GLACIER MASS BALANCE BULLETIN

Bulletin No. 11 (2008–2009)

A contribution to

the Global Terrestrial Network for Glaciers (GTN-G)
as part of the Global Terrestrial/Climate Observing System (GTOS/GCOS),

the Division of Early Warning and Assessment and the Global Environment Outlook
as part of the United Nations Environment Programme (DEWA and GEO, UNEP)

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Compiled by

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Edited by

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Cover Page

Freya Glacier on Clavering Island 10 km southeast of the Zackenberg research station at the northeastern coast of Greenland. Photo taken by B. Hynek, 26 August 2009.

PREFACE

In-situ measurements of glacier mass balance constitute a key element in worldwide glacier monitoring as part of global climate-related observation systems. They improve our understanding of the involved processes relating to Earth-atmosphere mass and energy fluxes, and provide quantitative data at high (annual, seasonal, monthly) temporal resolution. Mass balance data is widely used to estimate the glacier contribution to runoff and sea level changes and enable numerical models to be developed for analyzing climate-glacier relationships. Together with more numerous observations of glacier length change and air- and space-borne spatial information on large glacier samples, this helps to increase our process understanding and allows improved quantitative modelling as well as bridging the gap between detailed local studies and global coverage. It also fosters realistic anticipation of possible future developments. The latter includes worst-case scenarios of drastic to even complete deglaciation in many mountain regions of the world as soon as in the next few decades. Changes in glaciers and ice caps are an easily recognized indicator of rapid if not accelerating changes in the energy balance of the Earth's surface and, hence, are also among the most striking features of global climate change. The general losses in length, area, thickness and volume of firn and ice can be visually detected and qualitatively understood by everyone. Numeric values and comprehensive analysis, however, must be provided by advanced science: while the initial phases following the cold centuries of the Little Ice Age were most probably related to effects from natural climate variability, anthropogenic influences have increased over the past decades to such an extent that – for the first time in history – continued shrinking of glaciers and ice caps may have been brought about primarily by human impacts on the atmosphere.

International assessments such as the periodical reports of the Intergovernmental Panel on Climate Change (IPCC), the Cryosphere Theme Report of the WMO Integrated Global Observing Strategy (IGOS 2007) or various GCOS/ GTOS reports (for instance, the recently updated implementation plan for the Global Observing System for Climate in support of the UNFCCC; GCOS 2010) clearly recognize glacier changes as high-confidence climate indicators and as a valuable element of early detection strategies. The report on *Global Glacier Changes – facts and figures* recently published by the WGMS under the auspices of the UNEP (WGMS 2008) presents a corresponding overview and detailed background information. Glacier changes in the perspective of global cryosphere evolution is treated in the *Global Outlook for Ice and Snow* issued by the UNEP (2007).

In order to further document the evolution and to clarify the physical processes and relationships involved in glacier changes, the World Glacier Monitoring Service (WGMS) of the International Association for the Cryospheric Sciences/International Union of Geodesy and Geophysics (IACS/IUGG) as one of the permanent services of the World Data System within the International Council of Science (WDS/ICSU) regularly collects and publishes standardized glacier data. This long-term activity is a contribution to the Global Climate/Terrestrial Observing System (GCOS/GTOS), to the Division of Early Warning and Assessment and the Global Environment Outlook as part of the United Nations Environment Programme (DEWA and GEO, UNEP), as well as to the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO). In close cooperation with the Global Land Ice Measurement from Space (GLIMS) initiative and the U.S. National Snow and Ice Data Center (NSIDC) at Boulder, Colorado, an integrated and multi-level strategy within the Global Terrestrial Network for Glaciers (GTN-G) of GTOS is used to combine in-situ observations with remotely sensed data, process understanding with global coverage, and traditional measurements with new technologies. This approach, the Global hierarchical Observing Strategy (GHOST), applies observations in a system of tiers (cf. Haeberli et al. 2000, GTOS 2009). Tier 2 includes detailed glacier mass balance measurements within major climatic zones for improved process understanding and calibration of numerical models. Tier 3 uses cost-saving methodologies to determine regional glacier volume change within major mountain systems. The mass balance data compilation of the WGMS – a network of, at present, about 110 glaciers in 25 countries/regions, representing tiers 2 and 3 – is published in the form of the bi-annual *Glacier Mass Balance Bulletin* as well as annually in electronic form (www.wgms.ch). Such a sample of glaciers provides information on presently observed rates of change in glacier mass as well as their regional distribution patterns and acceleration trends as an independent climate proxy.

The publication of standardized glacier mass balance data in the *Glacier Mass Balance Bulletin* is restricted to measurements which are based on the direct glaciological method (cf. Østrem and Brugman 1991) and requested to be compared, and if necessary, adjusted to geodetic surveys repeated at about decadal time intervals. In accordance with an agreement made with the international organizations and countries involved, preliminary glacier mass balance values are made available on the WGMS homepage (www.wgms.ch) one year after the end of the measurement period. This internet homepage also contains issues of the *Glacier Mass Balance Bulletin* past and present, as well as explanations of the monitoring strategy.[1)]

The *Glacier Mass Balance Bulletin* series was designed at the beginning of the 1990s based on recommendations by an ICSI/IAHS (now IACS/IUGG) working group in order to speed up and facilitate access to information on glacier mass balances by reporting measured values from selected 'reference' glaciers at 2-year intervals. The results of glacier mass balance measurements are made more easily understandable for non-specialists through the use of graphic illustrations in addition to numerical data. The *Glacier Mass Balance Bulletin* complements the publication series *Fluctuations of Glaciers*, where the full collection of digital data, including geodetic volume changes and the more numerous observations of glacier length variation, can be found. It should also be kept in mind that this rapid and somewhat preliminary reporting of mass balance measurements may require slight correction and updating at a later time which can then be found in the *Fluctuations of Glaciers* series, available in digital format from the WGMS.

The present *Glacier Mass Balance Bulletin* reporting the results from the balance years 2007/08 and 2008/09 is the eleventh issue in this long-term series of publications. It marks both a change and a continuation at the same time. Exactly 20 years and ten bulletins after the *Glacier Mass Balance Bulletin* was initially published, the present issue is the first to be edited under the leadership of the new WGMS Director. It continues the well-established tradition of building up a strong data basis for scientific assessments of global glacier changes and related impacts, and solidly documents the joint efforts of the WGMS scientific collaboration network to improve and extend the long-term monitoring of an essential climate variable.

Special thanks are extended to our immediate-past Director Wilfried Haeberli and his co-workers of recent decades for their long-term commitment, and to all those who have helped to build up the database which, despite its limitations, nevertheless remains an indispensable treasure of international snow and ice research, readily available to the scientific community as well as to a vast public.

Zurich, 2011

Michael Zemp
Director, World Glacier Monitoring Service

[1)] The following series of reports on the variations of glaciers in time and space has already been published by the WGMS and its predecessor, the Permanent Service on the Fluctuations of Glaciers (PSFG):

- Fluctuations of Glaciers 1959–1965 (Vol. 1, P. Kasser)
- Fluctuations of Glaciers 1965–1970 (Vol. 2, P. Kasser)
- Fluctuations of Glaciers 1970–1975 (Vol. 3, F. Müller)
- Fluctuations of Glaciers 1975–1980 (Vol. 4, W. Haeberli)
- Fluctuations of Glaciers 1980–1985 (Vol. 5, W. Haeberli and P. Müller)
- Fluctuations of Glaciers 1985–1990 (Vol. 6, W. Haeberli and M. Hoelzle)
- Fluctuations of Glaciers 1990–1995 (Vol. 7, W. Haeberli, M. Hoelzle, S. Suter and R. Frauenfelder)
- Fluctuations of Glaciers 1995–2000 (Vol. 8, W. Haeberli, M. Zemp, R. Frauenfelder, M. Hoelzle and A. Kääb)
- Fluctuations of Glaciers 2000–2005 (Vol. 9, W. Haeberli, M. Zemp, A. Kääb, F. Paul and M. Hoelzle)

- Glacier Mass Balance Bulletin No. 1, 1988–1989 (W. Haeberli and E. Herren)
- Glacier Mass Balance Bulletin No. 2, 1990–1991 (W. Haeberli, E. Herren and M. Hoelzle)
- Glacier Mass Balance Bulletin No. 3, 1992–1993 (W. Haeberli, M. Hoelzle and H. Bösch)
- Glacier Mass Balance Bulletin No. 4, 1994–1995 (W. Haeberli, M. Hoelzle and S. Suter)
- Glacier Mass Balance Bulletin No. 5, 1996–1997 (W. Haeberli, M. Hoelzle and R. Frauenfelder)
- Glacier Mass Balance Bulletin No. 6, 1998–1999 (W. Haeberli, R. Frauenfelder and M. Hoelzle)
- Glacier Mass Balance Bulletin No. 7, 2000–2001 (W. Haeberli, R. Frauenfelder, M. Hoelzle and M. Zemp)
- Glacier Mass Balance Bulletin No. 8, 2002–2003 (W. Haeberli, J. Noetzli, M. Zemp, S. Baumann, R. Frauenfelder and M. Hoelzle)
- Glacier Mass Balance Bulletin No. 9, 2004–2005 (W. Haeberli, M. Hoelzle and M. Zemp)
- Glacier Mass Balance Bulletin No. 10, 2006–2007 (W. Haeberli, I. Gärtner-Roer, M. Hoelzle, F. Paul and M. Zemp)

- World Glacier Inventory – Status 1988 (W. Haeberli, H. Bösch, K. Scherler, G. Østrem and C. C. Wallén)

- Global Glacier Changes: facts and figures (M. Zemp., I. Roer, A. Kääb, M. Hoelzle, F. Paul and W. Haeberli)

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1 INTRODUCTION

The *Glacier Mass Balance Bulletin* reports on two main categories of data: basic information and detailed information. Basic information on specific mass balance, cumulative specific balance, accumulation area ratio and equilibrium line altitude is given for 114 glaciers. Such information provides a regional overview. Additionally, detailed information such as balance maps, balance/altitude diagrams, relationships between accumulation area ratios, equilibrium line altitudes and balance, as well as a short explanatory text with a photograph, is presented for 17 glaciers. These ones are chosen because they have a long and continuous series of direct glaciological measurements taken over many years. These long time series, based on high density networks of stakes and firn pits, are especially valuable for analyzing processes of mass and energy exchange at glacier/atmosphere interfaces and, hence, for interpreting climate/glacier relationships. In order to provide broader-based information on glaciers from all regions worldwide, additional selected glaciers with shorter measurement series have been included.

1.1 GENERAL INFORMATION ON THE OBSERVED GLACIERS

The glaciers for which data is reported in the present bulletin are listed below (Table 1.1, Figure 1.1). Glaciers with long measurement series of 15 years and more are also listed.

Table 1.1: General geographic information on the 114 glaciers for which basic information for the years 2007/08 and/or 2008/09 is reported. Additionally, 22 glaciers with long measument series of 15 or more years are listed.

No.	Glacier Name [1)]	1st/last survey [2)]	Country	Location	Coordinates [3)]	
1	Bahía del Diablo	2000/2009	Antarctica	Antarctic Peninsula	63.82° S	57.43° W
2	Hurd	2002/2009	Antarctica	Antarctic Peninsula	62.68° S	60.40° W
3	Johnsons	2002/2009	Antarctica	Antarctic Peninsula	62.66° S	60.35° W
4	Martial Este	2001/2009	Argentina	Andes Fueguinos	54.78° S	68.40° W
5	Piloto Este	1980/2003	Argentina	Andes Centrales	32.22° S	70.05° W
6	Filleckkees	1964/1980	Austria	Eastern Alps	47.13° N	12.60° E
7	Goldbergkees	1989/2009	Austria	Eastern Alps	47.03° N	12.47° E
8	Hintereisferner	1953/2009	Austria	Eastern Alps	46.80° N	10.77° E
9	Jamtalferner	1989/2009	Austria	Eastern Alps	46.87° N	10.17° E
10	Kesselwandferner	1953/2009	Austria	Eastern Alps	46.83° N	10.79° E
11	Kleinfleisskees	1999/2009	Austria	Eastern Alps	47.05° N	12.95° E
12	Pasterze	1980/2009	Austria	Eastern Alps	47.10° N	12.70° E
13	Stubacher Sonnblickkees	1959/2009	Austria	Eastern Alps	47.13° N	12.60° E
14	Vernagtferner	1965/2009	Austria	Eastern Alps	46.88° N	10.82° E
15	Wurtenkees	1983/2009	Austria	Eastern Alps	47.03° N	13.00° E
16	Chacaltaya [4)]	1992/2008	Bolivia	Tropical Andes	16.35° S	68.12° W
17	Charquini Sur	2003/2009	Bolivia	Tropical Andes	16.17° S	68.09° W
18	Zongo	1992/2009	Bolivia	Tropical Andes	16.25° S	68.17° W
19	Baby Glacier	1960/2005	Canada	High Arctic	79.43° N	90.97° W
20	Devon Ice Cap NW	1961/2009	Canada	High Arctic	75.42° N	83.25° W
21	Helm	1975/2009	Canada	Coast Mountains	49.97° N	123.00° W
22	Meighen Ice Cap	1976/2009	Canada	High Arctic	79.95° N	99.13° W

No.	Glacier Name [1)]	1st/last survey [2)]	Country	Location	Coordinates [3)]	
23	Peyto	1966/2009	Canada	Rocky Mountains	51.67° N	116.53° W
24	Place	1965/2009	Canada	Coast Mountains	50.43° N	122.60° W
25	Sentinel	1966/1989	Canada	Coast Mountains	49.90° N	122.98° W
26	White	1960/2009	Canada	High Arctic	79.45° N	90.67° W
27	Echaurren Norte	1976/2009	Chile	Central Andes	33.57° S	70.13° W
28	Urumqi Glacier No. 1 [5)]	1959/2009	China	Tien Shan	43.08° N	86.82° E
	– East Branch [5)]	1988/2009	China	Tien Shan	43.08° N	86.82° E
	– West Branch [5)]	1988/2009	China	Tien Shan	43.08° N	86.82° E
29	La Conejera	2006/2009	Colombia	Cordillera Central	4.48° N	75.22° W
30	Antizana 15 Alpha	1995/2009	Ecuador	Eastern Cordillera	0.47° S	78.15° W
31	Argentière	1976/2009	France	Western Alps	45.95° N	6.98° E
32	Gebroulaz	1995/2009	France	Western Alps	45.29° N	6.62° E
33	Ossoue	2002/2009	France	Pyrenees	42.77° N	0.14° W
34	Saint Sorlin	1957/2009	France	Western Alps	45.16° N	6.15° E
35	Sarennes	1949/2009	France	Western Alps	45.13° N	6.13° E
36	Freya	2008/2009	Greenland	North-eastern Greenland	74.39° N	20.83° W
37	Mittivakkat	1996/2009	Greenland	South-eastern Greenland	65.67° N	37.83° W
38	Brúarjökull	1994/2009	Iceland	Eastern Iceland	64.67° N	16.17° W
39	Dyngjujökull	1994/2009	Iceland	Central Northern Iceland	64.67° N	17.00° W
40	Eyjabakkajökull	1994/2009	Iceland	Eastern Iceland	64.65° N	15.58° W
41	Hofsjökull E	1989/2009	Iceland	Central Iceland	64.80° N	18.58° W
42	Hofsjökull N	1988/2009	Iceland	Central Iceland	64.95° N	18.92° W
43	Hofsjökull SW	1990/2009	Iceland	Central Iceland	64.72° N	19.05° W
44	Koeldukvislarjökull	1995/2009	Iceland	Central Iceland	64.58° N	17.83° W
45	Langjökull S. Dome	1997/2009	Iceland	Central Iceland	64.62° N	20.30° W
46	Tungnaárjökull	1994/2009	Iceland	Central Iceland	64.32° N	18.07° W
47	Calderone	2001/2009	Italy	Apennine Mountains	42.47° N	13.62° E
48	Caresèr [6)]	1967/2009	Italy	Central Alps	46.45° N	10.70° E
	Caresèr orientale [6)]	2006/2009	Italy	Central Alps	46.45° N	10.70° E
	Caresèr occidentale [6)]	2006/2009	Italy	Central Alps	46.45° N	10.69° E
49	Ciardoney	1992/2009	Italy	Western Alps	45.52° N	7.39° E
50	Fontana Bianca	1984/2009	Italy	Central Alps	46.48° N	10.77° E
51	Grand Etrèt	2008/2009	Italy	Western Alps	45.47° N	7.21° E
52	Lunga (Vedretta)	2004/2009	Italy	Central Alps	46.46° N	10.61° E
53	Malavalle/ Übeltalferner	2002/2009	Italy	Central Alps	46.95° N	11.12° E
54	Pendente	1996/2009	Italy	Central Alps	46.96° N	11.23° E
55	Vedretta occidentale di Ries	2009/2009	Italy	Eastern Alps	46.90° N	12.09° E
56	Hamaguri Yuki [7)]	1981/2009	Japan	Northern Japanese Alps	36.60° N	137.62° E
57	Igli Tuyuksu	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
58	Manshuk Mametov	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
59	Mayakovskiy	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E

No.	Glacier Name [1)]	1st/last survey [2)]	Country	Location	Coordinates [3)]	
60	Molodezhniy	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
61	Ordzhonikidze	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
62	Partizan	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
63	Shumskiy	1967/1991	Kazakhstan	Dzhungarskiy	45.08° N	80.23° E
64	Ts. Tuyuksuyskiy	1957/2009	Kazakhstan	Tien Shan	43.05° N	77.08° E
65	Visyachiy-1-2	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
66	Zoya Kosmodemya	1976/1990	Kazakhstan	Tien Shan	43.00° N	77.10° E
67	Abramov	1968/1998	Kyrgyzstan	Pamir Alai	39.63° N	71.60° E
68	Golubin	1969/1994	Kyrgyzstan	Tien Shan	42.47° N	74.50° E
69	Kara-Batkak	1957/1998	Kyrgyzstan	Tien Shan	42.10° N	78.30° E
70	Lewis	1979/1996	Kenya	East Africa	0.15° S	37.30° E
71	Brewster	2005/2009	New Zealand	Tititea Mt Aspiring NP	44.08° S	169.44° E
72	Ålfotbreen	1963/2009	Norway	Western Norway	61.75° N	5.65° E
73	Austdalsbreen	1987/2009	Norway	Western Norway	61.80° N	7.35° E
74	Austre Brøggerbreen	1967/2009	Norway	Spitsbergen	78.88° N	11.83° E
75	Blomstølskardsbreen	2007/2009	Norway	South-western Norway	59.97° N	6.35° E
76	Breidablikkbrea	1963/2009	Norway	South-western Norway	60.09° N	6.40° E
77	Elisebreen	2006/2009	Norway	Spitsbergen	78.64° N	12.25° E
78	Engabreen	1970/2009	Norway	Northern Norway	66.65° N	13.85° E
79	Gråfjellsbrea	1964/2009	Norway	South-western Norway	60.10° N	6.40° E
80	Gråsubreen	1962/2009	Norway	Central Norway	61.65° N	8.60° E
81	Hansbreen	1989/2009	Norway	Spitsbergen	77.08° N	15.67° E
82	Hansebreen	1986/2009	Norway	Western Norway	61.75° N	5.68° E
83	Hardangerjøkulen	1963/2009	Norway	Central Norway	60.53° N	7.37° E
84	Hellstugubreen	1962/2009	Norway	Southern Norway	61.57° N	8.43° E
85	Irenebreen	2002/2009	Norway	Spitsbergen	78.65° N	12.10° E
86	Kongsvegen	1987/2009	Norway	Spitsbergen	78.80° N	12.98° E
87	Langfjordjøkelen	1989/2009	Norway	Northern Norway	70.12° N	21.77° E
88	Midtre Lovénbreen	1968/2009	Norway	Spitsbergen	78.88° N	12.07° E
89	Nigardsbreen	1962/2009	Norway	Western Norway	61.72° N	7.13° E
90	Storbreen	1949/2009	Norway	Central Norway	61.57° N	8.13° E
91	Svelgjabreen	2007/2009	Norway	South-western Norway	59.98° N	6.28° E
92	Waldemarbreen	1995/2009	Norway	Spitsbergen	78.67° N	12.00° E
93	Artesonraju	2005/2009	Peru	Cordillera Blanca	8.95° S	77.62° W
94	Yanamarey	2005/2009	Peru	Cordillera Blanca	9.65° S	77.27° W
95	Djankuat	1968/2009	Russia	Northern Caucasus	43.20° N	42.77° E
96	Garabashi	1984/2009	Russia	Northern Caucasus	43.30° N	42.47° E
97	Kozelskiy	1973/1997	Russia	Kamchatka	53.23° N	158.82° E
98	Leviy Aktru	1977/2009	Russia	Altay	50.08° N	87.72° E
99	Maliy Aktru	1962/2009	Russia	Altay	50.08° N	87.75° E
100	No. 125 (Vodopadniy)	1977/2009	Russia	Altay	50.10° N	87.70° E
101	Maladeta	1992/2009	Spain	South Pyrenees	42.65° N	0.63° E
102	Mårmaglaciären	1990/2009	Sweden	Northern Sweden	68.83° N	18.67° E

