations, the glacier terminus has been mapped repeatedly, and photographs have been taken by observers from different locations, providing additional documentation of the glacier change. Ideally, cumulative glacier length change should agree with distance between mapped glacier termini, and the cumulative glacier length should be the same in years when the glacier terminus is located in the same position. Some differences must be expected and are due to how representative is the measuring line and the changing shape of the tongue, as well as different dates of maps and photos (mainly obtained in summer) and glacier length observations (mainly autumn). However, the differences between cumulative length change and surveyed or photographed changes have been considerable. To resolve this, the supplementary information has been analysed, and the glacier length record of Briksdalsbreen has been revised.

## Length change observations

The annual measurements have been carried out using traditional methods. Cairns or other marks were used as fixed points, and distance has been measured in well-defined directions to the glacier boundary.

**1900-1945:** Two measuring lines were established in 1900, one on each side of the glacier river. The glacier advanced between 1905 and 1910, retreated from 1911 until 1921, and advanced again from 1922 to 1925. The glacier front was then stable until 1932 when a major recession started. The mean of the two lines represents the terminus fairly well, the northern line being shorter than the southern line due to the curving valley. New fixed points were established in 1905, 1938, 1940 (southern side) and 1944.

**1945-1979:** Two measuring lines were used - one on each side of the lake. The measurements were probably less representative of the terminus due to calving of the central part of the tongue. New fixed points were established in 1953 after the extensive retreat had ended. The northern line was shorter than the southern line due to the shape of the lake.

**1979-2000:** The measuring line along the north shore of the lake was used. New fixed points were established in 1991 and 1993. The measuring line did not represent the central part of the tongue. In addition, the measuring direction was oblique to the central flow-line.

**2000-2006:** Two different lines were measured along the north shore by different bodies. None were representative of the central part of the glacier tongue. The measuring directions were oblique to the central flow-line.

## Maps and aerial vertical photographs

**1938:** Aerial photos taken on 22nd July 1938 show the glacier terminus at the junction of the rivers from Briksdalsbreen and Tjøtabreen. The trim line from around 1910 is clearly visible. The photos were taken in the middle of summer, and more retreat would have taken place by the time of the length measurements on 29th August.

**1945:** Aerial photographs taken on 9th September 1945. The emerging lake Briksdalsvatnet is not visible due to shadow.

**1967:** Maps (1:5000) constructed from aerial photographs taken on 9th August 1967 show that the glacier terminus was located at the upstream end of the lake.

**1981**: Aerial photographs taken on 29th August 1981.

**1993:** National topographic maps (M711, scale 1:50 000) constructed from aerial photographs taken on 23rd August 1993.

**1997-1999:** The front position was surveyed repeatedly by NVE.

**2004:** Ortho-rectified aerial photographs taken 12th August 2004. (www.norgeibilder.no).

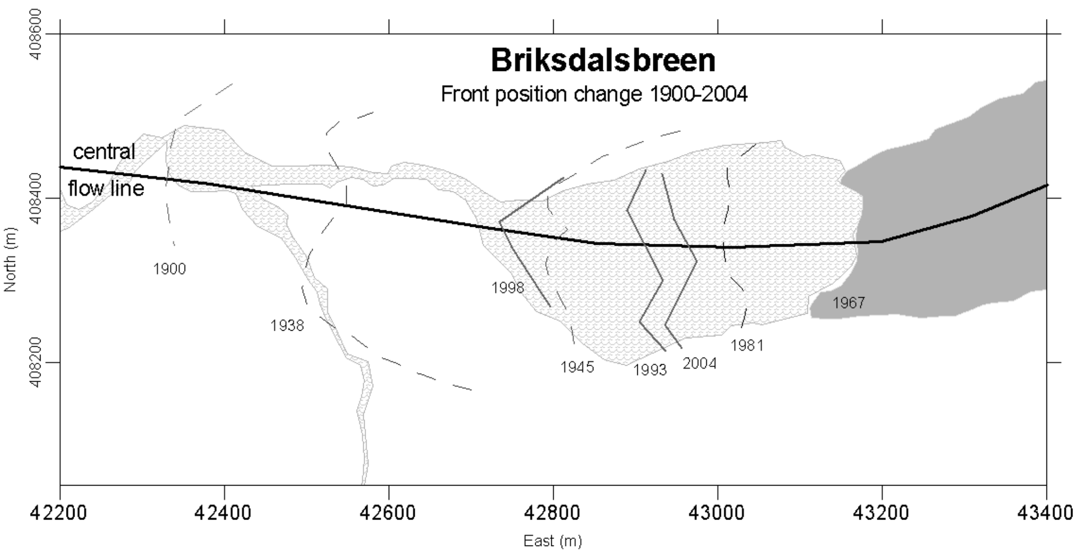



**Figure 13-4**
**Mapped (grey lines) and photographed (grey broken lines) termini positions at Briksdalsbreen. A central flow line (black line) used as axis for revised glacier length changes is shown. Glacier and lake outline is digitised from 1967-maps. Co-ordinate system is NGO axis 1.**

## Ground-based photography

A photo taken by Rekstad in 1900 shows the glacier in a retreating state at a bend in the river (Fig. 13-4). A number of photos collected by Pedersen (1976) taken between 1953 and 1975 show several advances and retreats, but illustrate that the net change in length is small until the 1973-80 advance. Figure 13-5 shows the glacier in 2007 at a similar size as it was in 1953, 1963 and 1972.