No.	Glacier Name [1)]	1st/last survey [2)]	Country	Location	Coordinates [3)]	
103	Rabots glaciär	1982/2009	Sweden	Northern Sweden	67.89° N	18.53° E
104	Riukojietna	1986/2009	Sweden	Northern Sweden	68.08° N	18.08° E
105	Storglaciären	1946/2009	Sweden	Northern Sweden	67.90° N	18.57° E
106	Tarfalaglaciären	1986/2009	Sweden	Northern Sweden	67.93° N	18.65° E
107	Basòdino	1992/2009	Switzerland	Western Alps	46.42° N	8.48° E
108	Findelen	2005/2009	Switzerland	Western Alps	46.00° N	7.87° E
109	Gries	1962/2009	Switzerland	Western Alps	46.44° N	8.33° E
110	Limmern	1948/1985	Switzerland	Western Alps	46.82° N	8.98° E
111	Plattalva	1948/1989	Switzerland	Western Alps	46.83° N	8.98° E
112	Pizol	2007/2009	Switzerland	Western Alps	46.97° N	9.4° E
113	Rhone	1885/1983	Switzerland	Western Alps	46.62° N	8.40° E
114	Silvretta	1960/2009	Switzerland	Eastern Alps	46.85° N	10.08° E
115	Blue Glacier	1956/1999	USA	Washington	47.82° N	123.68° W
116	Columbia (2057)	1984/2009	USA	North Cascades	47.97° N	121.35° W
117	Daniels	1984/2009	USA	North Cascades	47.57° N	121.17° W
118	Easton	1990/2009	USA	North Cascades	48.75° N	120.83° W
119	Emmons	2003/2009	USA	Mt Rainier	46.85° N	121.72° W
120	Foss	1984/2009	USA	North Cascades	47.55° N	121.20° W
121	Gulkana	1966/2009	USA	Alaska Range	63.25° N	145.42° W
122	Ice Worm	1984/2009	USA	North Cascades	47.55° N	121.17° W
123	Lemon Creek	1953/2009	USA	Coast Mountains	58.38° N	134.36° W
124	Lower Curtis	1984/2009	USA	North Cascades	48.83° N	121.62° W
125	Lynch	1984/2009	USA	North Cascades	47.57° N	121.18° W
126	Nisqually	2003/2009	USA	Mt Rainier	46.82° N	121.74° W
127	Noisy Creek	1993/2009	USA	Washington	48.67° N	121.53° W
128	North Klawatti	1993/2009	USA	Washington	48.57° N	121.12° W
129	Rainbow	1984/2009	USA	North Cascades	48.80° N	121.77° W
130	Sandalee	1995/2009	USA	Washington	48.42° N	120.80° W
131	Sholes	1990/2009	USA	North Cascades	48.80° N	121.78° W
132	Silver	1993/2009	USA	Washington	48.98° N	121.25° W
133	South Cascade	1953/2009	USA	North Cascades	48.37° N	121.05° W
134	Taku	1946/2009	USA	Coast Mountains	58.55° N	134.13° W
135	Wolverine	1966/2009	USA	Kenai Mountains	60.40° N	148.92° W
136	Yawning	1984/2009	USA	North Cascades	48.45° N	121.03° W

[1)] Countries and glaciers are listed in alphabetical order.
[2)] Years of first and most recent survey available to the WGMS
[3)] Coordinates in decimal notation
[4)] Chacaltaya disappeared entirely in 2009.
[5)] In 1993, Urumqi Glacier No. 1 separated into two parts: East Branch and West Branch.
[6)] In 2005, Caresèr separated into two parts: Caresèr orientale and Caresèr occidentale.
[7)] Perennial snowfield or glacieret

1.2 GLOBAL OVERVIEW MAP

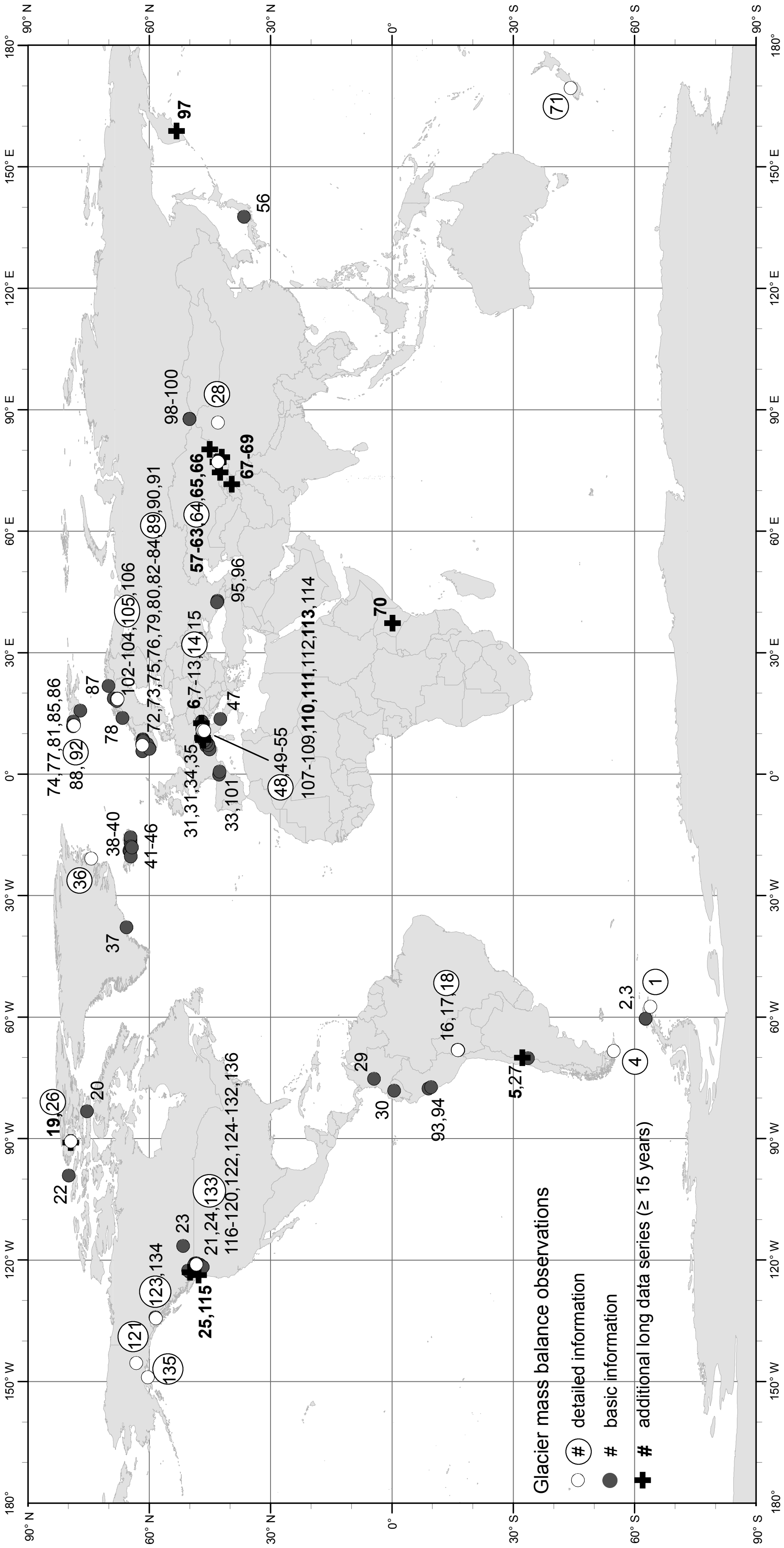


Figure 1.1: Location of the 114 glaciers for which basic information is reported. Additionally, 22 glaciers with long measument series of 15 or more years are marked.

2 BASIC INFORMATION

Specific mass balance (b), equilibrium line altitude (ELA) and accumulation area ratio (AAR) from the balance years 2007/08 and 2008/09 are presented in the table in Part 2.1. ELAs above and below the glacier elevation range are marked by > and <, respectively. In these cases, the value given is the glacier max/min elevation. The AAR values are given as integer values only.

Values for ELA_0 and AAR_0 are also listed. They represent the calculated ELA and AAR values for a zero mass balance, i.e., a hypothetical steady state. All values since the beginning of mass balance measurement-taking were used for this calculation on each glacier. Minimum sample size for regression was defined as six ELA or AAR values. In extreme years some of the observed glaciers can become entirely ablation or accumulation areas. Corresponding AAR values of 0 or 100 % as well as ELA values outside the altitude range of the observed glaciers were excluded from the calculation of AAR_0 and ELA_0 values. For the glaciers with detailed information, the corresponding graphs (AAR and ELA vs. specific mass balance) are given in Chapter 3.

The graphs in the second part (2.2), present the development of cumulative specific mass balance over the whole observation period for each glacier where three or more mass balances were reported, and the years 2007/08 or 2008/09 are included. For each country, the cumulative balances are plotted in a single graph. For countries with more than six glaciers, the cumulative balances were plotted in several graphs, which were split into groups of glaciers from the same region, similar glacier types or alphabetically separated groups. Some of the time series have data gaps and hence have to be interpreted with care. In these cases, the overall ice loss cannot be derived from the cumulative specific mass balance graphs and has to be determined by other means, such as geodetic methods. Generally, for glaciers with data gaps longer than one-fifth of the measurement time series, the cumulative balance has been plotted for the measurements taken after the most recent data gap only.

2.1 SUMMARY TABLE (MASS BALANCE, ELA, ELA_0, AAR, AAR_0)

Name	Country	b08 [mm w.e.]	b09 [mm w.e.]	ELA08 [m a.s.l.]	ELA09 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR08 [%]	AAR09 [%]	AAR_0 [%]
Bahía del Diablo	Antarctica	− 530	− 255	430	395	369	33	43	49
Hurd	Antarctica	+ 190	− 390	185	250	217	69	34	51
Johnsons	Antarctica	+ 90	− 170	180	210	192	67	37	58
Martial Este	Argentina	− 56	− 119	1074	1078	1078	56	51	56
Goldbergkees	Austria	− 651	− 542	> 3050	2975	2929	20	21	44
Hintereisferner	Austria	− 1235	− 1182	3276	3257	2907	22	25	66
Jamtalferner	Austria	− 981	− 953	> 3200	3113	2771	9	10	58
Kesselwandferner	Austria	− 444	− 795	3224	3252	3115	42	28	69
Kleinfleisskees	Austria	− 623	− 403	3020	2875	2844	24	26	63
Pasterze	Austria	− 1412	− 1120	> 3600	2960	—	16	45	—
Stubacher Sonnblickkees	Austria	− 777	− 254	2890	2780	2741	23	48	59
Vernagtferner	Austria	− 843	− 959	3289	3347	3079	17	14	66
Wurtenkees	Austria	− 938	− 584	> 3100	2950	2898	15	33	36
Chacaltaya [1)]	Bolivia	− 1549	—	> 5374	—	—	0	—	—
Charquini Sur	Bolivia	+ 161	− 1616	5096	—	—	93	—	—
Zongo	Bolivia	+ 257	− 631	5148	5363	5229	77	55	68

Name	Country	b08 [mm w.e.]	b09 [mm w.e.]	ELA08 [m a.s.l.]	ELA09 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR08 [%]	AAR09 [%]	AAR_0 [%]
Devon Ice Cap NW	Canada	− 394	− 523	1594	1470	1007	—	—	71 [2)]
Helm	Canada	− 2300	− 510	2125	2010	1999	2	12	36
Meighen Ice Cap	Canada	− 705	− 676	—	—	—	—	—	—
Peyto	Canada	− 230	− 1020	2620	2750	2610	41	18	52
Place	Canada	− 490	− 1500	2060	2340	2081	40	5	49
White	Canada	− 817	− 580	1399	1335	912	17	29	71
La Conejera	Colombia	+ 1556	− 2484	4741	4858	—	73	4	—
Echaurren Norte	Chile	− 560	+ 80	—	—	—	—	—	—
Urumqi Glacier No. 1 [3)]	China	− 931	+ 63	4168	3990	4004	17	64	59
− East Branch [3)]	China	− 1046	− 57	4152	3975	3950	10	56	64
− West Branch [3)]	China	− 719	+ 289	4184	4010	4028	31	81	65
Antizana 15 Alpha	Ecuador	+ 337	− 828	4985	5200	5059	85	54	70
Argentière	France	− 1320	− 2650	—	—	—	—	—	—
Gebroulaz	France	− 1050	− 1970	—	—	—	—	—	—
Ossoue	France	− 120	− 1630	3150	> 3200	—	43	7	—
Saint Sorlin	France	− 1810	− 2650	—	—	2863	—	—	—
Sarennes	France	− 2340	− 3900	—	—	—	—	—	—
Freya	Greenland	− 510	− 466	1030	830	—	14	41	—
Mittivakkat	Greenland	− 520	− 1010	—	—	—	41	18	58
Brúarjökull	Iceland	− 503	− 122	—	1225	1200	—	59	61
Dyngjujökull	Iceland	− 24	+ 227	—	1315	—	—	64	—
Eyjabakkajökull	Iceland	− 1282	− 507	—	1140	1077	—	42	55
Hofsjökull E	Iceland	− 790	− 170	—	1170	1196	—	50	53
Hofsjökull N	Iceland	− 570	− 350	—	1280	1263	—	49	50
Hofsjökull SW	Iceland	− 930	− 350	—	1290	1266	—	54	48
Koeldukvislarjökull	Iceland	− 587	− 134	—	1360	1311	—	57	59
Langjökull S. Dome	Iceland	− 1842	− 362	—	1050	997	—	50	57
Tungnaárjökull	Iceland	− 1340	− 809	—	1225	1142	—	48	61
Calderone	Italy	+ 275	+ 401	—	—	—	75	86	—
Caresèr [4)]	Italy	− 1851	− 1236	> 3277	3260	3095	0	1	44
Caresèr orientale [4)]	Italy	− 1884	− 1276	> 3274	> 3274	—	0	0	—
Caresèr occidentale [4)]	Italy	− 1560	− 846	> 3277	3250	—	0	5	—
Ciardoney	Italy	− 1510	− 490	> 3150	3100	2983	0	15	54
Fontana Bianca	Italy	− 1246	− 622	> 3400	3250	3254	0	9	54
Grand Etrèt	Italy	− 1363	+ 373	3050	—	—	13	76	—
Lunga (Vedretta)	Italy	− 1637	− 998	3320	3285	—	8	16	—
Malavalle/Übeltalferner	Italy	− 900	− 517	3223	3050	2964	9	36	50
Pendente	Italy	− 1484	− 844	> 3104	2966	2822	0	7	45
Vedretta occidentale di Ries	Italy	—	− 612	—	3100	—	—	17	—
Hamaguri Yuki [5)]	Japan	+ 1580	− 3188	—	—	—	—	—	—
Ts. Tuyuksuyskiy	Kazakhstan	− 1357	+ 206	3980	3710	3746	22	66	53
Brewster	New Zealand	− 1653	− 828	> 2390	2034	—	10	26	—
Ålfotbreen	Norway	+ 680	− 170	1130	1240	1200	79	48	57
Austdalsbreen	Norway	− 70	− 700	1420	1475	1422	71	56	66
Austre Brøggerbreen	Norway	− 127	− 246	341	389	286	25	16	49
Blomstølskardsbreen	Norway	+ 1330	+ 1070	1265	1290	—	85	84	—
Breidablikkbrea	Norway	− 300	− 520	1515	1565	1477	44	30	—
Elisebreen	Norway	− 172	− 579	352	385	—	58	42	—
Engabreen	Norway	+ 310	− 30	1093	1170	1156	77	63	60
Gråfjellsbrea	Norway	− 140	− 540	1490	1540	1460	56	31	—
Gråsubreen	Norway	+ 80	− 280	—	2235	2084	—	7	40
Hansbreen	Norway	+ 149	− 844	300	400	303	66	25	58

Name	Country	b08 [mm w.e.]	b09 [mm w.e.]	ELA08 [m a.s.l.]	ELA09 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR08 [%]	AAR09 [%]	AAR_0 [%]
Hansebreen	Norway	+ 260	− 970	1125	> 1327	1157	64	0	56
Hardangerjøkulen	Norway	+ 450	+ 150	1610	1655	1678	82	79	68
Hellstugubreen	Norway	− 60	− 230	1880	1920	1840	57	42	58
Irenebreen	Norway	− 357	− 630	396	489	344	31	6	42
Kongsvegen	Norway	+ 418	− 78	434	552	537	67	40	48
Langfjordjøkelen	Norway	− 350	− 1320	835	> 1050	722	53	0	64
Midtre Lovénbreen	Norway	− 9	− 138	331	366	299	38	29	55
Nigardsbreen	Norway	+ 1100	+ 240	1325	1465	1556	91	80	60
Storbreen	Norway	+ 110	− 220	1770	1760	1718	51	53	59
Svelgjabreen	Norway	+ 720	+ 360	1235	1310	—	74	64	—
Waldemarbreen	Norway	− 322	− 649	357	412	273	31	16	47
Artesonraju	Peru	+ 471	− 658	—	—	—	—	—	—
Yanamarey	Peru	+ 89	− 532	—	—	—	—	—	—
Djankuat	Russia	+ 100	− 120	—	—	3189	—	—	56
Garabashi	Russia	− 423	− 371	3870	3860	3791	50	52	60
Leviy Aktru	Russia	− 810	+ 470	—	3050	3161	—	67	61
Maliy Aktru	Russia	− 870	+ 590	—	3040	3155	—	82	70
No. 125 (Vodopadniy)	Russia	− 720	+ 380	—	3120	3202	—	85	68
Maladeta	Spain	− 38	− 1415	3100	> 3150	3063	34	0	40
Mårmaglaciären	Sweden	+ 120	− 1390	1600	1640	1600	43	15	33
Rabots glaciär	Sweden	+ 350	− 500	1380	1430	1376	43	36	49
Riukojietna	Sweden	− 590	− 720	> 1440	1440	1330	0	2	55
Storglaciären	Sweden	+ 580	− 530	1410	1495	1463	53	37	45
Tarfalaglaciären	Sweden	− 200	− 1710	1590	> 1790	—	30	0	—
Basòdino	Switzerland	− 1168	+ 130	3100	2750	2869	2	70	51
Findelen	Switzerland	− 300	+ 100	3240	3175	—	62	69	—
Gries	Switzerland	− 1601	− 883	3125	3134	2820	5	3	56
Pizol	Switzerland	− 731	− 1220	> 2786	> 2786	—	9	0	—
Silvretta	Switzerland	− 639	− 1097	2855	2995	2759	31	6	55
Columbia (2057)	USA	+ 960	− 900	1630	1640	—	86	37	65
Daniels	USA	+ 410	− 1350	—	—	—	76	28	58
Easton	USA	+ 450	− 2060	2125	2200	—	74	38	64
Emmons	USA	− 630	− 1800	2800	3770	—	36	—	—
Foss	USA	+ 180	− 2020	—	—	—	72	12	65
Gulkana	USA	− 180	− 720	1707	1789	1723	68	64	64
Ice Worm	USA	− 100	− 1560	—	—	—	60	35	62
Lemon Creek	USA	+ 778	− 700	900	1060	1009	80	64	70
Lower Curtis	USA	+ 120	− 2150	1710	1675	—	66	20	63
Lynch	USA	+ 510	− 1820	—	—	—	76	25	66
Nisqually	USA	− 1080	− 1640	3100	3110	—	25	—	—
Noisy Creek	USA	− 290	− 1190	1830	> 1920	1804	20	0	46
North Klawatti	USA	− 220	− 1830	2080	> 2409	2091	70	0	70
Rainbow	USA	+ 650	− 1980	1730	1850	—	80	36	66
Sandalee	USA	− 140	− 650	2175	2550	—	40	—	—
Sholes	USA	+ 200	− 2680	—	1920	—	75	15	64
Silver	USA	+ 260	− 1990	2370	2550	2314	40	—	45
South Cascade	USA	− 290	− 1860	—	> 2150	1905	32	0	52
Taku	USA	+ 950	− 310	800	960	974	90	—	—
Wolverine	USA	+ 880	− 1780	1050	1290	1151	63	42	63
Yawning	USA	+ 480	− 1620	—	—	—	70	30	65

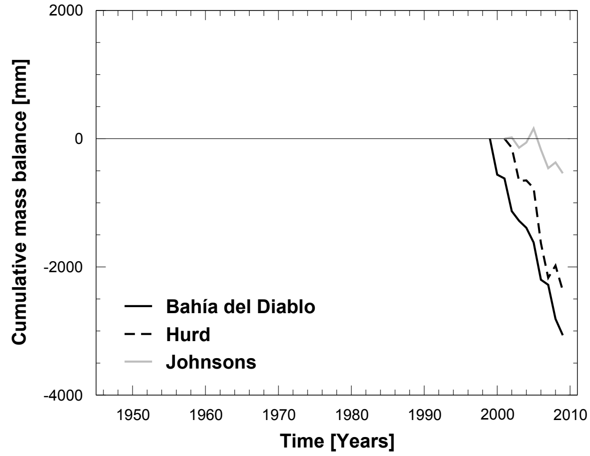
[1] Chacaltaya disappeared entirely in 2009.
[2] Based on AAR values from 1961–1980
[3] In 1993, Urumqi Glacier No. 1 separated into two parts: East Branch and West Branch.
[4] In 2005, Caresèr separated into two parts: Caresèr orientale and Caresèr occidentale.
[5] Perennial snowfield or glacieret

2.2 CUMULATIVE SPECIFIC MASS BALANCE GRAPHS

Note:

- Missing values are marked by gaps in the plotted data series with graphs restarting with the value of the previous available data point.
- Y-axes are scaled according to the data range of the cumulative mass balance graph.
- Glaciological mass balances of Engabreen (Norway) presented here show large deviations when compared with geodetic mass balances, cf. T. Haug et al., Ann. Glaciol. 50, 191−197 (2009). A revision of the mass balance record is planned in 2012.
- Taku Glacier (USA) is currently in the advance state of the tidewater glacier cycle, cf. M. Truffer et al., J. Glaciol. 55, 1052−1060 (2009).