**Figure 13-5**
**Briksdalsbreen on 7th January 2007 showing the terminus at the upstream end of Briksdalsvatnet. The terminus was quite similar to this in 1953, 1963 and 1972. Photo: Erling Briksdal.**

## Method

In order to revise the length change record of Briksdalsbreen, the available mapped or photographed (1938, 1945, 1967, 1981, 1993, 1997-1999 and 2004) front positions were parameterised on an axis representing the central flow line (Fig. 13-4). The difference in length between the date of the surveys and the date of the length measurements was estimated. The annual length changes were adjusted linearly using the ratio of the distance between mapped termini to the corresponding cumulative length change. Based on the small measured length variations between 1963 and 1972 and the map from 1967, we set the cumulative glacier length change in 1953, 1963 and 1972 to −840 m, 10 m shorter than in 1967.

## Results

The original and revised cumulative glacier length change is shown in Figure 13-6. The advancing and retreating periods are unchanged, but the amount of change has been adjusted to match the distance between mapped or otherwise known front positions. Between 1900 and 1938 the changes are small, and the net change is reduced by 20 metres. The front position in 1900 is not known precisely, but photos pinpoint the front position relative to the river fairly well. The retreat between 1938 and 1951 is reduced from 683 to 640 metres. The glacier length was at its shortest in 1954 (a change of −862 m since 1900). Between 1953 and 1973 the front position fluctuated slightly at the upstream end of the lake. The amount of advance between 1973 and 1980 has been increased from +151 to +190 m. This is reasonable when considering that the measurements were done along the lake shores and not at the central part of the glacier. The retreat between 1980 and 1987 was slightly adjusted (−44 m to −38 m). The major advance between 1987 and 1996 has been reduced from +391 to +304 metres. The length changes were over-estimated due to a combination of advance and widening of the glacier tongue. After 1999 the glacier has retreated considerably. The measurements have been done along the north shore while the central and southern side of the glacier has retreated faster than along the northern shore. Between 1999 and 2004 the retreat was increased from −176 to −220 metres. In 2005 the measurements along the northern shore showed a retreat of only 25 metres. At the same time the southern part of the glacier retreated considerably glacier. In 2006 (until 7th October) the glacier retreated 122 m along the north shore of the lake, while the southern part of the terminus seems to have retreated to its position in 1953, 1963 and 1972. The retreat in 2005 and 2006 has been increased to −50 and −140 metres, respectively.

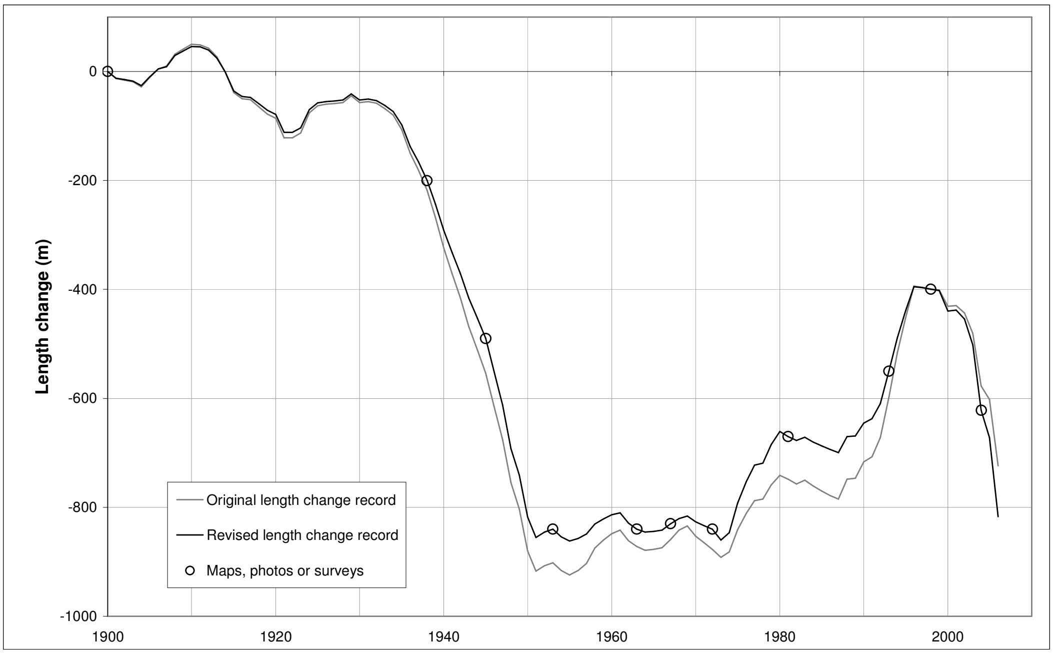



**Figure 13-6**
**Original and revised glacier length change record for Briksdalsbreen between 1900 and 2006.**

# 13.3 Monitoring of Baklibreen

Baklibreen (61°40′N, 7°05′E) is an outlet glacier of Jostedalsbreen. It has an area of 3 km$^2$ and covers an elevation range from 1950 m a.s.l. to about 1200 m a.s.l. An ice avalanche occurred from the glacier in the summer of 1986. The ice fell a total of 600-700 m and killed three tourists walking along the footpath below. The ice that fell is thought to have covered an area of 4000 m$^2$ and to have had a total volume of 200 000 m$^3$.

An observation programme was set up in 1987 to study the risk of future icefalls, and was in operation until 1999. A more limited monitoring programme has been in existence since 2000, and between 2001 and 2003 this was carried out as part of the European

Union 5th Framework Glaciorisk project. Since then, observations consist of photographs of the glacier front only, with no measurements on the glacier.