ANTARCTICA



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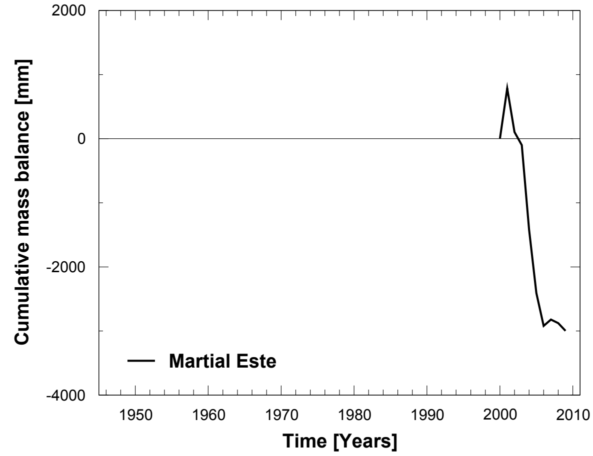

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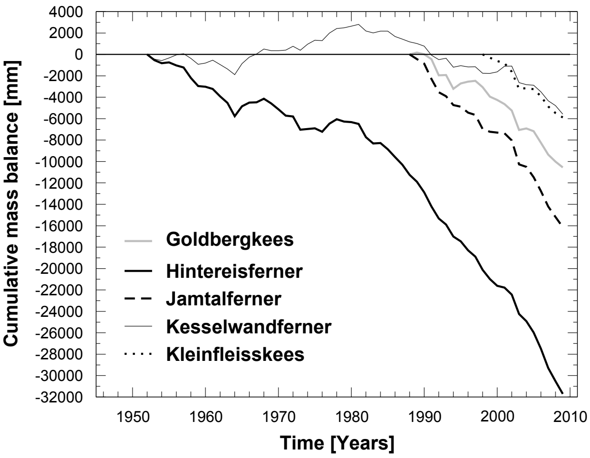
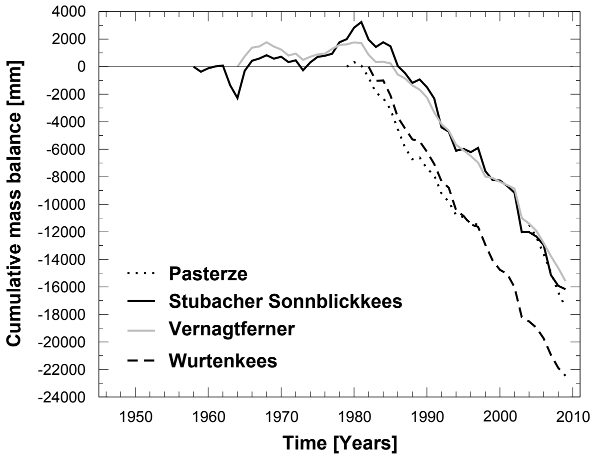


AUSTRIA 2



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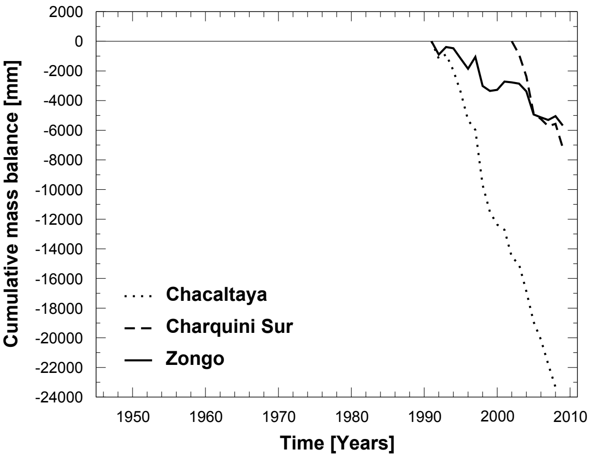

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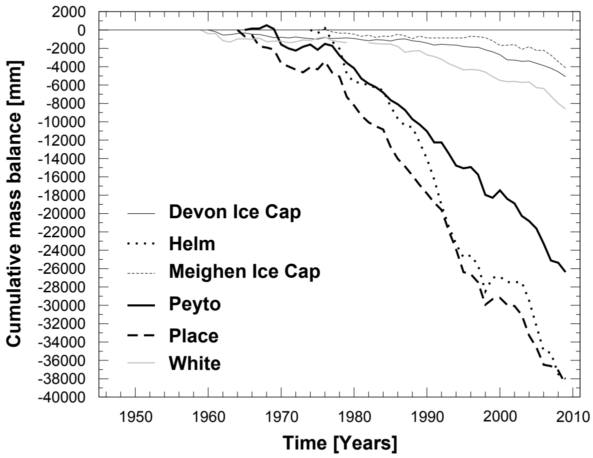

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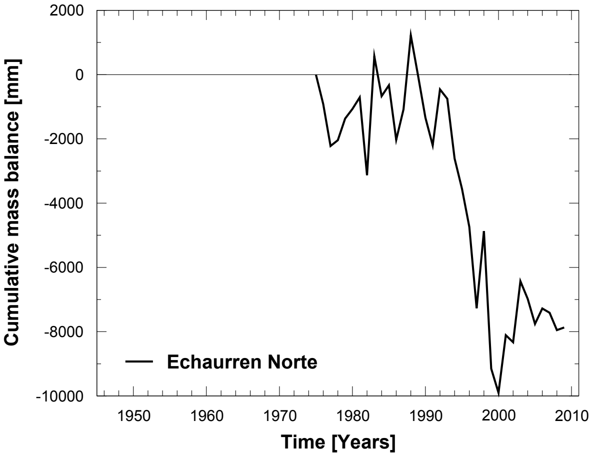

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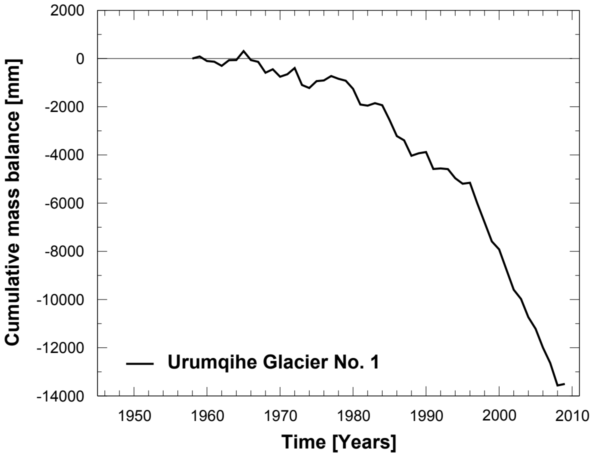

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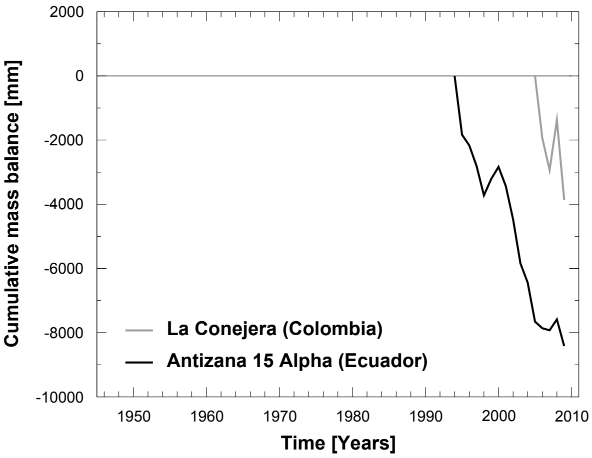

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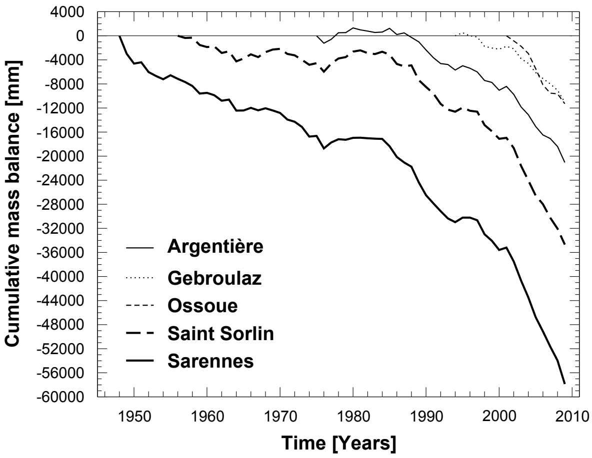

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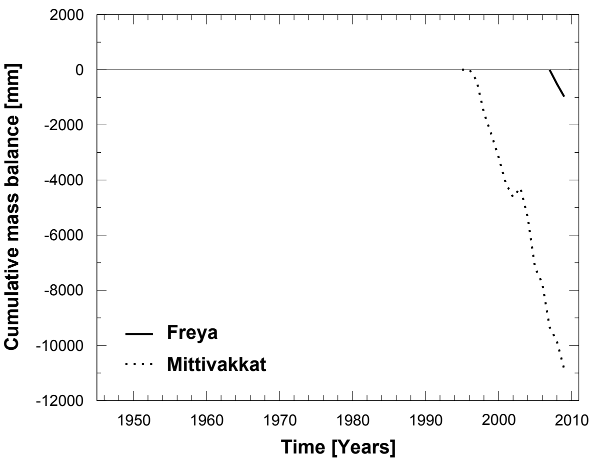

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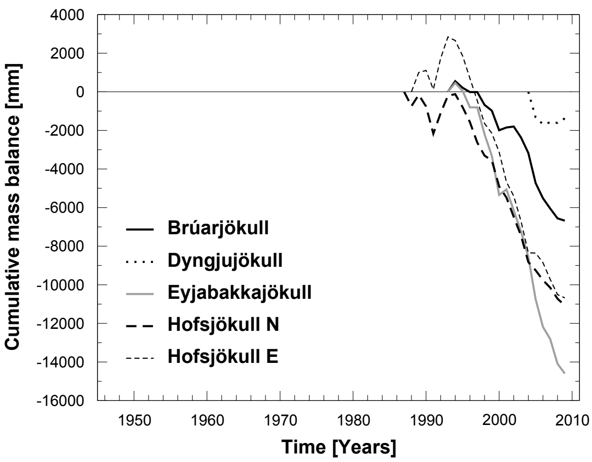

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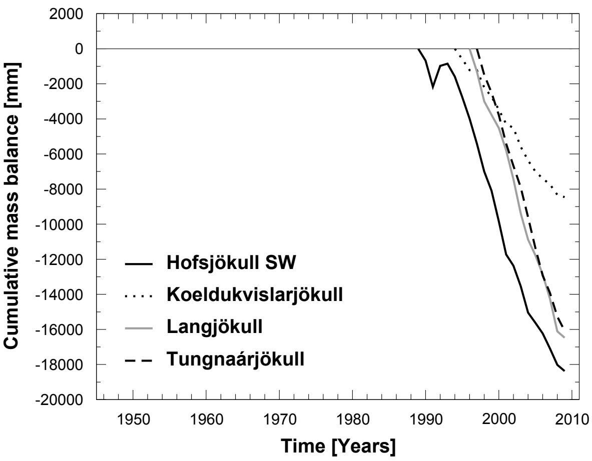

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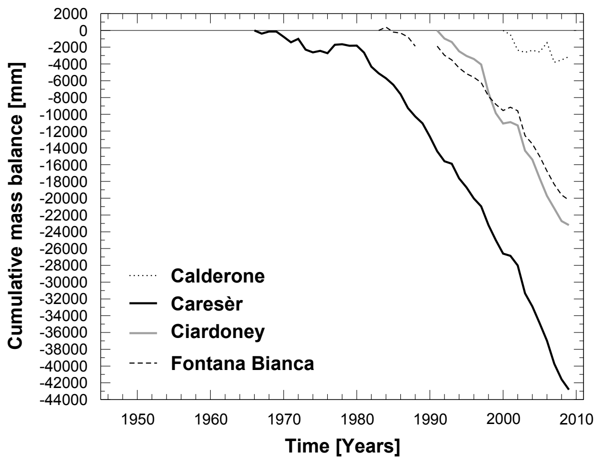

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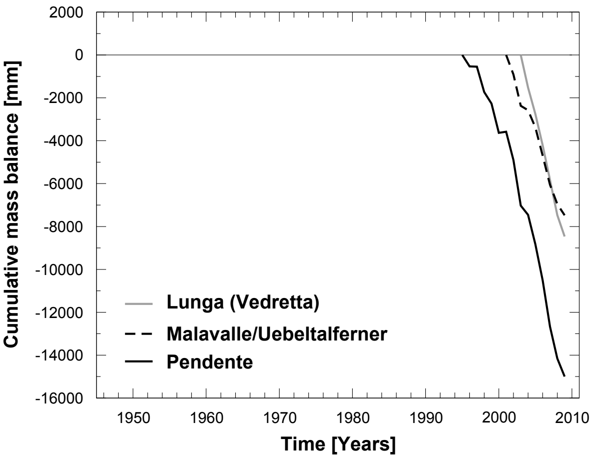

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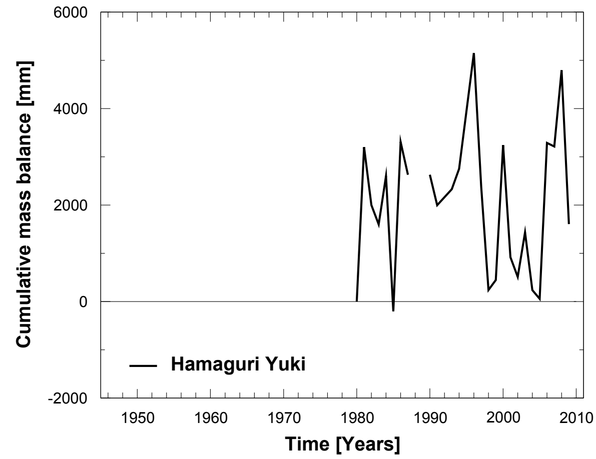

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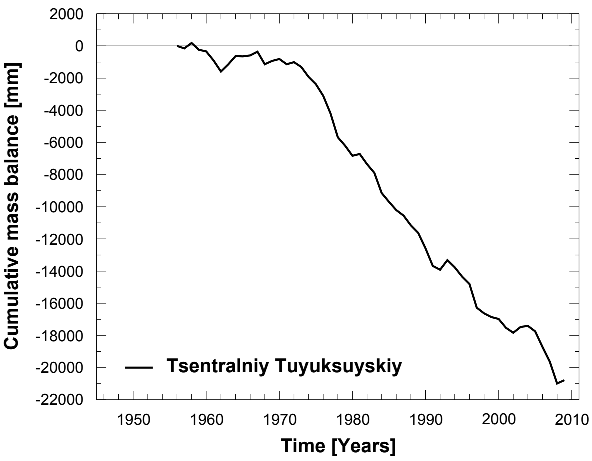
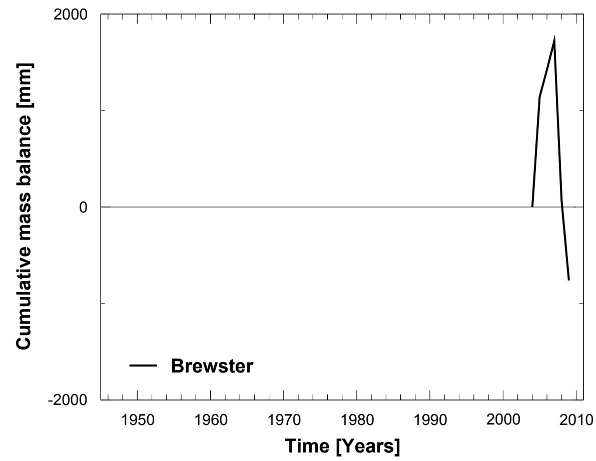


NEW ZEALAND



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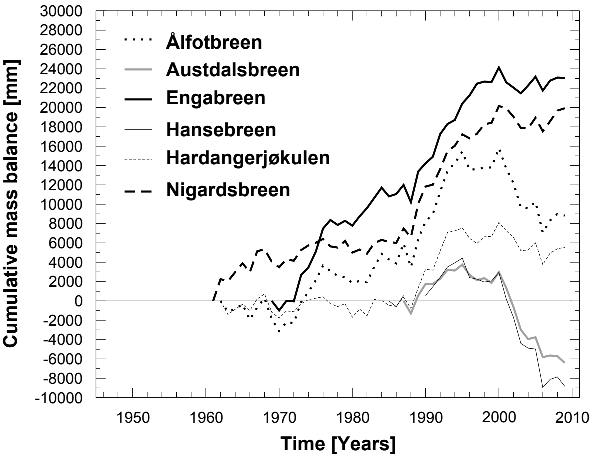

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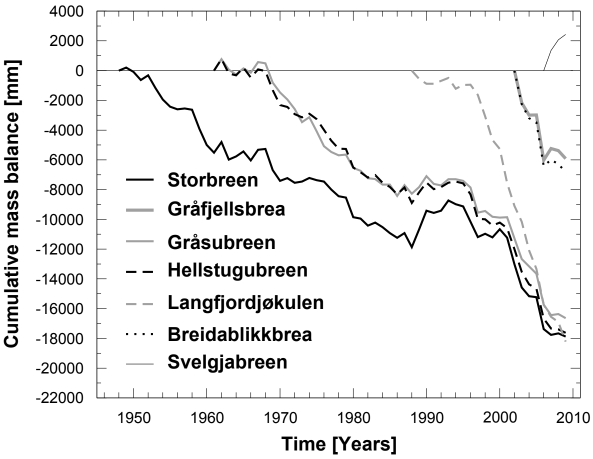

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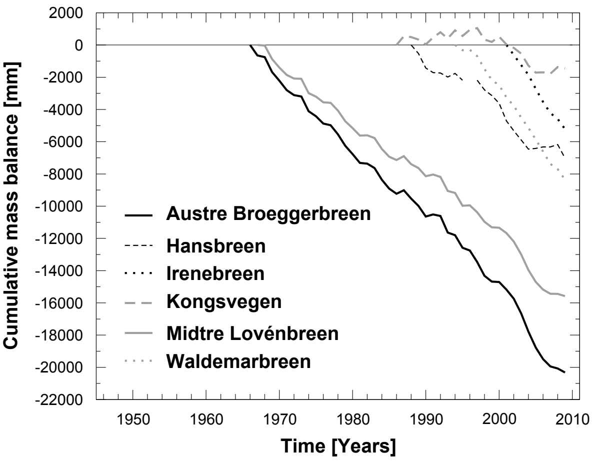

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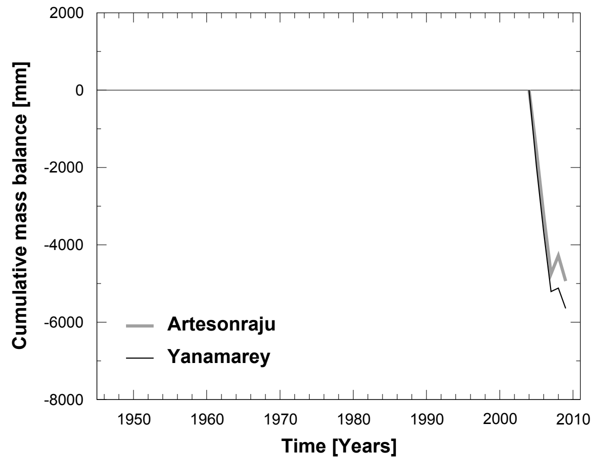

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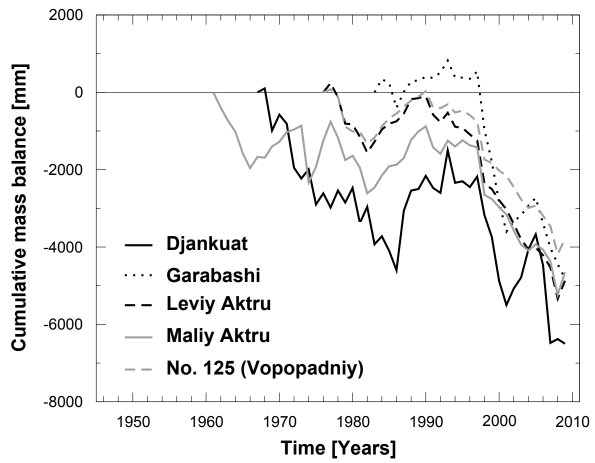

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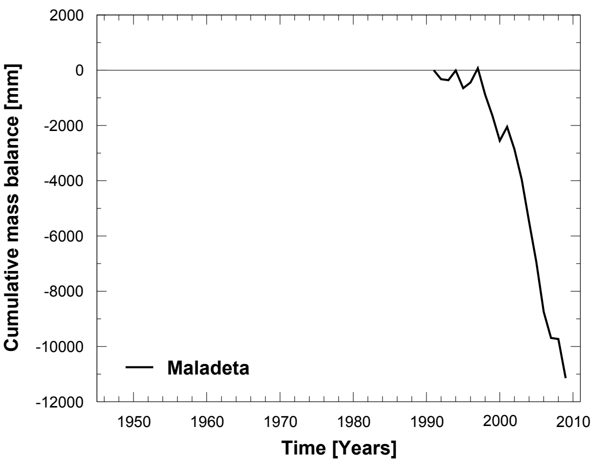
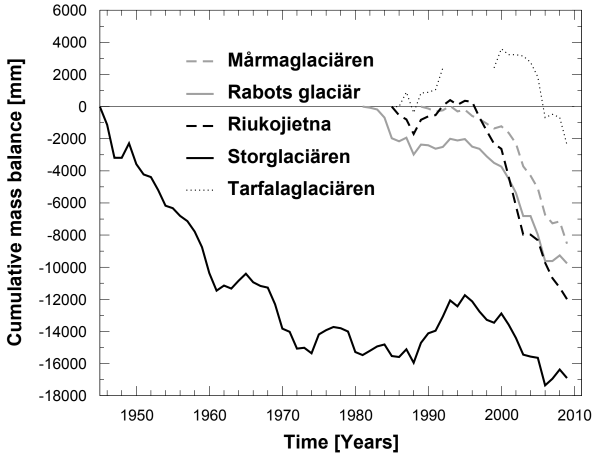
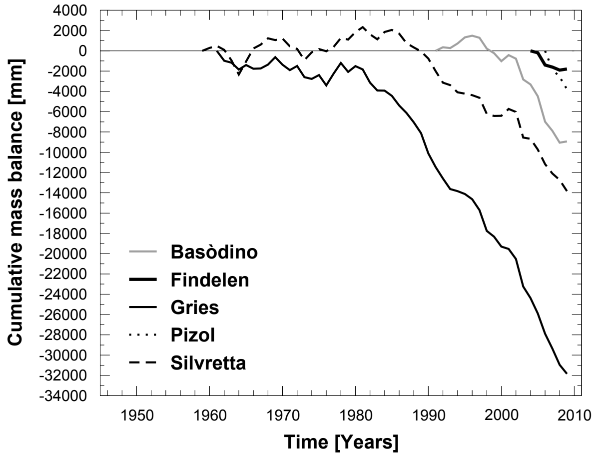