Figure 13-7 shows photographs of Baklibreen from 1991, only four years after the icefall, and from 2006. The glacier advanced until 2000, and has retreated rather dramatically since then.

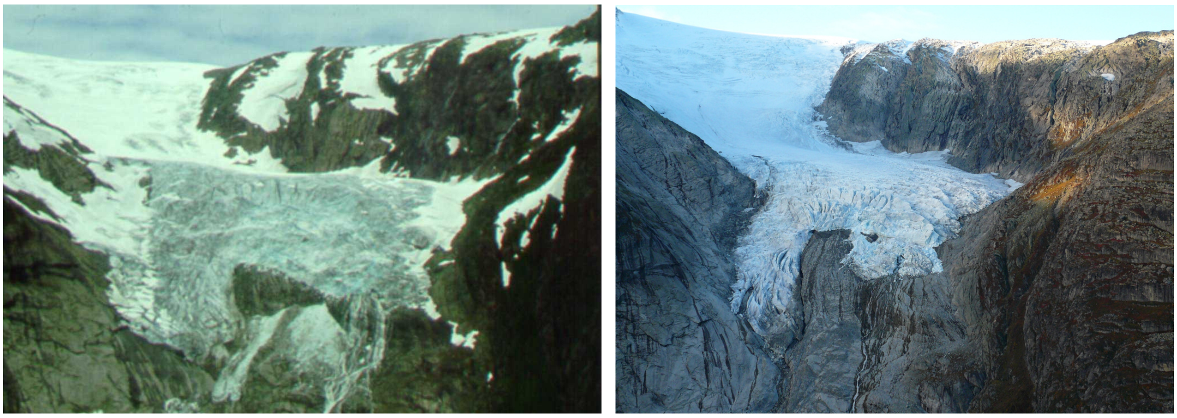


**Figure 13-7**
**Baklibreen in 1991 (left) and 2006 (right). Photos: Mike Kennett and Miriam Jackson.**

## Previous measurements

A comparison of glacier surface measurements done in 1989 with a map based on aerial photographs from 1984 shows little change in this period. The biggest increase took place in the period between 1989 and 1994 when ice thickness increased between 10 m and 20 m on the lower glacier below 1300 m a.s.l. A slight increase was measured between 1994 and 1996, and little change was registered between 1996 and 1999. More detailed information on these measurements is available in Kjøllmoen (ed.) (2000). Subsequent measurements show lowering of the glacier surface of 0 – 8 metres per year until 2003. The glacier surface has not been measured since then.

## Scenario

Continued surface lowering of Baklibreen suggests that a large ice avalanche, such as occurred in 1986, is less likely to occur. However, smaller icefalls can occur. The continued frontal retreat of neighbouring glacier Bergsetbreen also means that there is increased risk of people being in the danger zone of an ice fall. Bergsetbreen advanced 360 m from the mid 1980s to 1997, and the footpath in front of Baklibreen became inaccessible. However, Bergsetbreen has retreated 231 m since 2000, with a measured retreat of over 100m during the last year and separation of the lowest, stagnant part of the glacier from the main glacier. This means that there may be more foot traffic in coming years below Baklibreen, increasing the risk of injury if an icefall should occur.

# 14. References

Andreassen, L.M., H. Elvehøy, B. Kjøllmoen., R. Engeset & N. Haakensen
2005: Glacier mass balance and length variation in Norway. *Annals of Glaciology 42*, p 317-325.

Andreassen, L.M., B. Kjøllmoen, N.T. Knudsen, W.B. Whalley & J. Fjellanger
2000: Regional change of glaciers in northern Norway. *NVE Report No 1-2000*, 122 pp.

Geist, T., H. Elvehøy, M. Jackson & J. Stötter
2005: Investigations on intra-annual elevation changes using multi-temporal airborne laser scanning data: case study Engabreen, Norway. *Annals of Glaciology 42*, p 195-201.

Hoel, A & W. Werenskiold
1962: Glaciers and snowfields in Norway. *Norsk Polarinstitutt Skrifter Nr. 114*, 291 pp.

Jackson, M.
2000: Svartisen Subglacial Laboratory. *NVE Document 14 2000*, 27 pp.

Kjøllmoen, B. (ed.)
1998: Glasiologiske undersøkelser i Norge 1996 og 1997. *NVE Rapport 20-1998*, 134 pp.
2000: Glasiologiske undersøkelser i Norge 1999. *NVE Rapport 2-2000*, 140 pp.

Knudsen, N.T. & W.H. Theakstone
1980: Marginal changes and moraine formation at an advancing glacier, Corneliussens Bre, Okstindan, Norway. *Zeitschrift fur Gletcherkunde und Glazialgeologi. No 16*, p 185-201.

Laumann, T & B. Wold
1992: Reactions of a calving glacier to large changes in water level. *Annals of Glaciology 16*, p 158-162.

Liestøl, O.
1967: Storbreen glacier in Jotunheimen, Norway. *Norsk Polarinstitutt Skrifter 141*, 63 pp.

Pedersen, K.
1976: Briksdalsbreen, Vest-Norge. Glasiologiske og glasialgeologiske undersøkelser. *Unpublished Cand. Real. Thesis*, University of Bergen. 92 p. 151 p ill.

Pytte, R. (ed.)
1969: Glasiologiske undersøkelser i Norge 1969. *NVE Rapport 5 1970*, p 17-25.

Rekstad, J.
1902: Iagttagelser fra bræer i Sogn og Nordfjord. *Norges Geologiske Undersøgelse no. 34-3*, 48 pp.
1904: Fra Jostedalsbræen. *Bergen Museums Aarbog 1904, Naturvidenskaplig rekke No. 1*, 95 pp.

Tvede, A.M and T. Laumann
1997: Glacial variations on a meso-scale: examples from glaciers in the Aurland Mountains, southern Norway. *Annals of Glaciology no 24,* p 130-134.

Tvede, A.M.
1982: En metode til å beregne hvordan en avløpsserie er blitt påvirket av magasineffekten i brefelt. (A method for calculating the reservoir effect of glaciers on runoff series). In: Glasiologiske undersøkelser i Norge 1980. *NVE Rapport 1 1982*, p 64-71.

Wold, B and J.O. Hagen (ed.)
1977: Glasiologiske undersøkelser i Norge 1975. *NVE Rapport 2 1977*, p 13-15.

Worsley P.
1974: Recent 'annual' moraine ridges at Austre Okstindbreen, Okstindan, north Norway. *Journal of Glaciology 13*, p 265-277.

Østrem, G., K. Dale Selvig & K. Tandberg
1988: Atlas over breer i Sør-Norge. *Meddelelse No 61.*

Østrem, G. & M. Brugman
1991: Glacier mass-balance measurements. A manual for field and office work. National Hydrology Research Institute, *Scientific Report, No. 4.* Environment Canada, N.H.R.I., Saskatoon and Norwegian Water Resources and Energy Directorate, Oslo, 224 pp.

# Appendix A

## Publications published in 2006

Andreassen, L.M., H. Elvehøy, T. Johannesson, J. Oerlemans, S. Beldring and M. van den Broeke
Modelling the climate sensitivity of Storbreen and Engabreen, Norway. *NVE Report 3 2006*, 38 pp.

Andreassen, L.M., H. Elvehøy, T. Johannesson, J. Oerlemans and S. Beldring
Changes in run-off from glaciated areas due to climate change. Case studies of Storbreen and Engabreen, Norway. *European Conference on Impacts of Climate Change on renewable Energy Sources, Reykjavik, Iceland, June 5-9 2006*, p 57-60.

Andreassen, L.M., B. Kjøllmoen, A.L. Rasmussen and Ø. Nordli
Rapid thinning of Langfjordjøkelen in northern Norway. *Extended abstracts, Workshop and GLACIODYN planning meeting, Obergurgl, Austria, January 29 – February 3 2006*, p 16-19.

Cohen, C, T. S. Hooyer, N. R. Iverson, J. F. Thomason and M. Jackson
Effects of water pressure fluctuations on quarrying: subglacial experiments using acoustic emissions. *Geophysical Research Abstracts, Vol. 8*, *02784*.

Cohen, D., Hooyer, T.S., Iverson, N.R., Thomason, J., and M. Jackson
Role of transient water pressure in quarrying: a subglacial experiment using acoustic emissions. *Journal of Geophysical Research-Earth Surface, Vol. 111, F03006, doi:10.1029/2005JF000439.*

Jackson, M and H. Elvehøy
Engabreen - mass balance results and work in the subglacial lab. *Extended abstracts, Workshop and GLACIODYN planning meeting, Obergurgl, Austria, January 29 – February 3 2006*, p 52-53.

Kjøllmoen, B., L.M. Andreassen, R.V. Engeset, H. Elvehøy, M. Jackson and R. Giesen
Glaciological investigations in Norway in 2005. *NVE Report 2 2006*, 91 pp.

Lappegard, G., S. Beldring, L. Roald, T. Engen-Skaugen and E.J. Førland
Projection of future streamflow in glaciated and non-glaciated catchments in Norway. *NVE Oppdragsrapport A, 9 2006*, 61 pp.

Lappegard G, J. Kohler, M. Jackson and J.O. Hagen
Characteristics of subglacial drainage systems deduced from long-term load-cell measurements at Engabreen, Norway. *Journal of Glaciology, Vol. 52, No. 176,* p 137-148.

# Appendix B

## Mass balance measurements in Norway – an overview

During the period 1949-2006 there are carried out mass balance measurements at 42 Norwegian glaciers. The table below shows some characteristic data for the individual glaciers.