SWEDEN



SWITZERLAND



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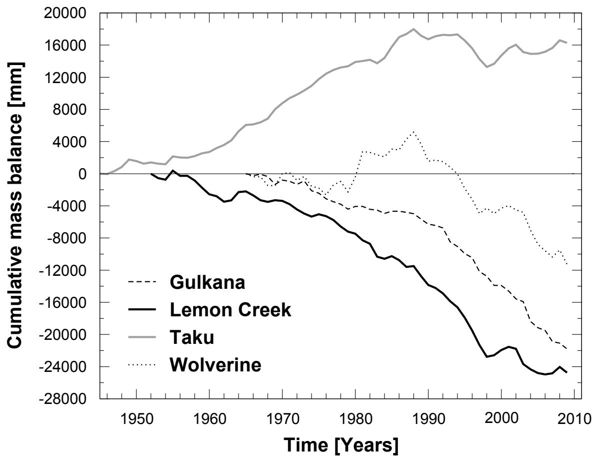

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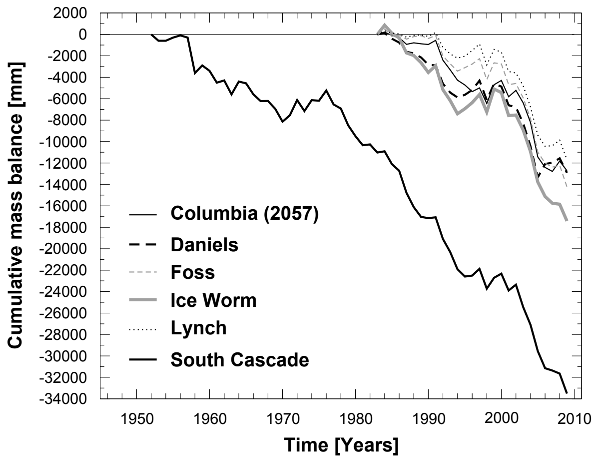

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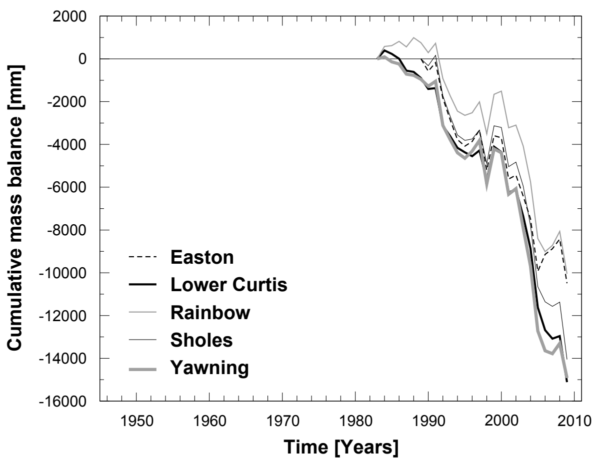
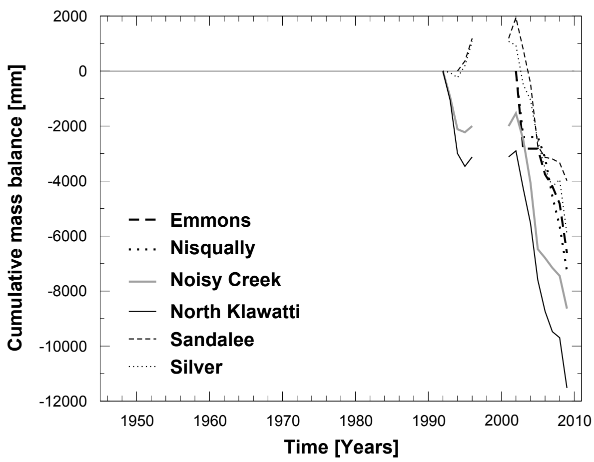


USA (WASHINGTON 3)



3 DETAILED INFORMATION

Detailed information about selected glaciers with ongoing direct glaciological mass balance measurements in various mountain ranges is presented here, in addition to the basic information contained in the previous chapter. In order to facilitate comparison between the individual glaciers, the submitted material (text, maps, graphs and tables) was standardized and rearranged.

The text provides general information on the glacier followed by characteristics of the two reported balance years. General information concerns basic geographic, geometric, climatic and glaciological characteristics of the observed glacier which may help with the interpretation of climate/glacier relationships. A recent oblique photograph showing the glacier is included.

Three maps are presented for each glacier: the first one, a topographic map, shows the stakes, snow pits and snow probing network. This network is basically the same from one year to the next on most glaciers. In cases of differences between the two reported years, the second was chosen, i.e., the network from the year 2008/09. The second and third maps are mass balance maps from the reported years, illustrating the pattern of ablation and accumulation. The accuracy of such mass balance maps depends on the density of the observation network, the complexity of the mass balance distribution and the experience of the local investigators.

A graph of glacier mass balance versus altitude is given for both reported years, overlaid with the corresponding glacier hypsography and point measurements (if available). The relationship between mass balance and altitude – the mass balance gradient – is an important parameter in climate/glacier relationships and represents the climatic sensitivity of a glacier. It constitutes the main forcing function of glacier flow over long time intervals. Therefore, the mass balance gradient near the equilibrium line is often called the ‘activity index’ of a glacier. The glacier hypsography reveals the glacier elevation bands that are most influential for the specific mass balance, and indicates how the specific mass balance changes with a shift of the ELA.

The last two graphs show the relationship between the specific mass balance and the accumulation area ratio (AAR) and the equilibrium line altitude (ELA) for the whole observation period. The linear regression equation is given at the top of both diagrams. The AAR regression equation is calculated using integer values only (in percent). AAR values of 0 or 100 % as well as corresponding ELA values outside the altitude range of the observed glaciers were excluded from the regression analysis. Such regressions were used to determine the AAR_0 and ELA_0 values (cf. Chapter 2). The points from the two reported balance years (2007/08 and 2008/09) are marked in black. Minimum sample size for regression was defined as 6 ELA or AAR values.

3.1 BAHÍA DEL DIABLO (ANTARCTICA/A. PENINSULA)

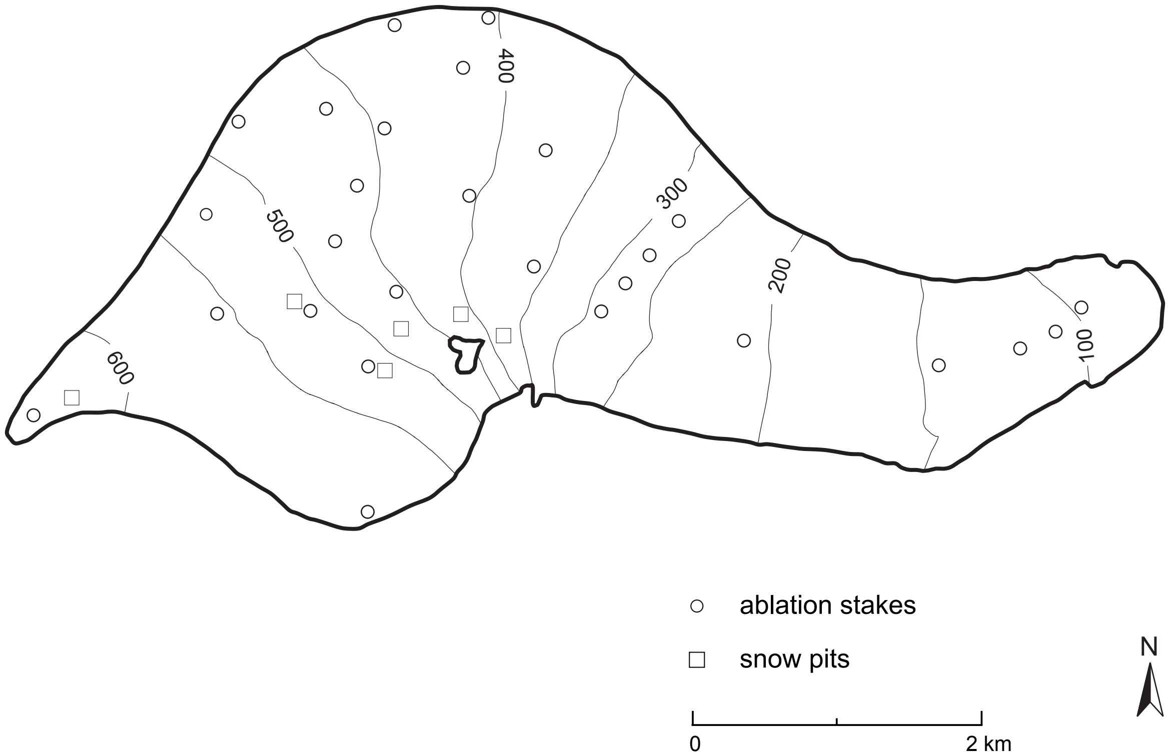
COORDINATES: 63.82° S / 57.43° W

Photo taken by P. Skvarca, 1 March 2005.

This polythermal outlet glacier is located on Vega Island, north-eastern side of the Antarctic Peninsula. The glacier is exposed to the north-east, covers an area of 14.3 km^2 and extends from an altitude of 630 m to 50 m a.s.l. The mean annual air temperature at the equilibrium line around 400 m a.s.l. ranges between −7 and −8 °C. The snout of the glacier overrides an ice-cored moraine over a periglacial plain of continuous permafrost.

Detailed mass balance measurements of this glacier began in austral summer 1999/2000. A simplified version of combined stratigraphic annual mass balance method is applied because the glacier can be visited only once a year. Despite the coldest mean annual temperature of the series (–8.6 °C), the balance year 2007/08 resulted in –530 mm w.e., probably due to a relatively high mean summer air temperature of 1.1 ºC. This is one of the four lowest values recorded since the initiation of measurements. The net budget of balance year 2008/09 was –255 mm w.e., i.e. almost half of the previous year although the mean summer air temperature was very similar (1.0 ºC). However, during this balance year the precipitation increased by about 30 %. The two additional years of detailed mass balance further confirm the strong correlation existing between the annual mass balance, mean summer air temperature and annual precipitation.

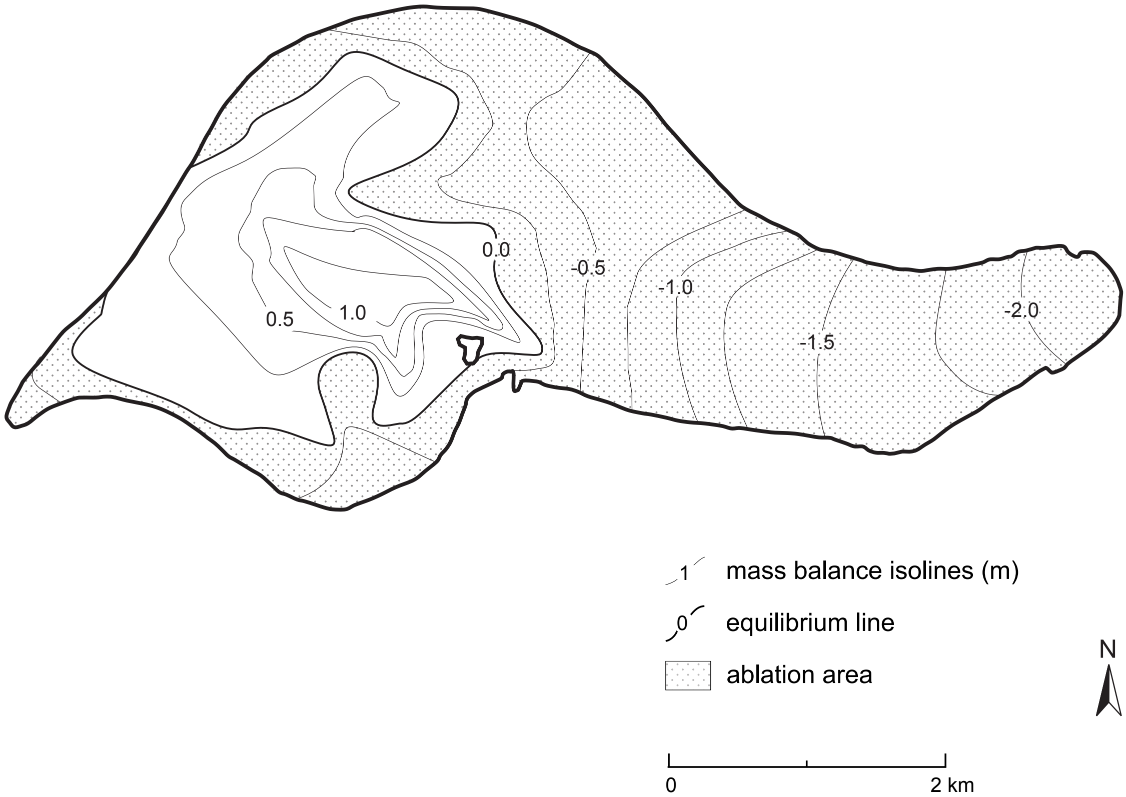
3.1.1 Topography and observation network



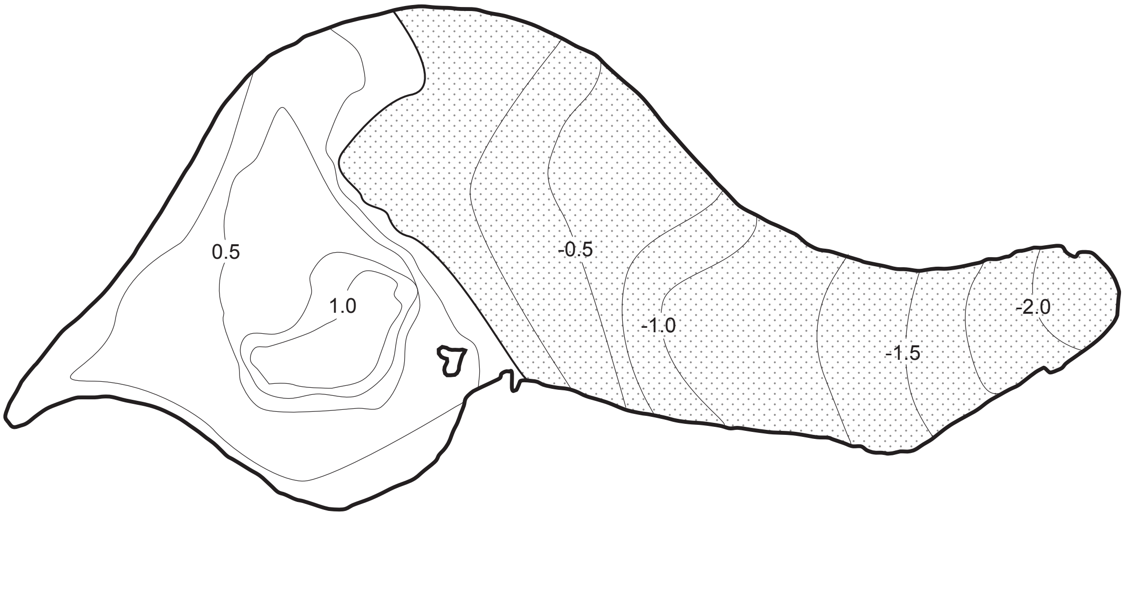
Glaciar Bahía del Diablo (ANTARCTICA)

3.1.2 Mass balance maps 2007/08 and 2008/09

2007/08

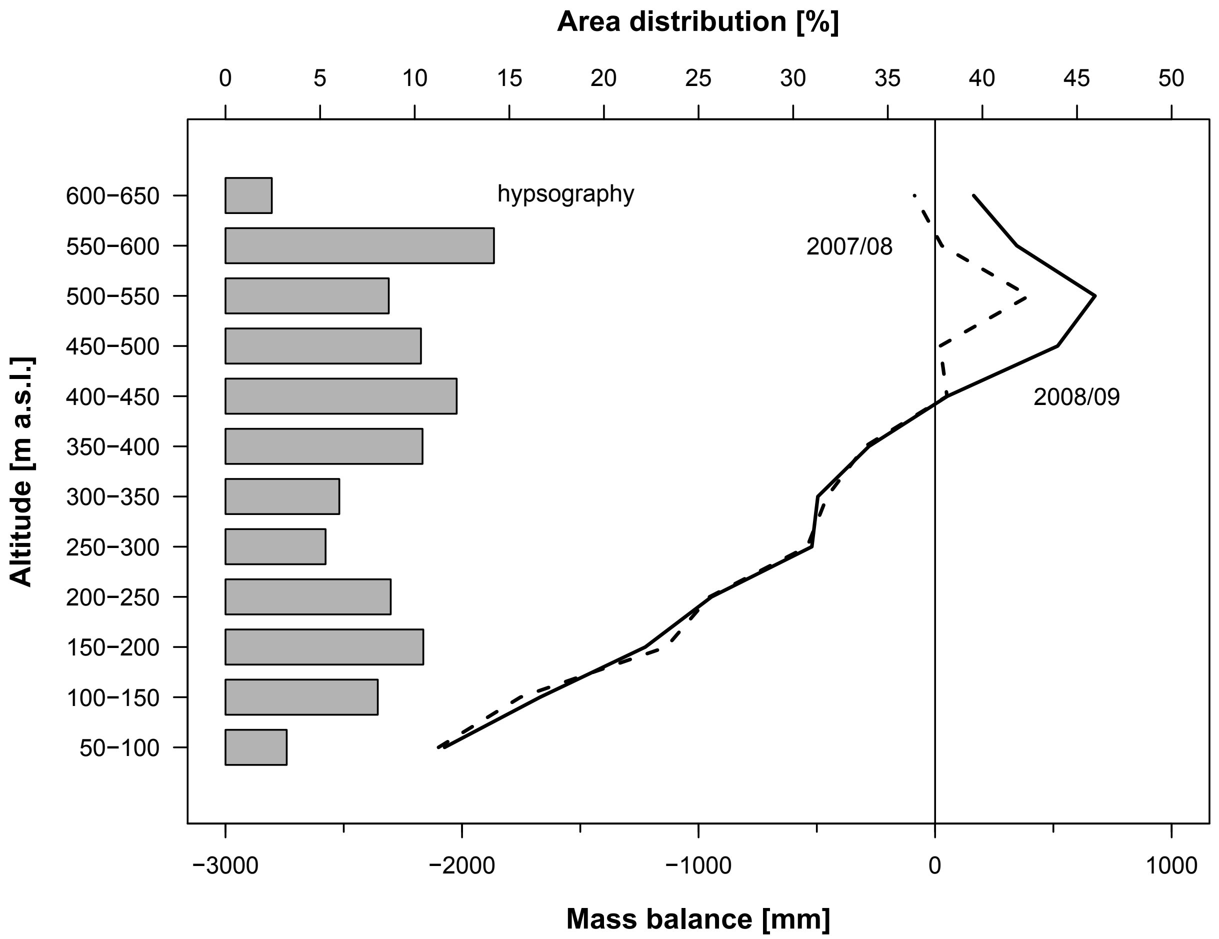


2008/09

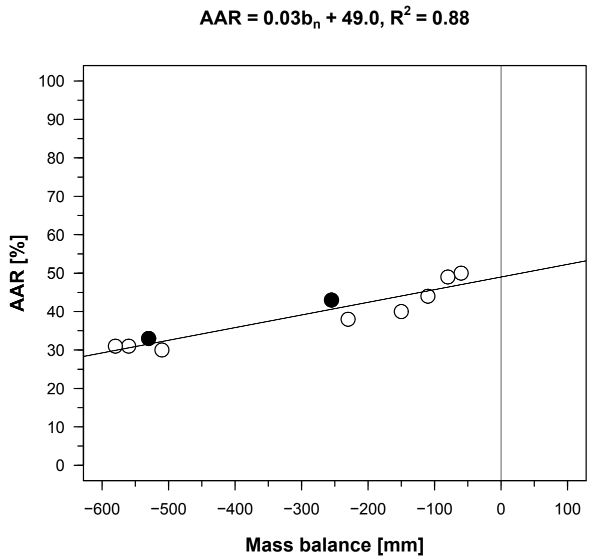


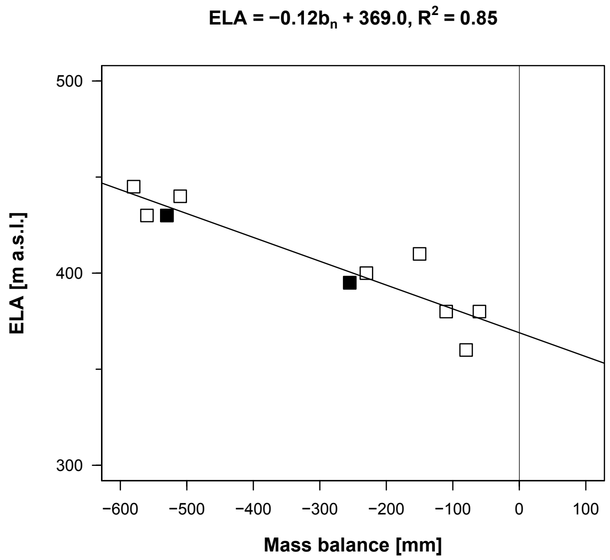
Glaciar Bahía del Diablo (ANTARCTICA)

3.1.3 Mass balance versus altitude (2007/08 and 2008/09)



3.1.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Glaciar Bahía del Diablo (ANTARCTICA)

3.2 MARTIAL ESTE (ARGENTINA/ANDES FUEGUINOS)

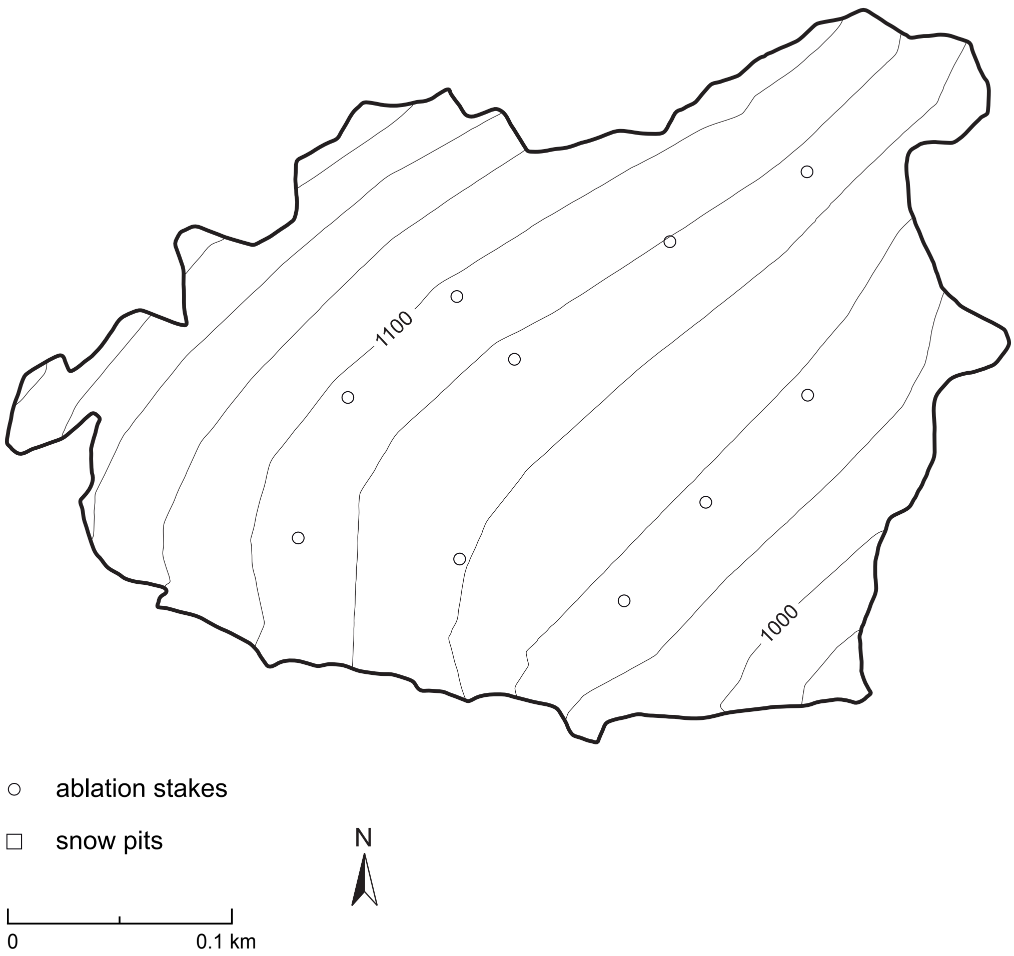
COORDINATES: 54.78° S / 68.40° W

Photo of Martial Este Glacier by R. Iturraspe, 18 March 2011.

The Martial Este is one of the four small glaciers situated in the well-defined glacial cirque of the Cordon Martial (1319 m a.s.l at Mt Martial) very close to Ushuaia city and to the Beagle channel, south of Tierra del Fuego. Glacier runoff contributes to the water supply of this city. The total ice area on this cirque attains 0.33 km^2. The Martial Este Glacier has a surface area of 0.1 km^2 that extends from 1180 m to 970 m a.s.l. with a mean slope of 29° and south-east exposition. It receives less direct solar radiation than the rest of the glaciers in the cirque. Mean annual air temperature at the equilibrium line (about 1100 m a.s.l.) is −1.5 °C and the average precipitation amounts to 1300 mm, extending over the whole year. The precipitation regime has no dry season. The hydrological cycle starts in April and the maximum accumulation on the glacier is reached in October or November. Since the Little Ice Age these glaciers have lost 75 % of their total area. From 1984 to 1998 vertical thinning at the Martial Este Glacier was 7.0 m w.e. (450 mm w.e. a^{-1}).

For the hydrological years 2007/08 and 2008/09, mass balances of the Martial Este Glacier were negative but close to being stable. These results and a slight positive mass balance for 2006/07 are indicative of a tendency to steady budgets, which differ with the marked recessive glacier behaviour in the 1990s and in the first years of the current decade. This reduction of the recessive behaviour is a consequence of cold and snowy springs which gave rise to short ablation periods.

3.2.1 Topography and observation network

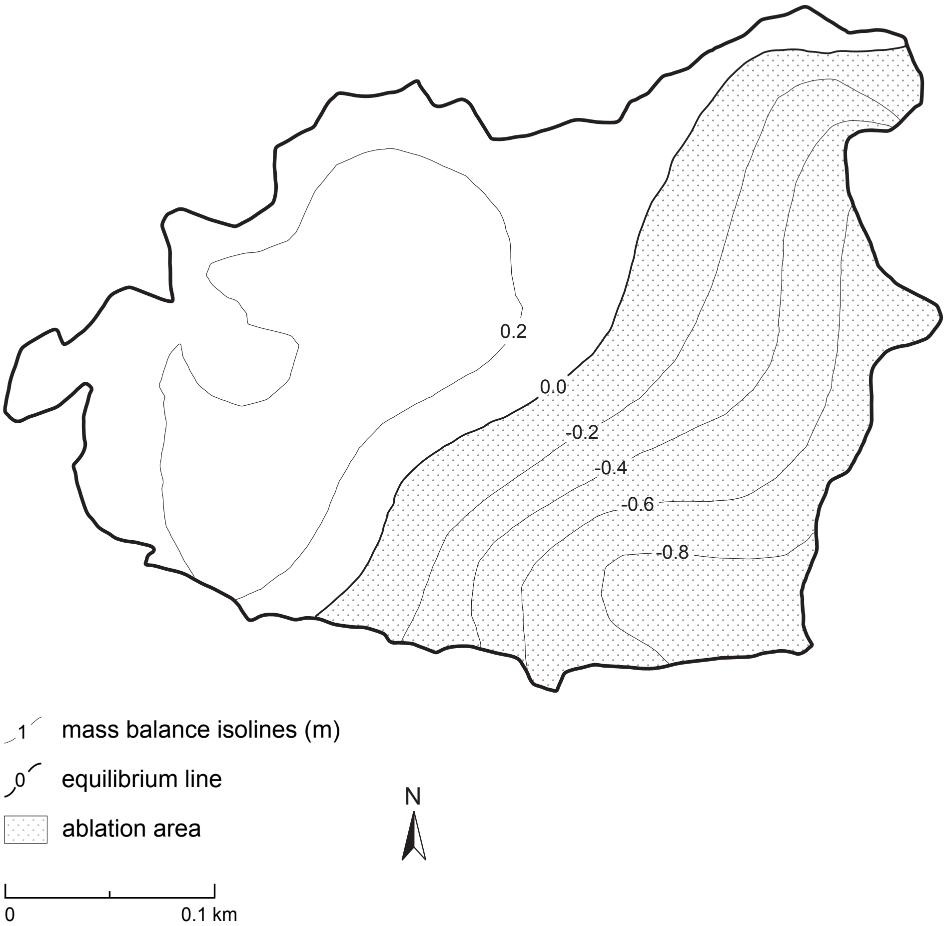


Martial Este (ARGENTINA)

3.2.2 Mass balance maps 2007/08 and 2008/09

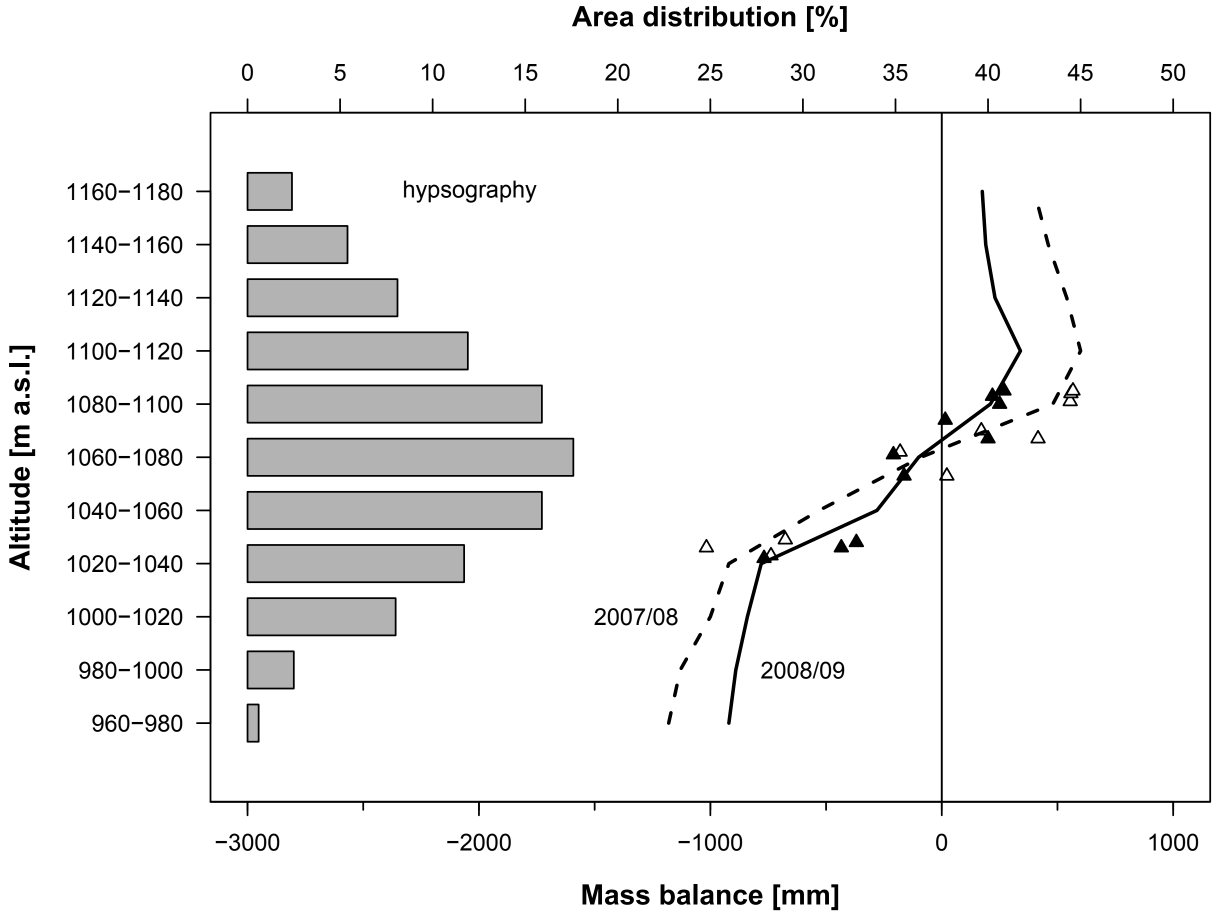
2007/08

2008/09

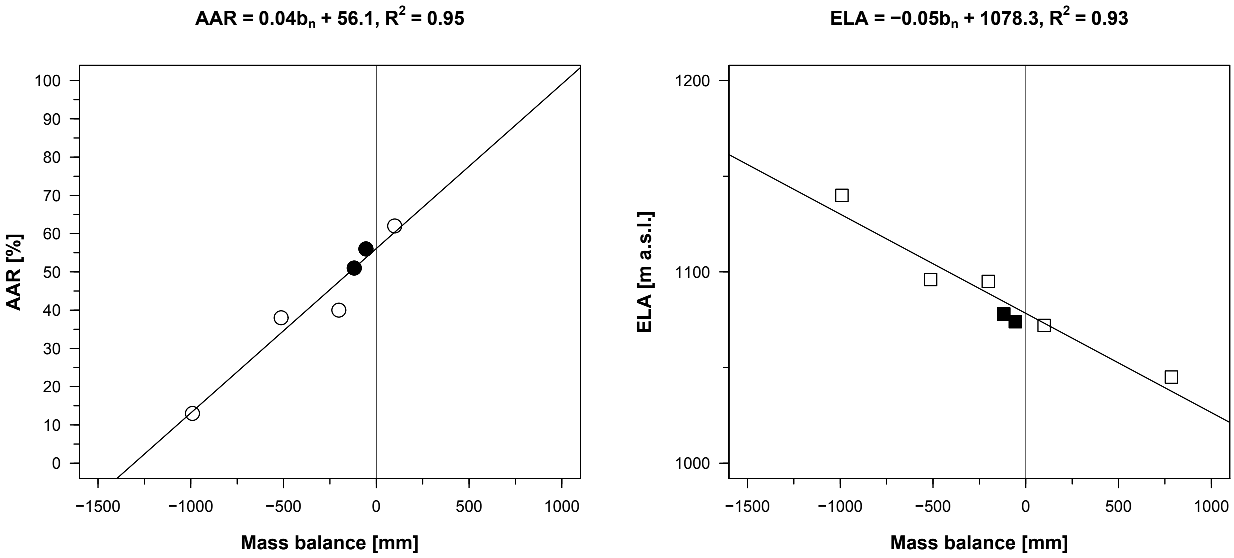


Martial Este (ARGENTINA)

3.2.3 Mass balance versus altitude (2007/08 and 2008/09)



3.2.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period



Martial Este (ARGENTINA)

3.3 VERNAGTFERNER (AUSTRIA/EASTERN ALPS)

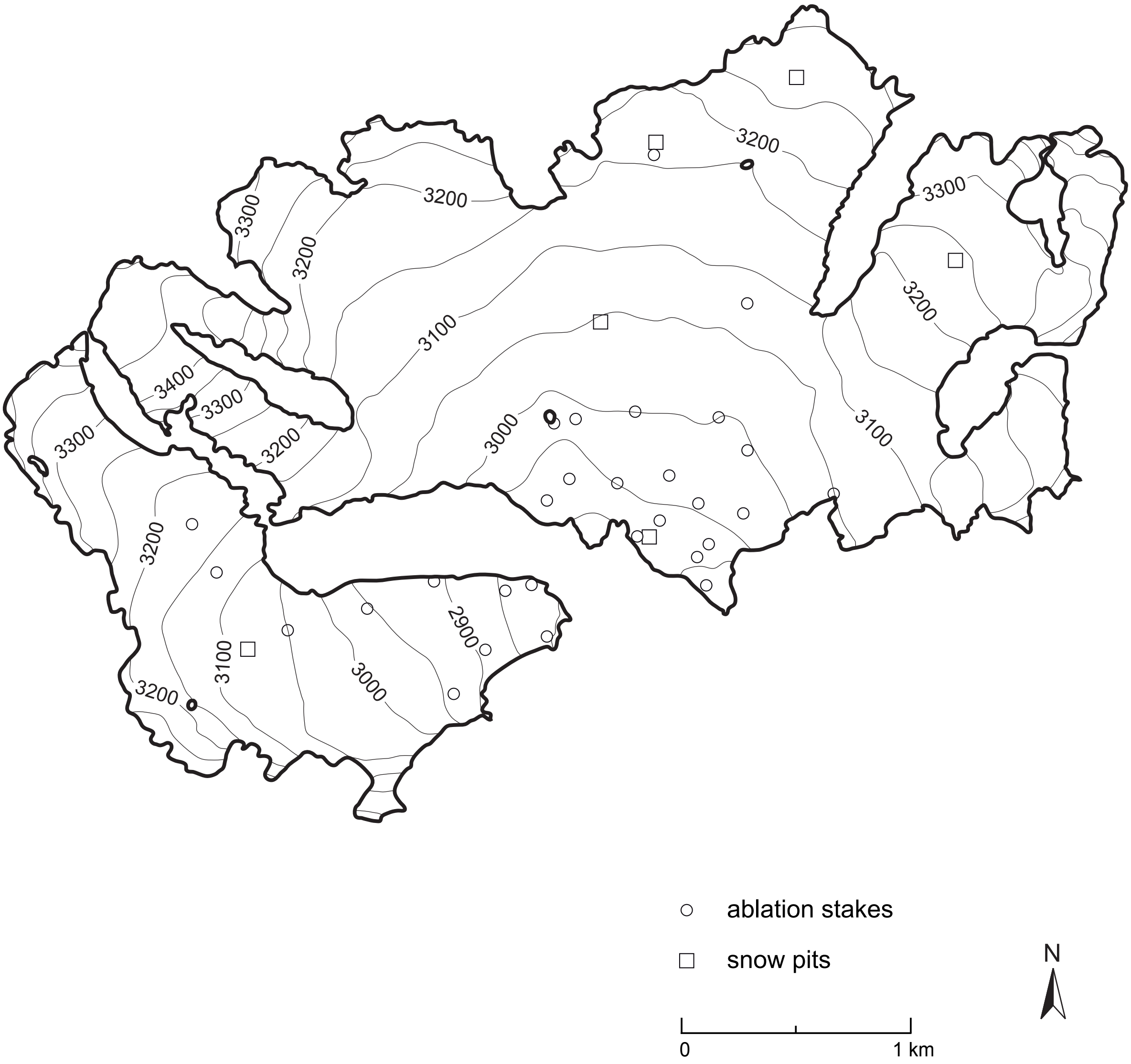
COORDINATES: 46.88° N / 10.82° W

Photo taken by J. Abermann, 9 September 2008.

The rather flat temperate plateau glacier is located in the southern part of the Ötztal Alps (Austria) near the main Alpine ridge. The present surface area of 8.3 km^2 is unevenly distributed between 2800 and 3628 m a.s.l., with a mean elevation of 3150 m a.s.l., and 70 % of the total area lying between 3000 and 3300 m a.s.l. The mean annual air temperature at the equilibrium line altitude (for balanced years at 3065 m a.s.l.) lies between –3.5 and –4.5 °C, based on records at the Vernagt gauging station at 2640 m a.s.l. and the Schwarzkögele climate station at 3050 m a.s.l. The mean annual precipitation for the Vernagt drainage basin (11.4 km^2) amounts to 1550 mm, 60 % of which are, on average, deposited during the accumulation season. The glacier has been volumetrically monitored since 1889, direct glaciological measurements related to the fixed-date system have been conducted since 1965, and discharge measurements date back to 1974. Detailed glacier mass balance data are available on the homepage of the Commission for Glaciology (www.glaziologie.de), additionally there are topographic maps at the 1:10,000 scale based on photogrammetric surveys for 1889, 1969, 1979, 1982, 1990 and 1999.

The year 2007/08 brought a strongly negative mass balance (–843 mm, AAR = 0.17). The year 2008/09 showed a similar but slightly larger mass loss (–959 mm, AAR = 0.14).