| Area/ No. Glacier | No. of WGMS | Area ($km^2$) | Altitude (m a.s.l.) | Period | No. of years |
|---|---|---|---|---|---|
| **Ålfotbreen** | | | | | |
| 1 Ålfotbreen | BL004 | 4.5 | 903-1382 | 1963- | 44 |
| 2 Hansebreen | BO002 | 3.1 | 930-1327 | 1986- | 21 |
| **Folgefonna** | | | | | |
| 3 Blomsterskardsbreen | AJ008 | 45.7 | 850-1640 | 1970-77 | 8 |
| 4 Bondhusbrea | AJ002 | 10.7 | 480-1635 | 1977-81 | 5 |
| 5 Breidablikkbrea | AJ001 | 3.9 | 1219-1660 | 1963-68, 2003- | 10 |
| 6 Gråfjellsbrea | AK007 | 9.4 | 1039-1660 | 64-68, 74-75, 2003- | 11 |
| 7 Blåbreen and Ruklebreen | AJ011/AJ026 | 4.5 | 1065-1610 | 1963-68 | 6 |
| 8 Midtre Folgefonna | AJ017/AJ024 | 8.7 | 1100-1570 | 1970-71 | 2 |
| **Jostedalsbreen** | | | | | |
| 9 Jostefonn | BA005 | 3.8 | 960-1622 | 1996-2000 | 5 |
| 10 Vesledalsbreen | BU033 | 4.2 | 1130-1730 | 1967-72 | 6 |
| 11 Tunsbergdalsbreen | A4007 | 50.1 | 540-1930 | 1966-72 | 7 |
| 12 Nigardsbreen | A4014 | 47.8 | 320-1960 | 1962- | 45 |
| 13 Store Supphellebreen | A8015 | 12.0 | 80-300/ 720-1740 | 1964-67, 73-75, 79-82 | 11 |
| 14 Austdalsbreen | A4023 | 11.8 | 1200-1757 | 1988- | 19 |
| 15 Spørteggbreen | * | 27.9 | 1260-1770 | 1988-91 | 4 |
| 16 Harbardsbreen | A2004 | 13.2 | 1250-1960 | 1997-2001 | 5 |
| **Hardangerjøkulen** | | | | | |
| 17 Rembesdalsskåka | AO001 | 17.1 | 1020-1865 | 1963- | 44 |
| 18 Midtdalsbreen | AG002 | 6.7 | 1380-1862 | 2000-2001 | 2 |
| 19 Omnsbreen | AG003/AY002 | 1.5 | 1460-1570 | 1966-70 | 5 |
| **Jotunheimen** | | | | | |
| 20 Tverråbreen | AD022 | 5.9 | 1415-2200 | 1962-63 | 2 |
| 21 Blåbreen | AB040 | 3.6 | 1550-2150 | 1962-63 | 2 |
| 22 Storbreen | AD041 | 5.4 | 1390-2100 | 1949- | 58 |
| 23 Vestre Memurubre | AB031 | 9.0 | 1570-2230 | 1968-72 | 5 |
| 24 Austre Memurubre | AB033 | 8.7 | 1630-2250 | 1968-72 | 5 |
| 25 Hellstugubreen | AD011 | 3.0 | 1480-2210 | 1962- | 45 |
| 26 Gråsubreen | AB047 | 2.3 | 1830-2290 | 1962- | 45 |
| **Okstindbreene** | | | | | |
| 27 Charles Rabot Bre | CV020 | 1.1 | 1090-1760 | 1970-73 | 4 |
| 28 Austre Okstindbre | CW002/CW003 | 14.0 | 730-1750 | 1987-96 | 10 |
| **Svartisen** | | | | | |
| 29 Høgtuvbreen | C2019 | 2.6 | 590-1170 | 1971-77 | 7 |
| 30 Svartisheibreen | CX009 | 5.5 | 770-1420 | 1988-94 | 7 |
| 31 Engabreen | C4011 | 39.6 | 10-1575 | 1970- | 37 |
| 32 Storglombreen | C7013/C7014 | 59.0<br>62.4 | 520-1580<br>520-1580 | 1985-88<br>2000-05 | 10 |
| 33 Tretten-null-tobreen | C7016 | 4.3 | 580-1260 | 1985-86 | 2 |
| 34 Glombreen | C6003/C6004 | 2.2 | 870-1110 | 1954-56 | 3 |
| 35 Kjølbreen | CX023 | 3.9 | 850-1250 | 1954-56 | 3 |
| 36 Trollbergdalsbreen | DE007 | 1.8<br>1.6 | 900-1375<br>900-1300 | 1970-75<br>1990-94 | 11 |
| **Blåmannsisen** | | | | | |
| 37 Rundvassbreen | DI021/DI022 | 11.6 | 788-1537 | 2002-04 | 3 |
| **Skjomen** | | | | | |
| 38 Blåisen | DZ011 | 2.2 | 850-1200 | 1963-68 | 6 |
| 39 Storsteinsfjellbreen | DW011 | 6.1<br>5.9 | 920-1850<br>970-1850 | 1964-68<br>1991-95 | 10 |
| 40 Cainhavarre | DW034 | 0.7 | 1210-1540 | 1965-68 | 4 |
| **Vest-Finnmark** | | | | | |
| 41 Svartfjelljøkelen | ET001 | 2.7 | 500-1080 | 1978-79 | 2 |
| 42 Langfjordjøkelen | ET008 | 3.7 | 280-1050 | 1989-93, 1996- | 16 |

*A3001/A3003/A3004/A4027/A4028/A4029/A4030

# Appendix C

## Mass balance measurements in Norway – annual results

There are results from 557 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 - 4.5 km² (1997)**

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 |
| 39 | 01 | 1.86 | -3.95 | -2.09 | 12.99 | >1382 |
| 40 | 02 | 3.78 | -5.31 | -1.53 | 11.46 | >1382 |
| 41 | 03 | 2.52 | -5.03 | -2.51 | 8.95 | >1382 |
| 42 | 04 | 3.32 | -3.42 | -0.10 | 8.85 | 1225 |
| 43 | 05 | 4.99 | -4.32 | 0.67 | 9.52 | 1135 |
| 44 | 06 | 2.69 | -5.88 | -3.19 | 6.33 | >1382 |
| Mean 1963-2006 | | 3.71 | -3.56 | 0.14 | | |