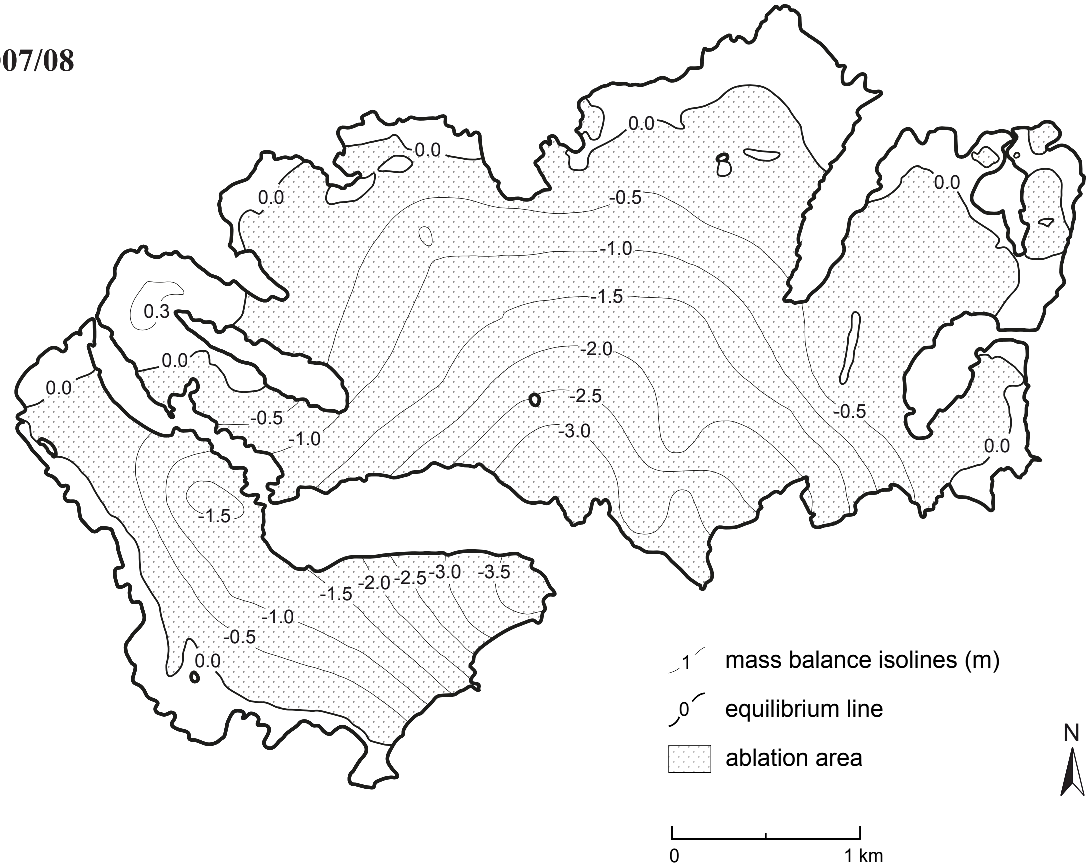
3.3.1 Topography and observation network



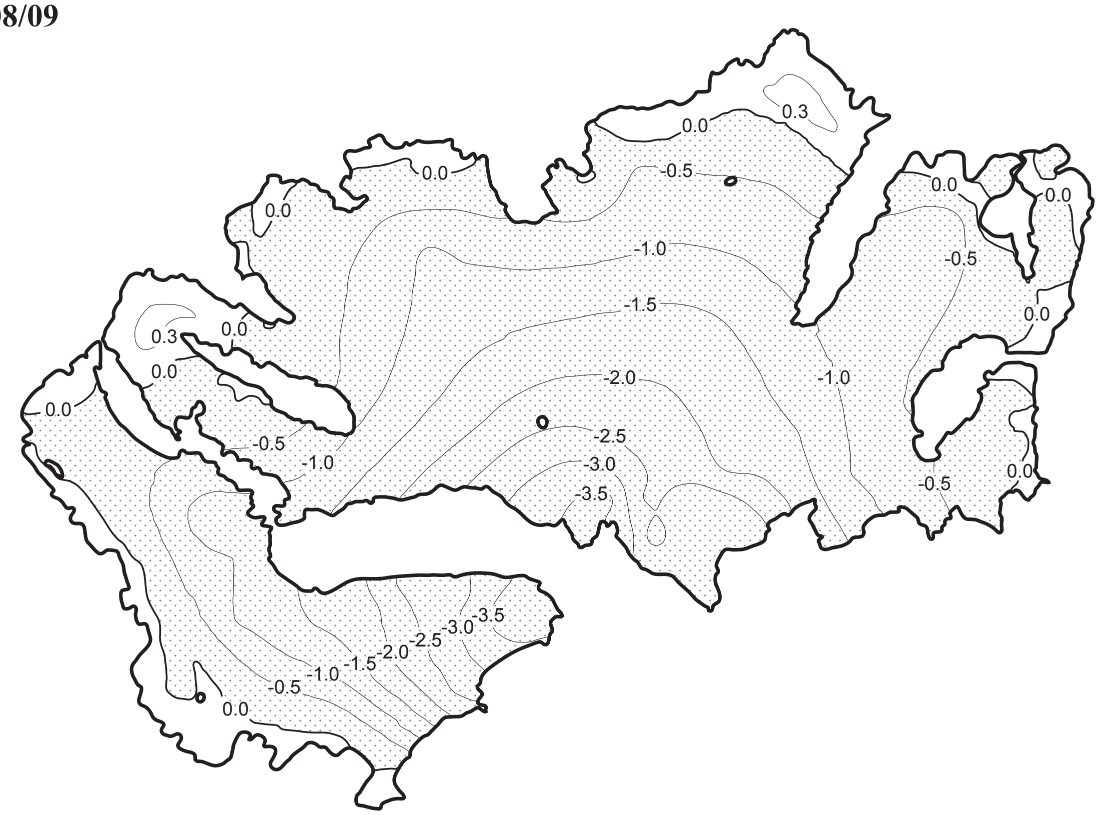
Vernagtferner (AUSTRIA)

3.3.2 Mass balance maps 2007/08 and 2008/09

2007/08

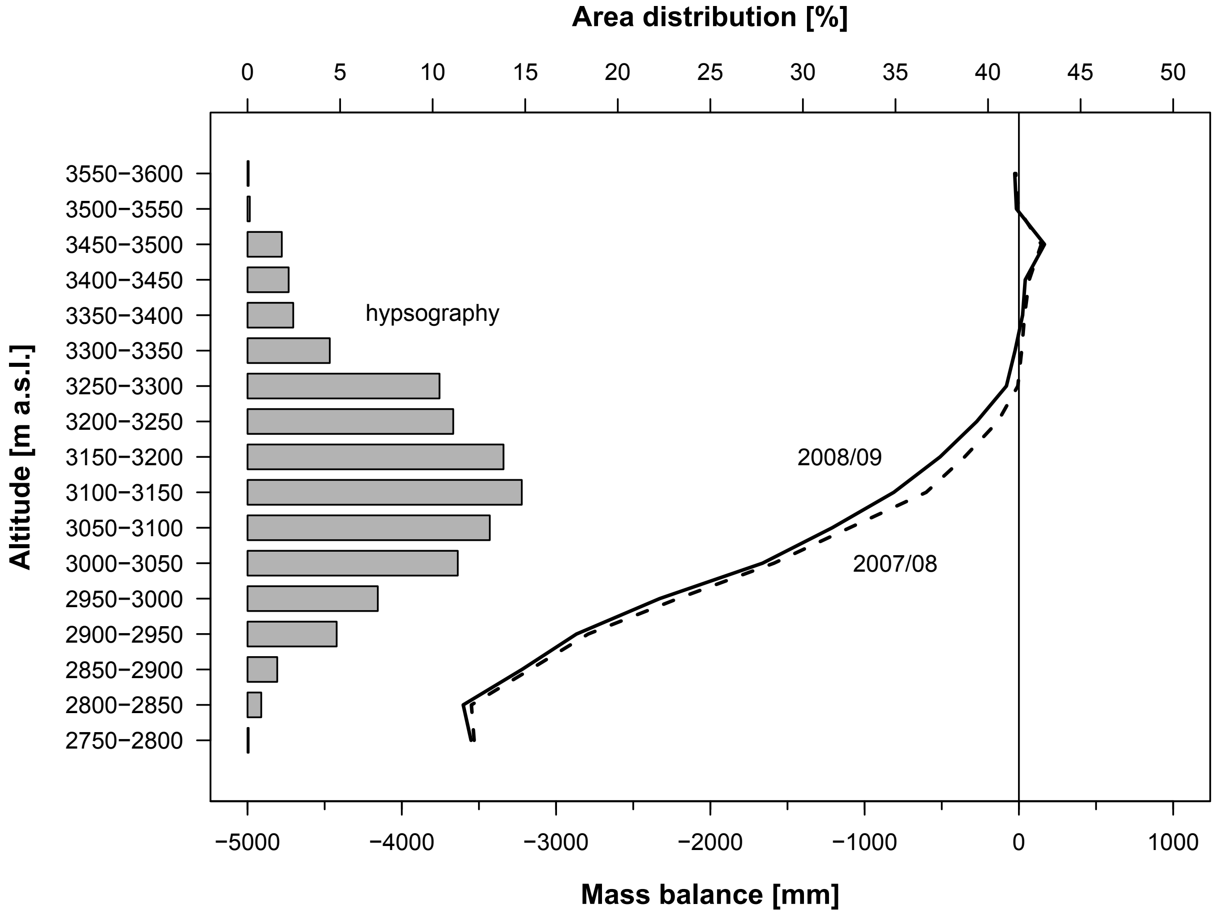


2008/09

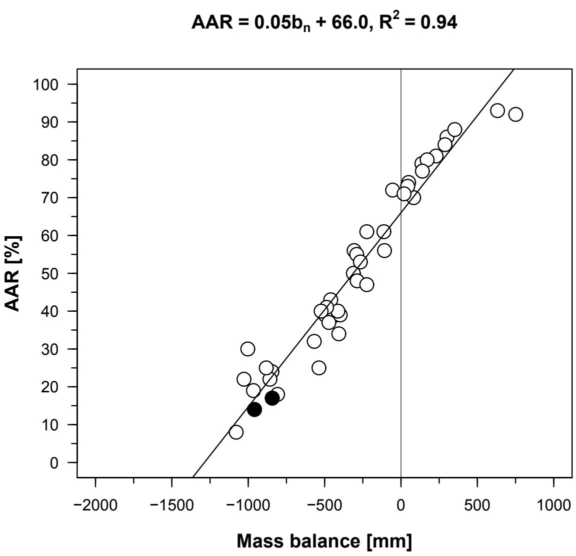


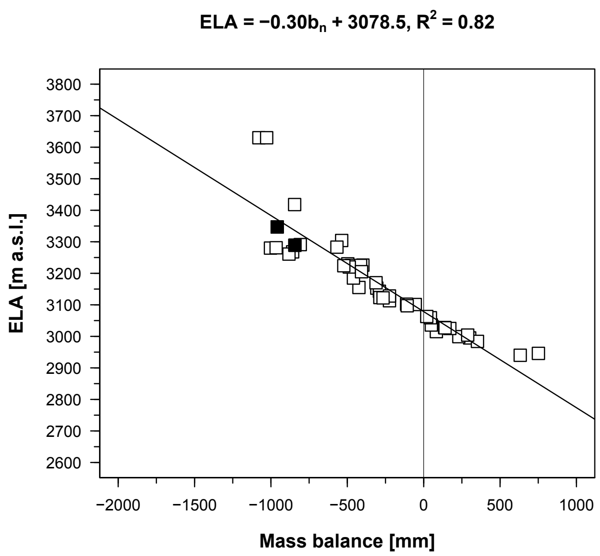
Vernagtferner (AUSTRIA)

3.3.3 Mass balance versus altitude 2007/08 and 2008/09



3.3.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Vernagtferner (AUSTRIA)

3.4 ZONGO (BOLIVIA/TROPICAL ANDES)

COORDINATES: 16.25° S / 68.17° W

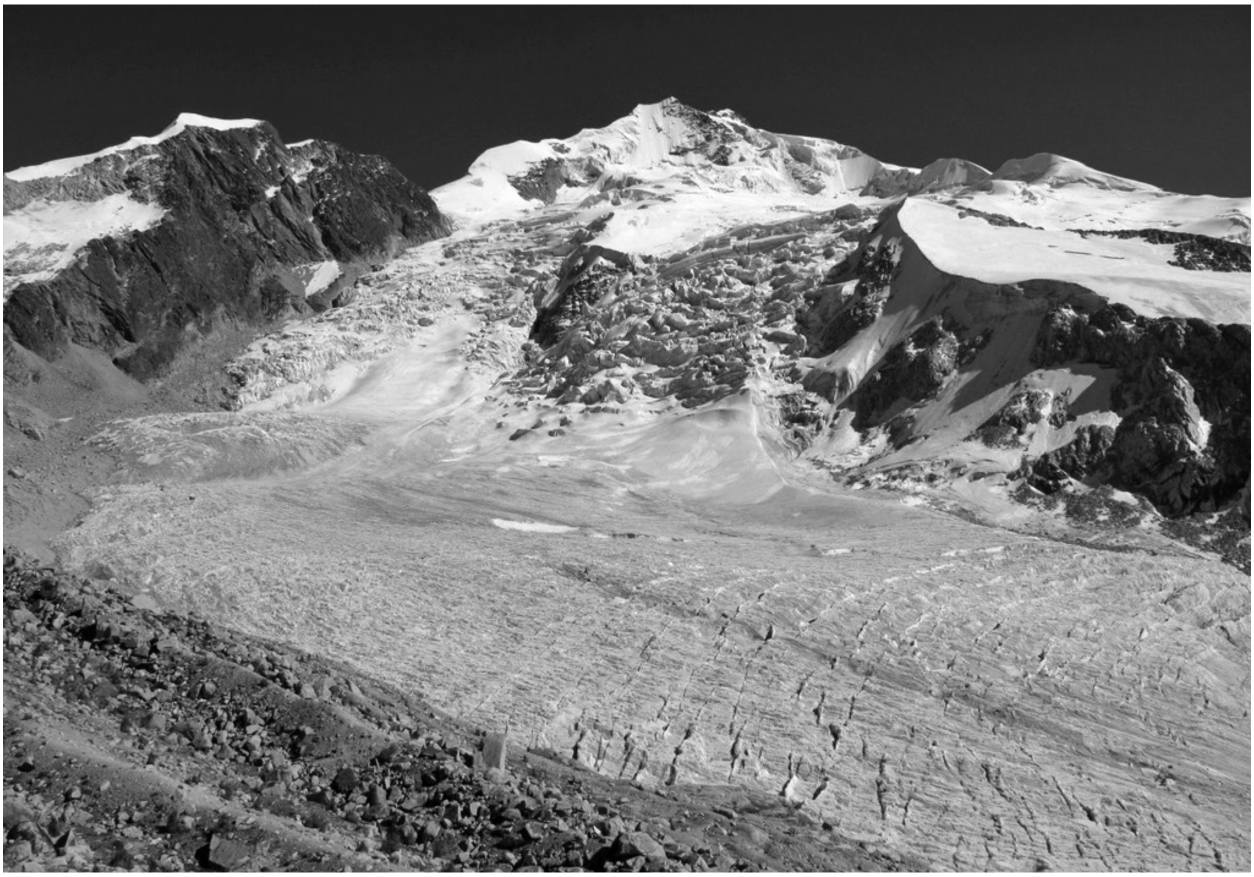
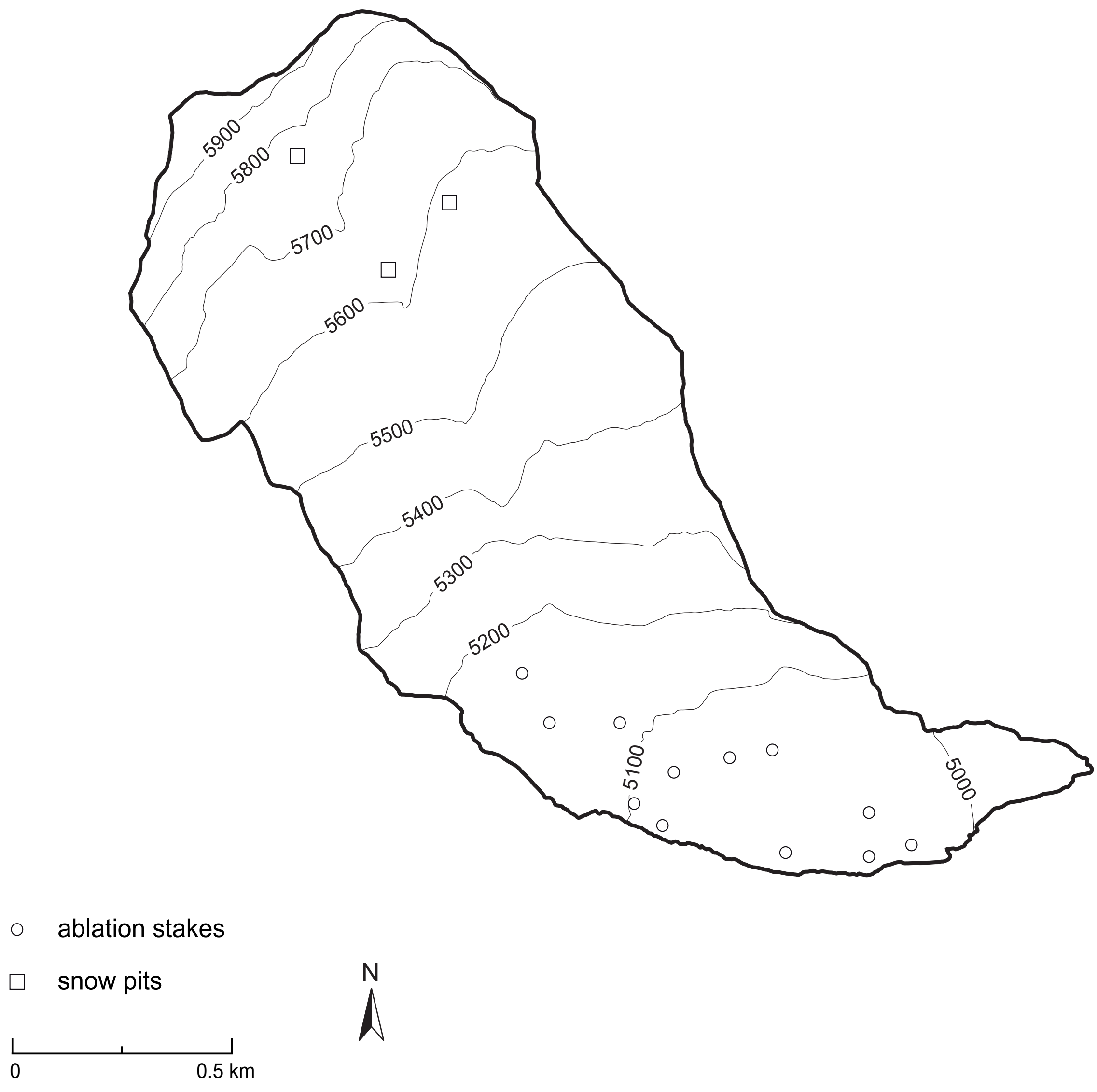


Photo provided by P. Ginot, August 2009.

Zongo is a small valley glacier located in the Huayna Potosi region (Cordillera Real, Bolivia), 30 km north of La Paz city, between the dry Altiplano plateau in the west and the wet Amazonian basin in the east. The glacier is temperate and covers an area of 1.87 km^2 (in 2009) over a hydropower catchment area of 3.3 km^2. Its length is around 3 km, its width amounts to about 0.75 km. The glacier flows from 6100 to 4900 m a.s.l., and the average ice flow velocity is 20 m a^{-1} between 5200 and 4900 m a.s.l.

Meteorological conditions in the outer tropics are characterized by strong seasonality in precipitation. For the 2008/09 cycle the mean annual temperature was 1.76 °C at 4750 m a.s.l. and –0.57 °C at the the glacier tongue at 5050 m a.s.l. The mean annual precipitation measured in the catchment was 726 mm. Melting processes took place mainly during November and February (austral summer), between the precipitation peaks (January and March). As all glaciers in the region, Zongo glacier showed a negative mass balance. The greatest loss (–2173 mm w.e.) took place during the El Niño event of 1997/98. Some periods (1996/97, 2000/01) with positive mass balances were concomitant with La Niña events. In 2007/08, the glacier mass balance was +257 mm w.e. The 2008/09 period presented a negative mass balance (–631 mm w.e.). The 2008/09 mean annual temperature and precipitation were lower than the 1994–2009 annual means. This year was characterized by a negative MEI (Multivariate ENSO Index) at the beginning and positive at the end, showing a transition between El Niño to La Niña conditions. However, the MEI variation was lower than one standard deviation.

3.4.1 Topography and observation network

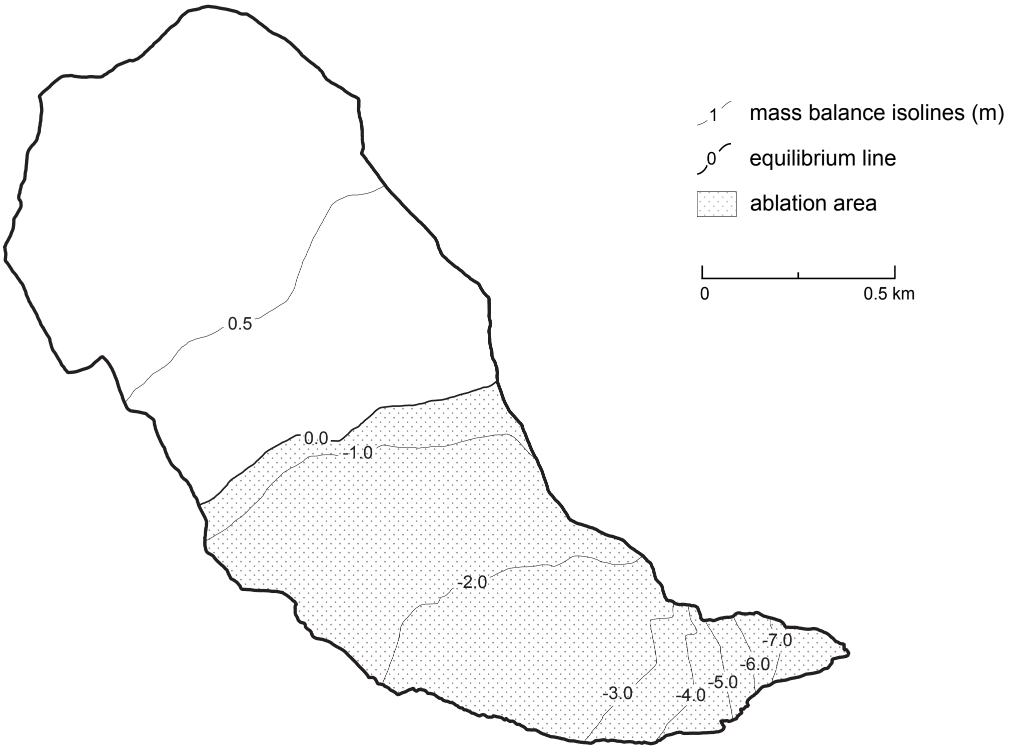


Zongo (BOLIVIA)