**2 Hansebreen - 3.1 km² (1997)**

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 |
| 16 | 01 | 1.71 | -4.43 | -2.72 | -2.45 | >1327 |
| 17 | 02 | 3.51 | -5.44 | -1.93 | -4.38 | >1327 |
| 18 | 03 | 2.45 | -5.12 | -2.67 | -7.05 | >1327 |
| 19 | 04 | 2.87 | -3.38 | -0.51 | -7.56 | 1220 |
| 20 | 05 | 4.52 | -4.61 | -0.09 | -7.65 | 1150 |
| 21 | 06 | 2.45 | -6.43 | -3.98 | -11.63 | >1327 |
| Mean 1986-2006 | | 3.43 | -3.99 | -0.55 | | |

**3 Blomsterskardsbreen - 45.7 km² (1959)**

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (m a.s.l.) |
|---|---|---|---|---|---|---|
| 1 | 1970 | | | | | 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 1971-77 | | | | 0.73 | | |

**4 Bondhusbrea - 10.7 km² (1979)**

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 Breidablikkbrea - 3.6 km$^2$ (1997)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (m a.s.l.) |
|---|---|---|---|---|---|---|
| 1 | 1963 | 1.11 | -2.32 | -1.21 | -1.21 | 1635 |
| 2 | 64 | 1.92 | -1.68 | 0.24 | -0.97 | 1450 |
| 3 | 65 | 1.72 | -2.28 | -0.56 | -1.53 | 1525 |
| 4 | 66 | 1.52 | -3.17 | -1.65 | -3.18 | >1660 |
| 5 | 67 | 3.40 | -2.23 | 1.17 | -2.01 | 1355 |
| 6 | 68 | 3.55 | -2.68 | 0.87 | -1.14 | 1360 |
| 7 | 2003 | 2.08 | -4.35 | -2.27 | -2.27 | >1659 |
| 8 | 04 | 2.21 | -3.16 | -0.95 | -3.22 | 1605 |
| 9 | 05 | 3.09 | -3.37 | -0.28 | -3.50 | 1500 |
| 10 | 06 | 1.49 | -4.43 | -2.94 | -6.44 | >1659 |
| Mean 1963-68 | | 2.20 | -2.39 | -0.19 | | |
| Mean 2003-06 | | 2.22 | -3.83 | -1.61 | | |

### 6 Gråfjellsbrea - 8.9 km$^2$ (1997)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (m a.s.l.) |
|---|---|---|---|---|---|---|
| 1 | 1964 | 1.94 | -1.62 | 0.32 | 0.32 | 1385 |
| 2 | 65 | 2.01 | -2.29 | -0.28 | 0.04 | 1490 |
| 3 | 66 | 1.58 | -2.93 | -1.35 | -1.31 | >1660 |
| 4 | 67 | 3.46 | -2.14 | 1.32 | 0.01 | 1355 |
| 5 | 68 | 3.39 | -2.82 | 0.57 | 0.58 | 1380 |
| 6 | 1974 | 2.11 | -1.53 | 0.58 | 0.58 | 1370 |
| 7 | 75 | 2.53 | -2.28 | 0.25 | 0.83 | 1420 |
| 8 | 2003 | 1.90 | -4.07 | -2.17 | -2.17 | >1659 |
| 9 | 04 | 2.04 | -2.85 | -0.81 | -2.98 | 1565 |
| 10 | 05 | 3.16 | -3.15 | 0.01 | -2.97 | 1460 |
| 11 | 06 | 1.40 | -4.44 | -3.04 | -6.01 | >1659 |
| Mean 1964-68 | | 2.48 | -2.36 | 0.12 | | |
| Mean 1974-75 | | 2.32 | -1.91 | 0.42 | | |
| Mean 2003-06 | | 2.13 | -3.63 | -1.50 | | |

### 7 Blåbreen and Ruklebreen - 4.5 km$^2$ (1959)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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

### 8 Midtre Folgefonna - 8.7 km$^2$ (1959)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 | | |

### 9 Jostefonn - 3.8 km$^2$ (1993)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 | | |

### 10 Vesledalsbreen - 4.2 km$^2$ (1966)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 | | |

### 11 Tunsbergdalsbreen - 50.1 km$^2$ (1964)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 | | |

### 12 Nigardsbreen - 47.8 km$^2$ (1984)

| No. of years | Year | bw (m w.eqv.) | bs | bn (m w.eqv.) | Cum. bn | ELA (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 |
| 40 | 01 | 1.75 | -1.97 | -0.22 | 19.35 | 1560 |
| 41 | 02 | 2.41 | -3.30 | -0.89 | 18.46 | 1715 |
| 42 | 03 | 1.56 | -2.72 | -1.16 | 17.30 | >1960 |
| 43 | 04 | 1.97 | -2.01 | -0.04 | 17.26 | 1530 |
| 44 | 05 | 2.80 | -1.70 | 1.10 | 18.36 | 1395 |
| 45 | 06 | 1.75 | -3.15 | -1.40 | 16.96 | 1850 |
| Mean 1962-2006 | | 2.37 | -1.99 | 0.38 | | |

**13 Store Supphellebreen - 12.0 km$^2$ (1966)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

**14 Austdalsbreen - 11.8 km$^2$ (1988)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 |
| 14 | 01 | 1.04 | -2.66 | -1.62 | 1.36 | >1757 |
| 15 | 02 | 1.91 | -3.92 | -2.01 | -0.65 | >1757 |
| 16 | 03 | 1.60 | -3.94 | -2.34 | -2.99 | >1757 |
| 17 | 04 | 1.60 | -2.56 | -0.96 | -3.95 | 1495 |
| 18 | 05 | 2.85 | -2.66 | 0.19 | -3.76 | 1385 |
| 19 | 06 | 1.32 | -3.38 | -2.06 | -5.82 | >1757 |
| Mean 1988-2006 | | 2.19 | -2.49 | -0.31 | | |

**15 Spørteggbreen - 27.9 km$^2$ (1988)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

**16 Harbardsbreen - 13.2 km$^2$ (1996)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 |
| 5 | 01 | 0.88 | -1.99 | -1.11 | -1.16 | >1960 |
| Mean 1997-2001 | | 1.76 | -2.00 | -0.23 | | |

**17 Rembesdalsskåka - 17.1 km$^2$ (1995)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (m w.eqv.) | | (m w.eqv.) | | (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 | 1425 |
| 39 | 01 | 1.03 | -1.88 | -0.85 | 7.28 | 1760 |
| 40 | 02 | 2.39 | -3.10 | -0.71 | 6.57 | 1750 |
| 41 | 03 | 1.33 | -2.69 | -1.36 | 5.21 | >1860 |
| 42 | 04 | 1.89 | -1.81 | 0.08 | 5.29 | 1670 |
| 43 | 05 | 2.79 | -2.07 | 0.72 | 6.01 | 1590 |
| 44 | 06 | 0.90 | -3.12 | -2.22 | 3.79 | >1860 |
| Mean 1963-2006 | | 2.09 | -2.00 | 0.09 | | |

**18 Midtdalsbreen - 6.7 km$^2$ (1995)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (m w.eqv.) | | (m w.eqv.) | | (m a.s.l.) |
| 1 | 2000 | 2.89 | -1.57 | 1.32 | 1.32 | 1500 |
| 2 | 01 | 1.26 | -1.90 | -0.64 | 0.68 | 1785 |
| Mean 2000-2001 | | 2.08 | -1.74 | 0.34 | | |

**19 Omnsbreen - 1.5 km$^2$ (1969)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (m w.eqv.) | | (m w.eqv.) | | (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 | | |

**20 Tverråbreen - 5.9 km$^2$ ()**

| No. of | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| years | | (m w.eqv.) | | (m w.eqv.) | | (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 | | |

**21 Blåbreen - 3.6 km$^2$ (1961)**

| No. of | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| years | | (m w.eqv.) | | (m w.eqv.) | | (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 | | |

**22 Storbreen - 5.4 km$^2$ (1997)**

| No. of | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| years | | (m w.eqv.) | | (m w.eqv.) | | (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 | -1.20 | 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 | -1.70 | -0.31 | -7.54 | 1770 |
| 25 | 73 | 1.48 | -1.40 | 0.08 | -7.46 | 1705 |
| 26 | 74 | 1.26 | -1.02 | 0.24 | -7.22 | 1630 |
| 27 | 75 | 1.55 | -1.70 | -0.15 | -7.37 | 1760 |
| 28 | 76 | 1.81 | -1.90 | -0.09 | -7.46 | 1740 |
| 29 | 77 | 0.94 | -1.48 | -0.54 | -8.00 | 1840 |
| 30 | 78 | 1.26 | -1.70 | -0.44 | -8.44 | 1815 |
| 31 | 79 | 1.55 | -1.45 | 0.10 | -8.34 | 1700 |
| 32 | 1980 | 0.99 | -2.30 | -1.31 | -9.65 | 1975 |
| 33 | 81 | 1.30 | -1.40 | -0.10 | -9.75 | 1730 |
| 34 | 82 | 1.28 | -1.75 | -0.47 | -10.22 | 1785 |
| 35 | 83 | 1.90 | -1.70 | 0.20 | -10.02 | 1625 |
| 36 | 84 | 1.70 | -2.00 | -0.30 | -10.32 | 1765 |
| 37 | 85 | 1.20 | -1.60 | -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 | 1570 |
| 40 | 88 | 1.45 | -2.40 | -0.95 | -11.67 | 1970 |
| 41 | 89 | 2.30 | -1.10 | 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 | 1605 |
| 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 | 1680 |
| 51 | 99 | 1.67 | -1.91 | -0.24 | -11.03 | 1830 |
| 52 | 2000 | 2.04 | -1.49 | 0.55 | -10.48 | 1650 |
| 53 | 01 | 1.05 | -1.32 | -0.27 | -10.75 | 1845 |
| 54 | 02 | 1.09 | -2.87 | -1.78 | -12.53 | 2075 |
| 55 | 03 | 1.11 | -2.68 | -1.57 | -14.10 | 2025 |
| 56 | 04 | 1.01 | -1.59 | -0.58 | -14.68 | 1855 |
| 57 | 05 | 1.83 | -1.89 | -0.06 | -14.74 | 1795 |
| 58 | 06 | 0.86 | -3.01 | -2.15 | -16.89 | >2100 |
| Mean 1949-2006 | | 1.43 | -1.72 | -0.29 | | |

**23 Vestre Memurubre - 9.0 km$^2$ (1966)**

| No. of | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| years | | (m w.eqv.) | | (m w.eqv.) | | (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 | | |

**24 Austre Memurubre - 8.7 km$^2$ (1966)**

| No. of | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| years | | (m w.eqv.) | | (m w.eqv.) | | (m a.s.l.) |
| 1 | 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 | | |