3.4.2 Mass balance maps 2007/08 and 2008/09

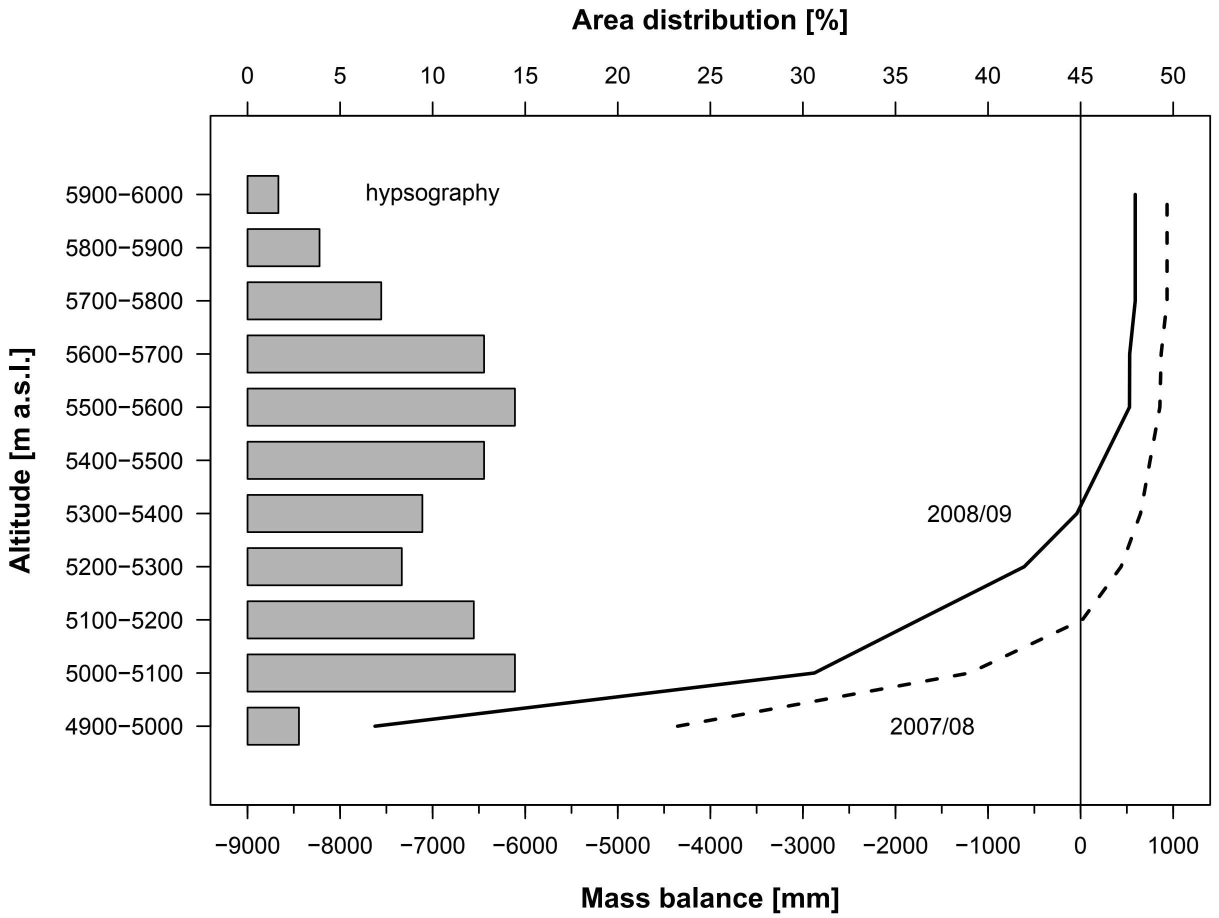
2007/08

2008/09

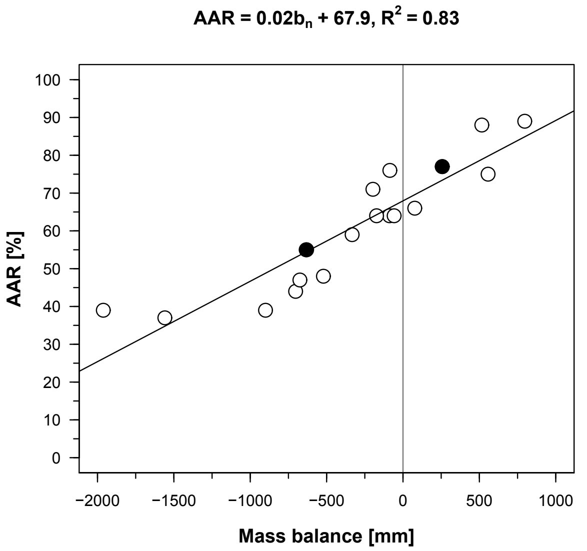


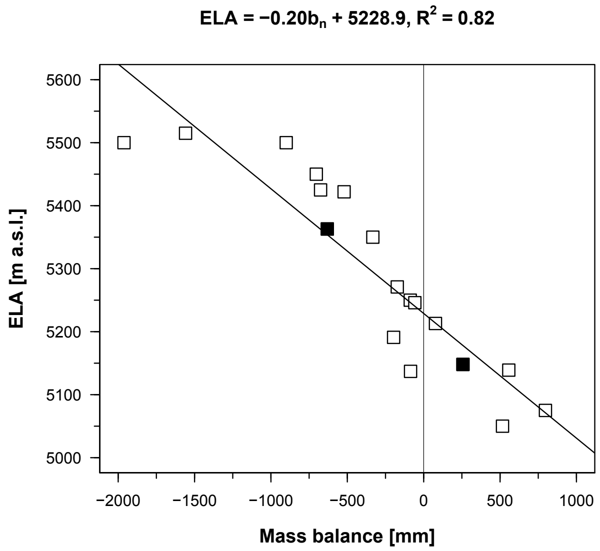
Zongo (BOLIVIA)

3.4.3 Mass balance versus altitude (2007/08 and 2008/09)



3.4.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Zongo (BOLIVIA)

3.5 WHITE (CANADA/HIGH ARCTIC)

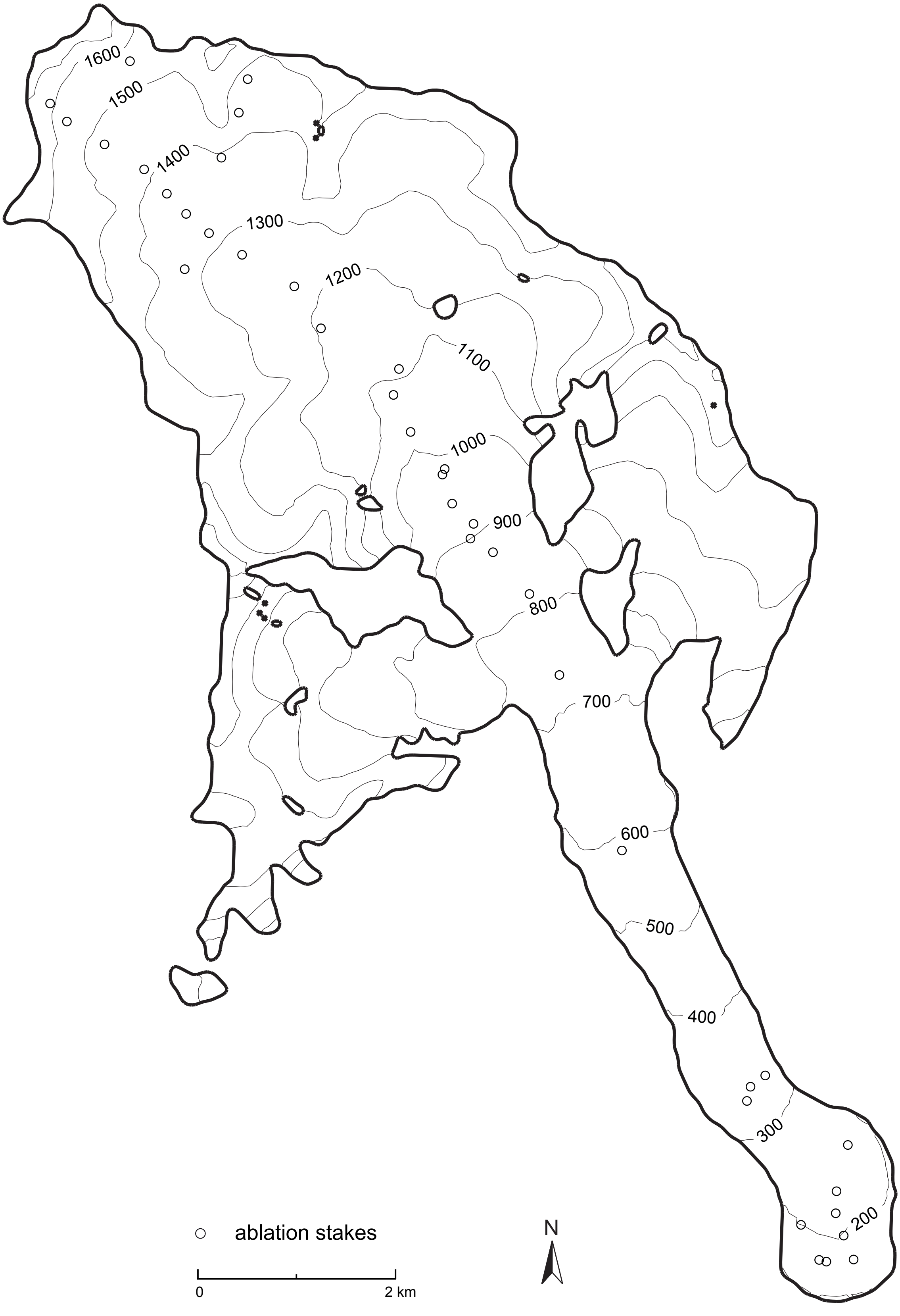
COORDINATES: 79.45° N / 90.67° W

Aerial view of White Glacier taken on 2 July 2008. Photo by J. Alean.

White Glacier is a valley glacier in the Expedition Fiord area of Axel Heiberg Island, Nunavut. It extends in elevation from 1782 m to 85 m a.s.l. and at present occupies 39.4 km^2, having shrunk by gradual retreat of its terminus from an extent of 40.2 km^2 in 1960. Sea level temperature in the Expedition Fiord area averages about –20 °C, but the glacier is known to have a bed which is partly unfrozen, at least beneath the valley tongue; ice thickness is typically 200 m, but reaches or exceeds 400 m. Annual precipitation at sea level is very low, about 100 mm, although annual accumulation at higher altitudes reaches a few hundred mm. The annual ablation at the terminus of White Glacier ranges between 2000 and 4000 mm a^{-1}. There is now evidence that the retreat of the terminus, previously about –5 m a^{-1}, is decelerating. White Glacier‘s larger neighbour, Thompson Glacier (384 km^2), has been advancing in a state of „slow surge“ since the time of the earliest photographs in 1948, but measurements of its terminus in 2008 and 2009 show that it has now begun a slow retreat. The terminuses of the two glaciers have been in contact since at least 1948, but, although the two terminuses remain distinguishable, White Glacier has become a tributary of Thompson Glacier.

The cumulative mass balance of White Glacier from 1959/60 to 2008/09, with due allowance for three missing years, was –8679 mm w.e. The mass balance for 2007/08, at –817 mm w.e., was identical, given the uncertainty (± 200 to 250 mm w.e.) of the measurements, with the –818 mm w.e. measured in 2006/07. Neither of these measurements is statistically distinguishable from the previous record of –781 mm w.e. in 1961/62. The balance for 2008/09, –580 mm w.e., was also negative but did not break records. However, the mass balance for the decade 2000/01 to 2009/10 appears certain to be the most negative of the five decades over which the measurement record now extends. The mass balance normal for 1960 to 1991, an average of 29 annual measurements, was –95 mm w.e. a^{-1}, slightly but significantly negative.

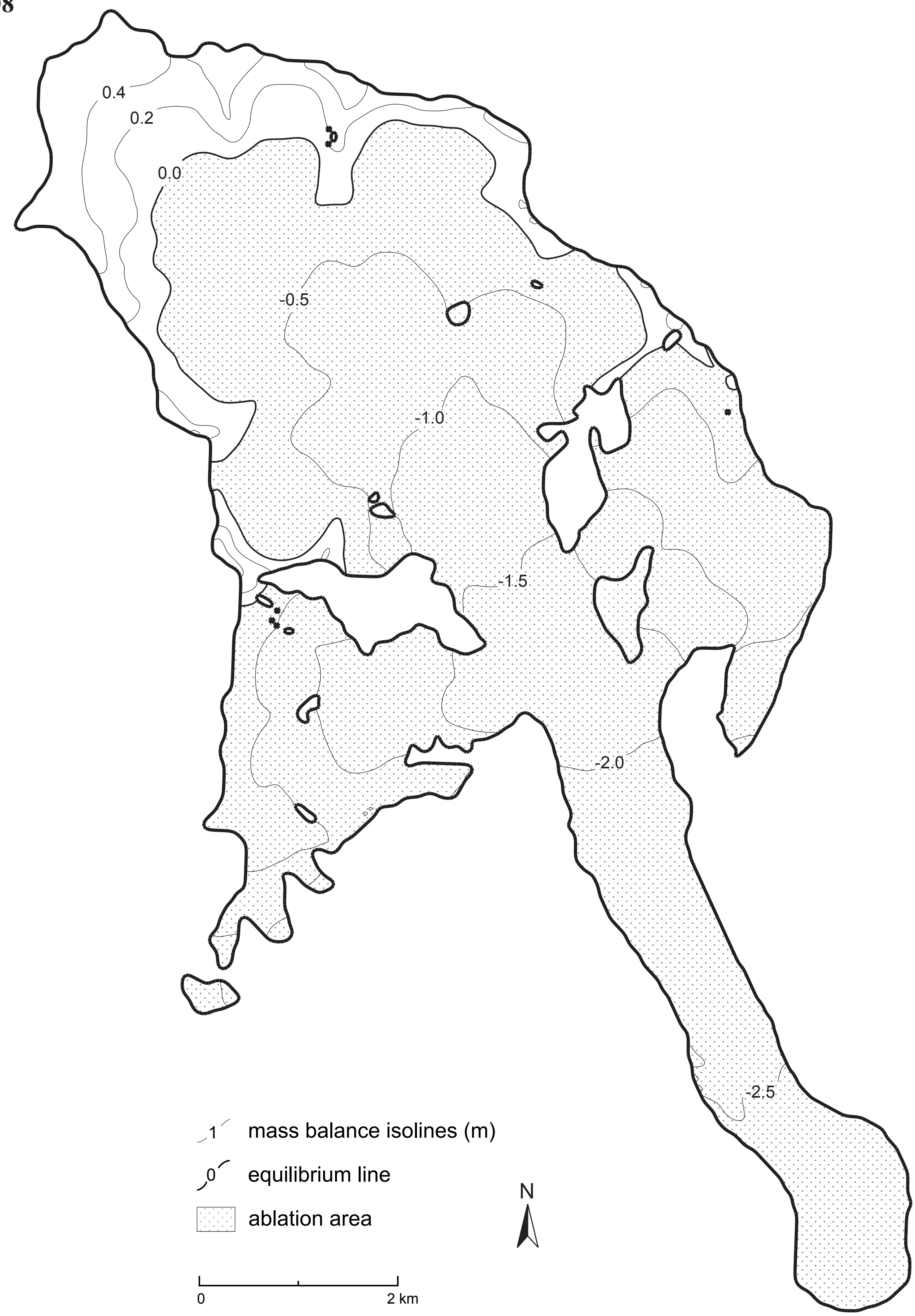
3.5.1 Topography and observation network



White (CANADA)

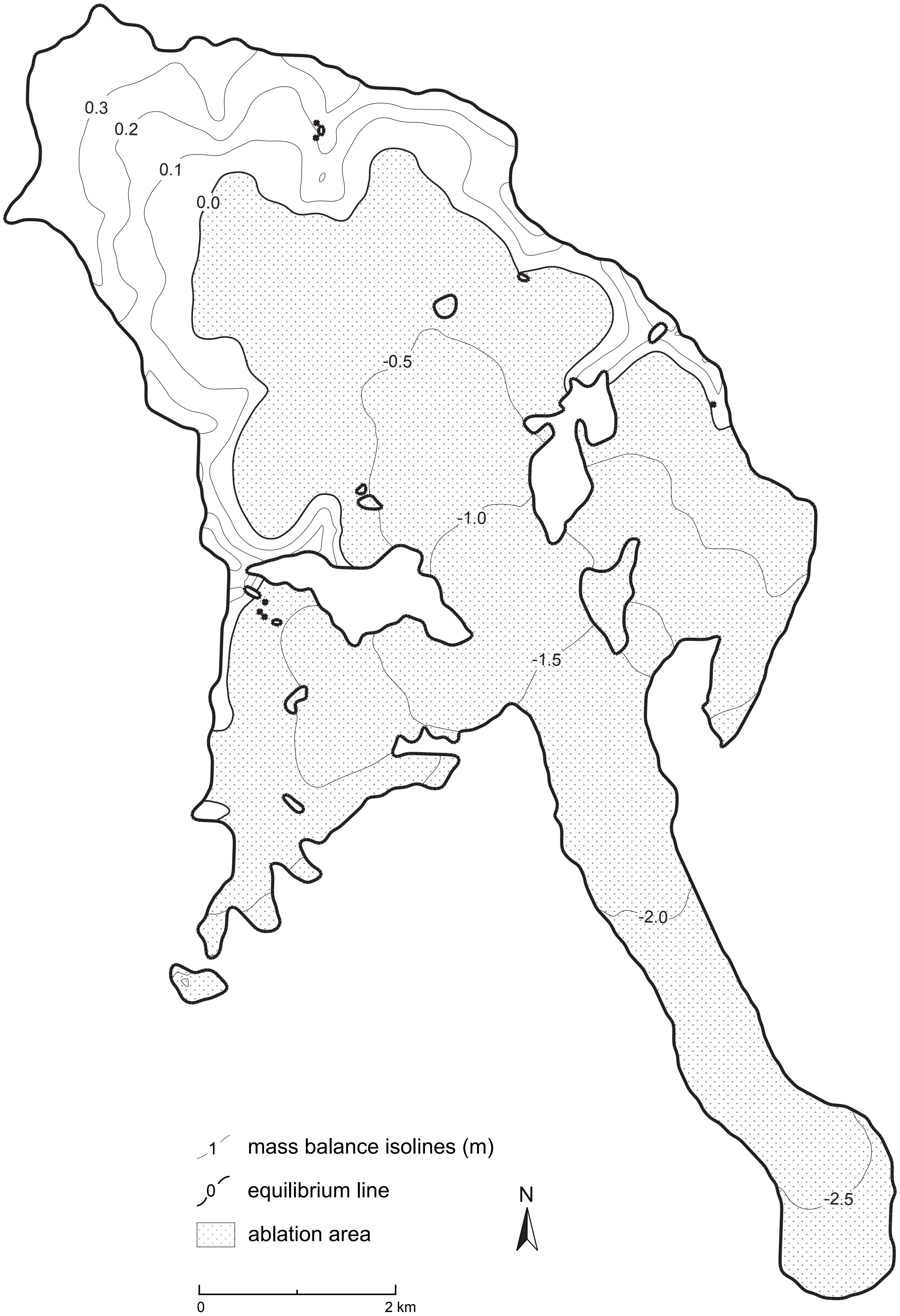
3.5.2 Mass balance maps 2007/08 and 2008/09

2007/08



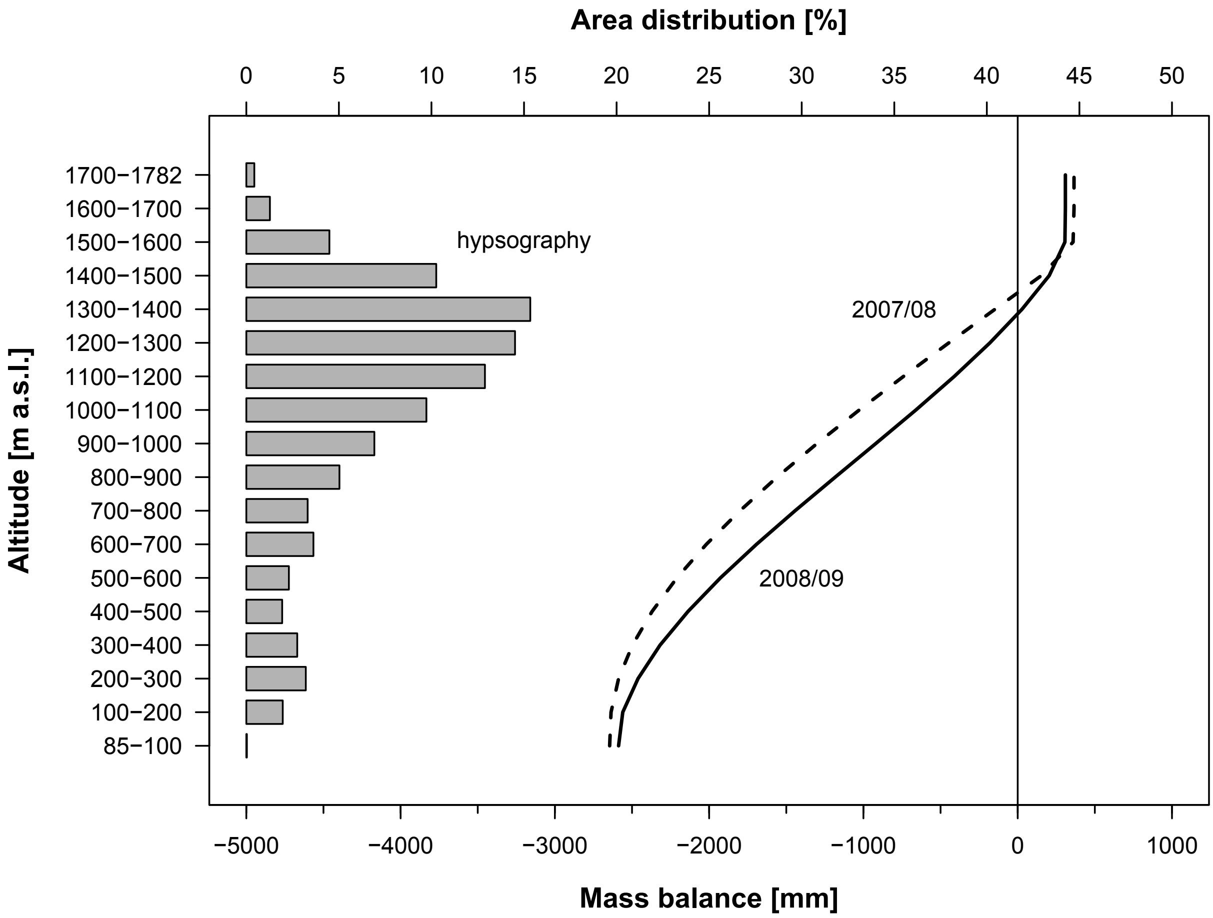
White (CANADA)