**25 Hellstugubreen - 3.0 km$^2$ (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 |
| 40 | 01 | 0.85 | -1.21 | -0.36 | -10.67 | 1910 |
| 41 | 02 | 0.96 | -2.37 | -1.41 | -12.08 | 2080 |
| 42 | 03 | 0.71 | -2.23 | -1.52 | -13.60 | 2200 |
| 43 | 04 | 0.65 | -1.49 | -0.84 | -14.44 | 1980 |
| 44 | 05 | 1.34 | -1.63 | -0.29 | -14.73 | 1930 |
| 45 | 06 | 0.73 | -2.74 | -2.01 | -16.74 | >2210 |
| Mean 1962-2006 | | 1.09 | -1.47 | -0.37 | | |

**26 Gråsubreen - 2.3 km$^2$ (1997)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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. |
| 40 | 01 | 0.80 | -0.78 | 0.02 | -9.86 | 2070 |
| 41 | 02 | 0.63 | -2.05 | -1.42 | -11.28 | >2290 |
| 42 | 03 | 0.45 | -1.84 | -1.39 | -12.67 | >2290 |
| 43 | 04 | 0.48 | -0.97 | -0.49 | -13.16 | 2210 |
| 44 | 05 | 0.83 | -1.33 | -0.50 | -13.66 | 2180 |
| 45 | 06 | 0.51 | -2.59 | -2.08 | -15.74 | >2290 |
| Mean 1962-2006 | | 0.76 | -1.11 | -0.35 | | |

**27 Charles Rabots Bre - 1.1 km$^2$ (1965)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

**28 Austre Okstindbre - 14.0 km$^2$ (1962)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

**29 Høgtuvbreen - 2.6 km$^2$ (1972)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

**30 Svartisheibreen - 5.5 km$^2$ (1985)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

**31 Engabreen - 39.6 km$^2$ (2001)**

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 |
| 32 | 01 | 1.05 | -2.58 | -1.53 | 22.65 | >1594 |
| 33 | 02 | 2.89 | -3.48 | -0.59 | 22.06 | 1200 |
| 34 | 03 | 2.41 | -3.00 | -0.59 | 21.47 | 1195 |
| 35 | 04 | 2.92 | -2.10 | 0.82 | 22.29 | 1040 |
| 36 | 05 | 3.31 | -2.42 | 0.89 | 23.18 | 1060 |
| 37 | 06 | 1.73 | -3.16 | -1.43 | 21.75 | 1325 |
| Mean 1970-2006 | | 2.91 | -2.32 | 0.59 | | |

### 32 Storglombreen - 62.4 km$^2$ (1968)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 |
| 6 | 01 | 1.15 | -2.91 | -1.76 | -0.65 | >1580 |
| 7 | 02 | 2.33 | -3.58 | -1.25 | -1.90 | >1580 |
| 8 | 03 | 2.18 | -3.28 | -1.10 | -3.00 | >1580 |
| 9 | 04 | 2.26 | -2.14 | 0.12 | -2.88 | 1075 |
| 10 | 05 | 2.74 | -2.41 | 0.33 | -2.55 | 1060 |
| Mean 1985-88 | | 2.06 | -2.80 | -0.75 | | |
| Mean 2000-05 | | 2.22 | -2.65 | -0.43 | | |

### 33 Tretten-null-tobreen - 4.9 km$^2$ (1968)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 34 Glombreen - 2.2 km$^2$ (1953)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 35 Kjølbreen - 3.9 km$^2$ (1953)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 36 Trollbergdalsbreen - 1.6 km$^2$ (1985)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 37 Rundvassbreen - 11.6 km$^2$ (1998)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (m w.eqv.) | | (m w.eqv.) | | (m a.s.l.) |
| 1 | 2002 | 2.14 | -3.19 | -1.05 | -1.05 | 1320 |
| 2 | 03 | 1.88 | -2.95 | -1.07 | -2.12 | 1360 |
| 3 | 04 | 1.95 | -2.16 | -0.21 | -2.33 | 1260 |
| Mean 2002-04 | | 1.99 | -2.77 | -0.777 | | |

### 38 Blåisen - 2.2 km$^2$ (1960)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 39 Storsteinsfjellbreen - 5.9 km$^2$ (1993)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 40 Cainhavarre - 0.7 km$^2$ (1960)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | |

### 41 Svartfjelljøkelen - 2.7 km$^2$ (1966)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 | | | | |

### 42 Langfjordjøkelen - 3.7 km$^2$ (1994)

| No. of years | Year | bw | bs | bn | Cum. bn | ELA |
|---|---|---|---|---|---|---|
| | | (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 |
| 11 | 01 | 1.36 | -3.64 | -2.28 | -6.58 | >1050 |
| 12 | 02 | 2.19 | -3.73 | -1.54 | -8.12 | >1050 |
| 13 | 03 | 2.44 | -3.51 | -1.07 | -9.19 | >1050 |
| 14 | 04 | 1.69 | -3.61 | -1.92 | -11.11 | >1050 |
| 15 | 05 | 1.88 | -3.14 | -1.26 | -12.37 | 940 |
| 16 | 06 | 1.42 | -3.83 | -2.41 | -14.78 | >1050 |
| Mean 1989-93 | | 2.54 | -2.63 | -0.10 | | |
| Mean 1996-2006 | | 1.96 | -3.30 | -1.34 | | |

Norwegian Water Resources and Energy Directorate
NVE

Norwegian Water Resources and Energy Directorate
Middelthunsgate 29
PB. 5091 Majorstua, N-0301 Oslo Norway

Telephone: +47 22 95 95 95
Telefax: +47 22 95 90 00
Internet: www.nve.no