2008/09

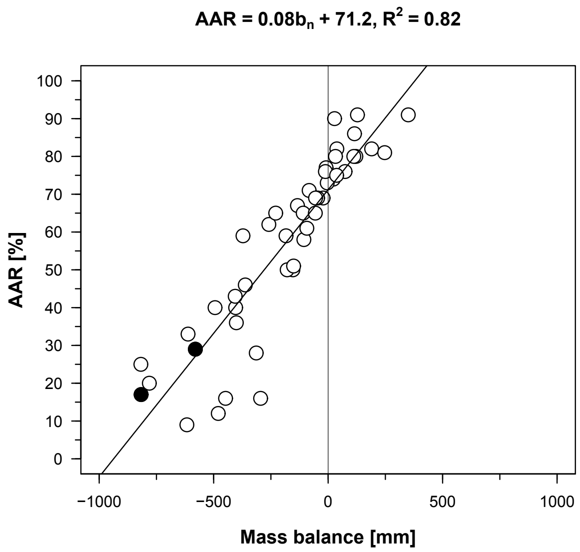


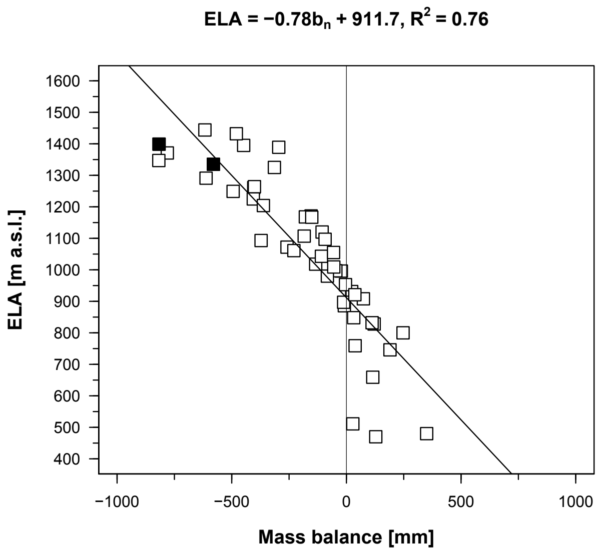
White (CANADA)

3.5.3 Mass balance versus altitude (2007/08 and 2008/09)



3.5.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





3.6 URUMQI GLACIER NO. 1 (CHINA/TIEN SHAN)

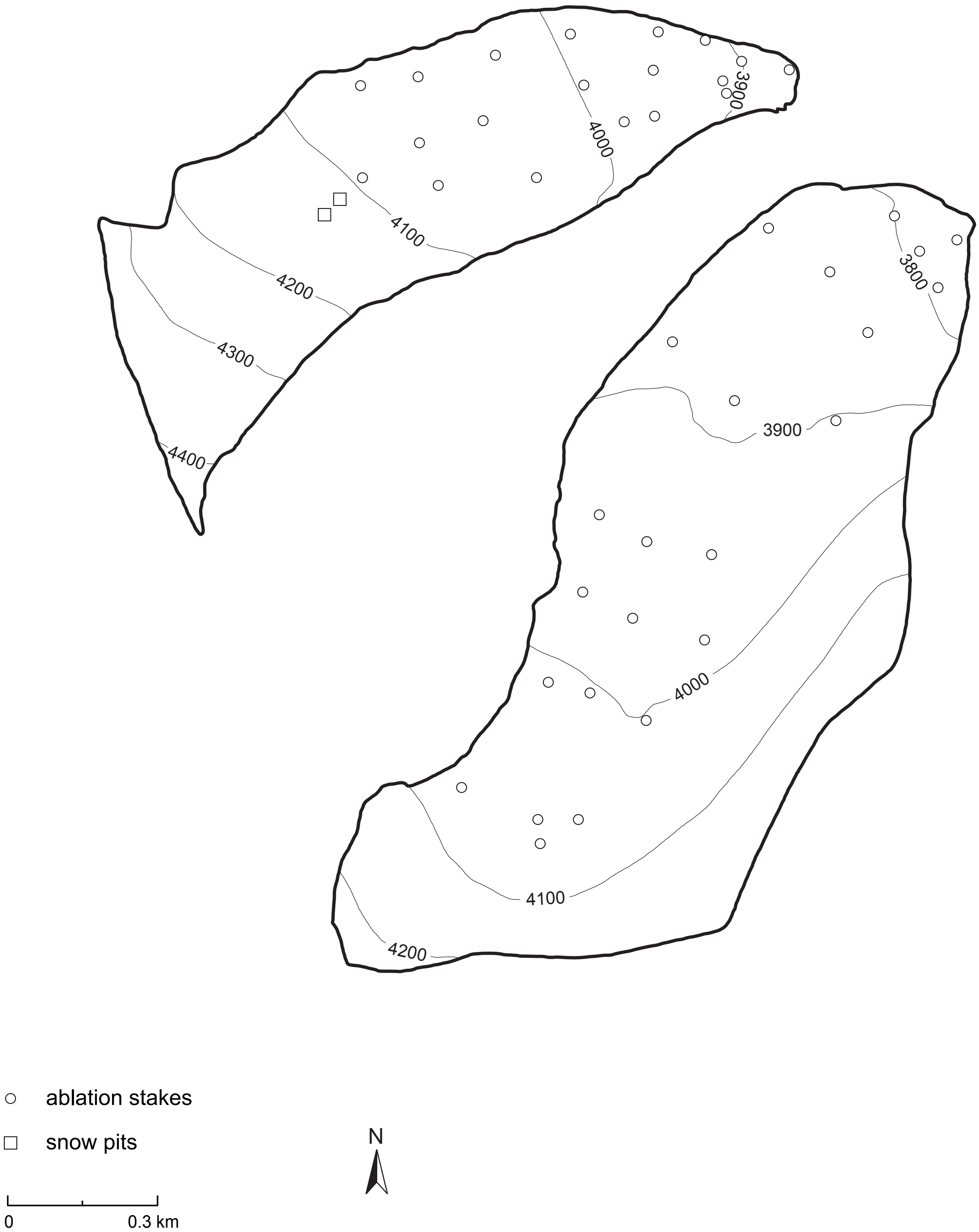
COORDINATES: 43.08° N / 86.82° E

Photo taken by Huilin Li, July 2009.

Urumqi Glacier No. 1 at the headwaters of Urumqi River has been in constant recession since it was first observed in 1959. Due to retreat, the two branches of the former glacier became separated into two small glaciers in 1993 but are still called the East and West Branch of Glacier No. 1. According to the survey in 2006, the East Branch has a total area of 1.086 km^2, the highest and lowest points are at 4267 m and 3743 m a.s.l. The West Branch has a total area of 0.591 km^2, the highest and lowest points are at 4484 m and 3845 m a.s.l. The average annual precipitation is 400 to 600 mm at the nearby meteorological station located at 3539 m a.s.l., and 600 to 700 mm at the glacier. Mean annual air temperature at the equilibrium line (4096 m a.s.l. for years with a zero balance) is estimated at −8.0 to −9.0 °C. The predominantly cold glacier is surrounded by continuous permafrost but attains melting temperatures over wide areas of the bed. Accumulation and ablation both primarily take place during the warm season and the formation of superimposed ice on this continental glacier is significant. A 1:5,000 topographic map of the glaciers and their forefields in August 2006 is available for further analysis.

The mass balance remained negative in 2007/08 (−1046 mm w.e. for the East Branch and −719 mm w.e. for the West Branch). The calculated mean for the entire glacier was −931 mm w.e. For the year 2008/09, a slightly positive mass balance of +63 mm w.e. was observerd (−57 mm w.e. for the East Branch and +289 mm w.e. for the West Branch).

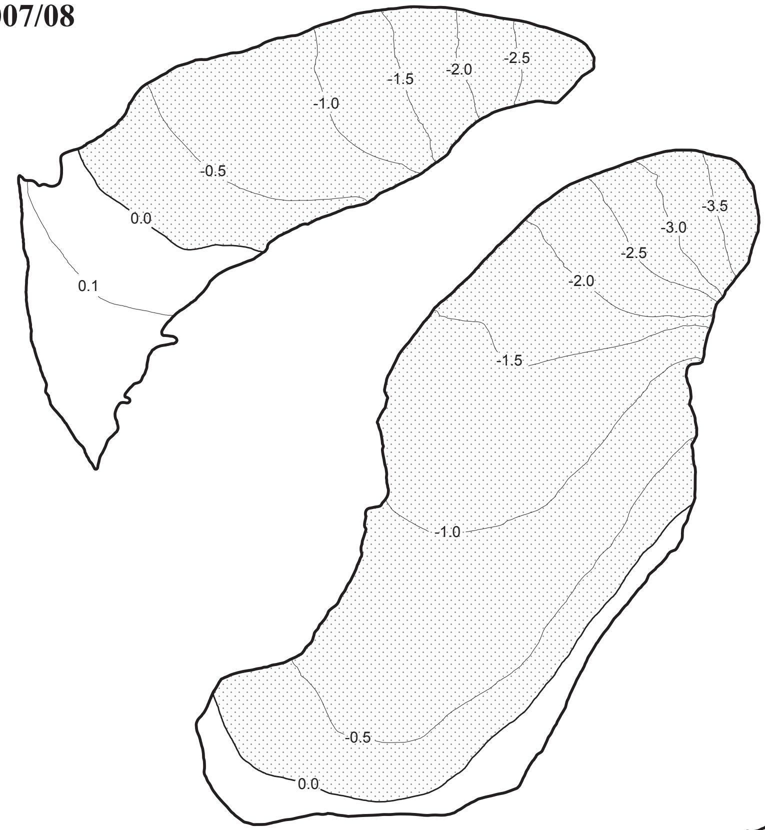
3.6.1 Topography and observation network



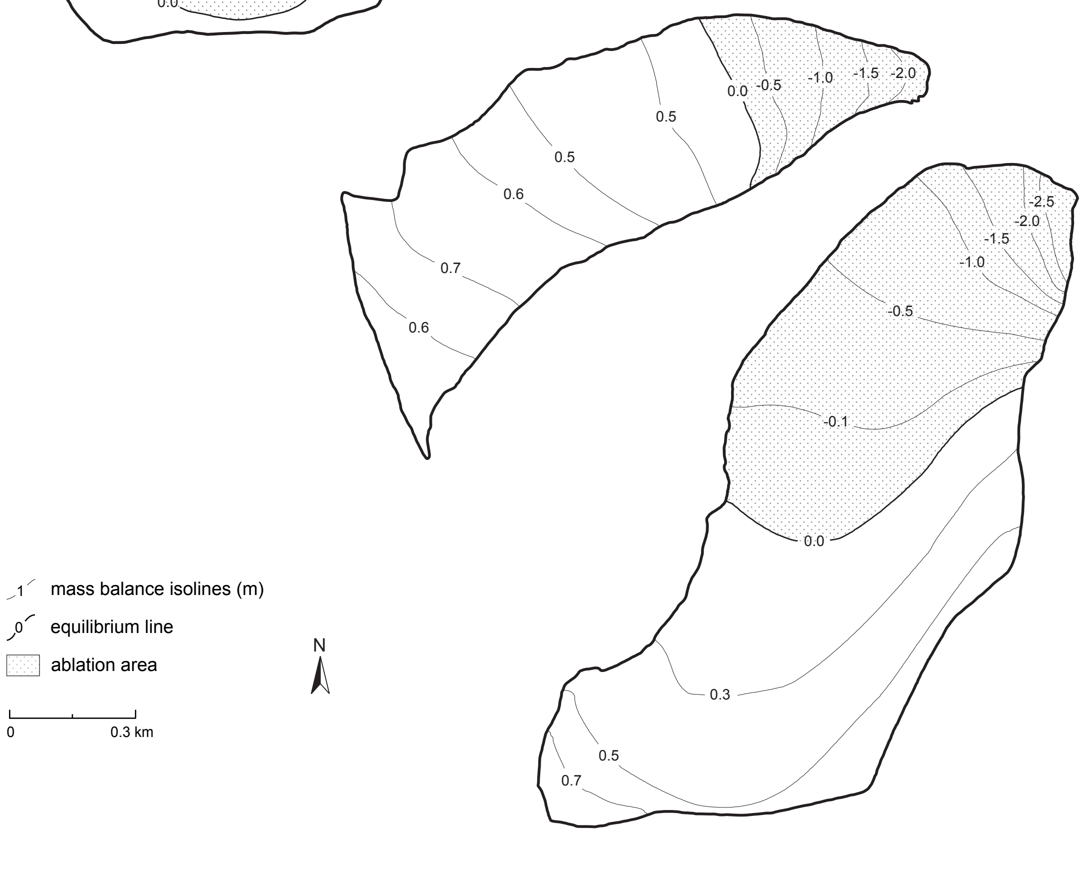
Urumqi Glacier No. 1 (CHINA)

3.6.2 Mass balance maps 2007/08 and 2008/09

2007/08

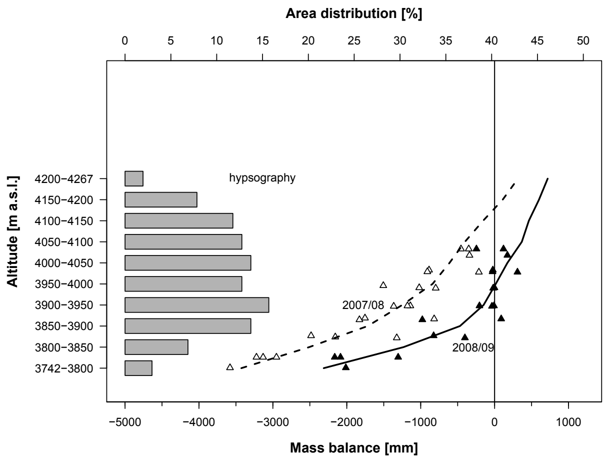


2008/09

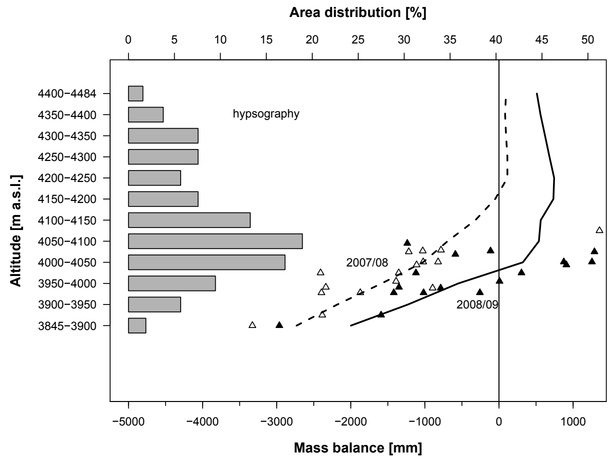


Urumqi Glacier No. 1 (CHINA)

3.6.3 Mass balance versus altitude (2007/08 and 2008/09) of the two branches

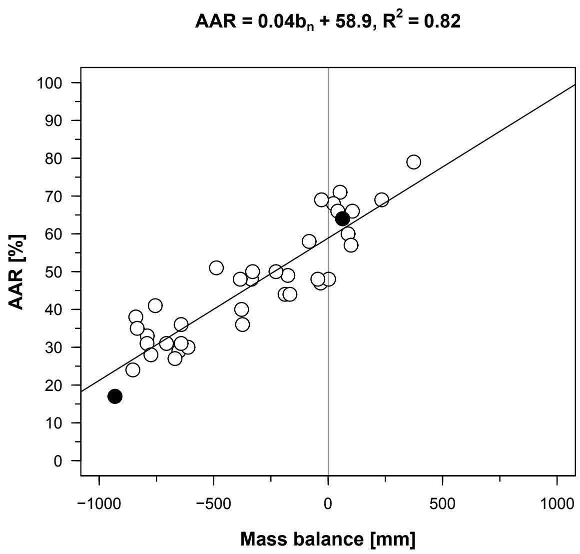


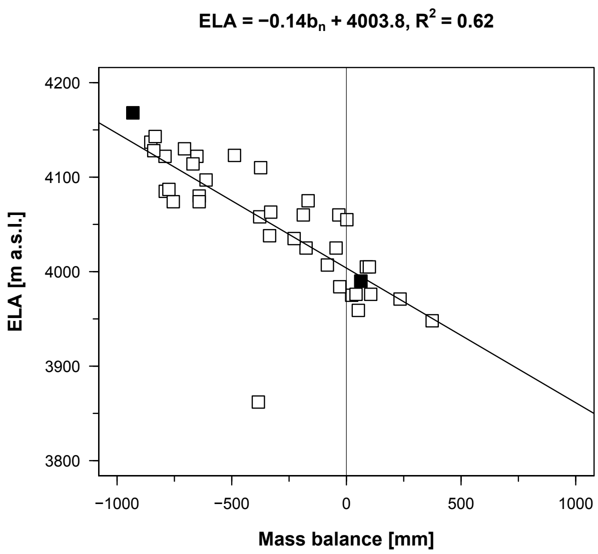
Urumqi Glacier No. 1 East Branch



Urumqi Glacier No. 1 West Branch

3.6.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period for the entire glacier





Urumqi Glacier No. 1 (CHINA)

3.7 FREYA (GREENLAND/NORTHEAST GREENLAND)

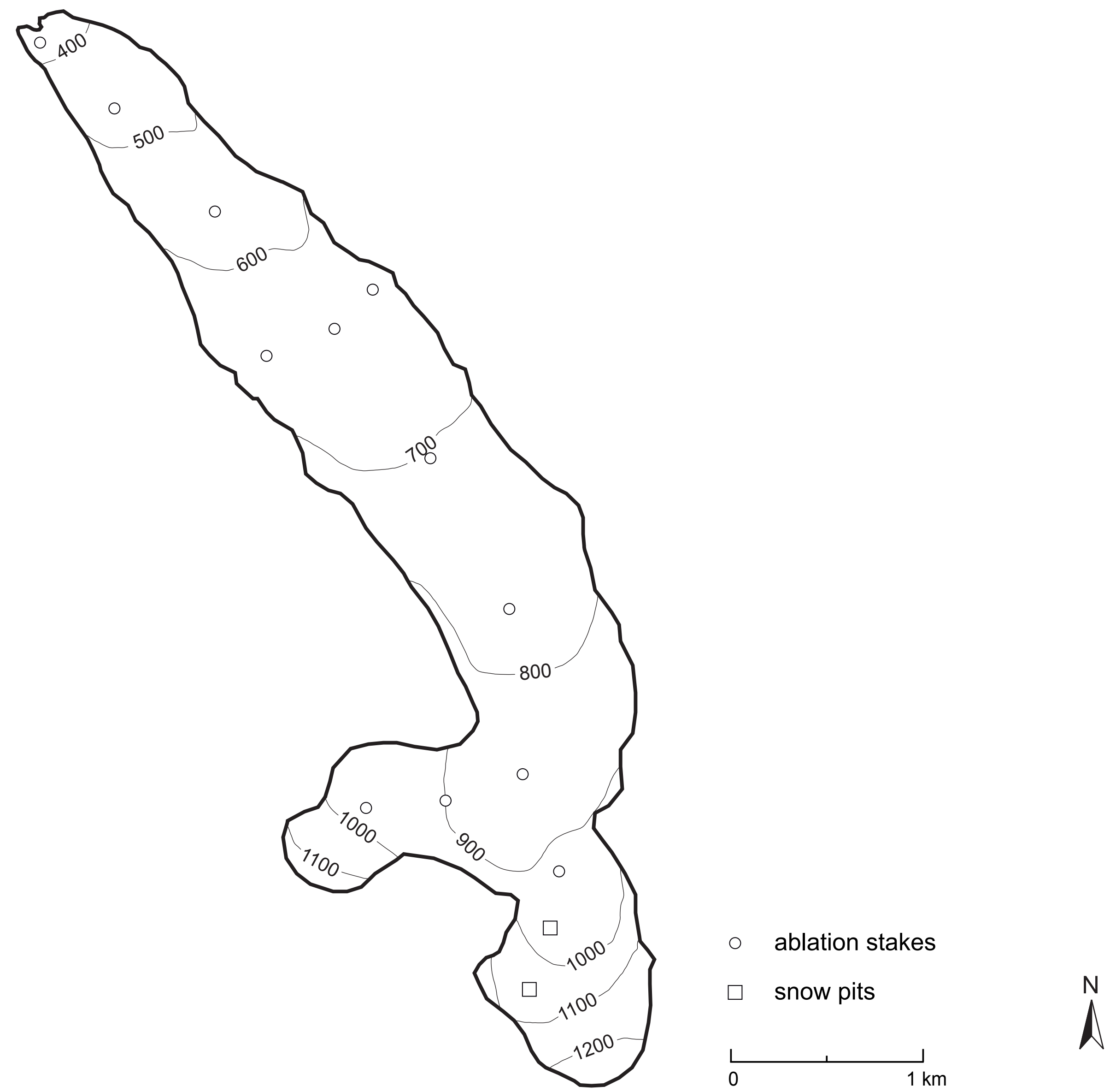
COORDINATES: 74.39° N / 20.83° W

Photo taken by B. Hynek, 26 August 2009.

Freya (Fröya) Glacier is a 6 km long valley glacier situated on Clavering Island 10 km southeast of the Zackenberg research station at the northeastern coast of Greenland. Its surface area is 5.6 km^2 (1987), extending from 1250 m to 330 m a.s.l. and mainly oriented to NW with two separated accumulation areas oriented to NE and NW. The thickest ice was found during a GPR survey in May 2008 is 200 m, located at the confluence of the two accumulation areas. GPR data suggest that Freya Glacier is a polythermal glacier with temperate ice in a limited area only, at the ELA near the bottom of the glacier. Mean values (1996–2005) of annual temperature and precipitation at Zackenberg (38 m a.s.l.) are −9.2 °C and 230 mm.

The annual surface mass balances 2007/08 and 2008/09 were both negative: −510 mm w.e. and −466 mm w.e., respectively. Ablation rates were in the same range of those measured by H. W:son Ahlmann in 1939/40. In both balance years, mean annual temperatures at the ELA (1030 m a.s.l. and 830 m a.s.l., respectively) equaled −9.5 °C. In 2009, mean summer temperatures (JJA) were 2 °C higher compared to 2008. The only measured winter balance (2007/08) was 686 mm w.e.. Snow height measurements at the nearby Zackenberg station show that snowfall during that winter was 60 % above the ten-year mean value.

3.7.1 Topography and observation network

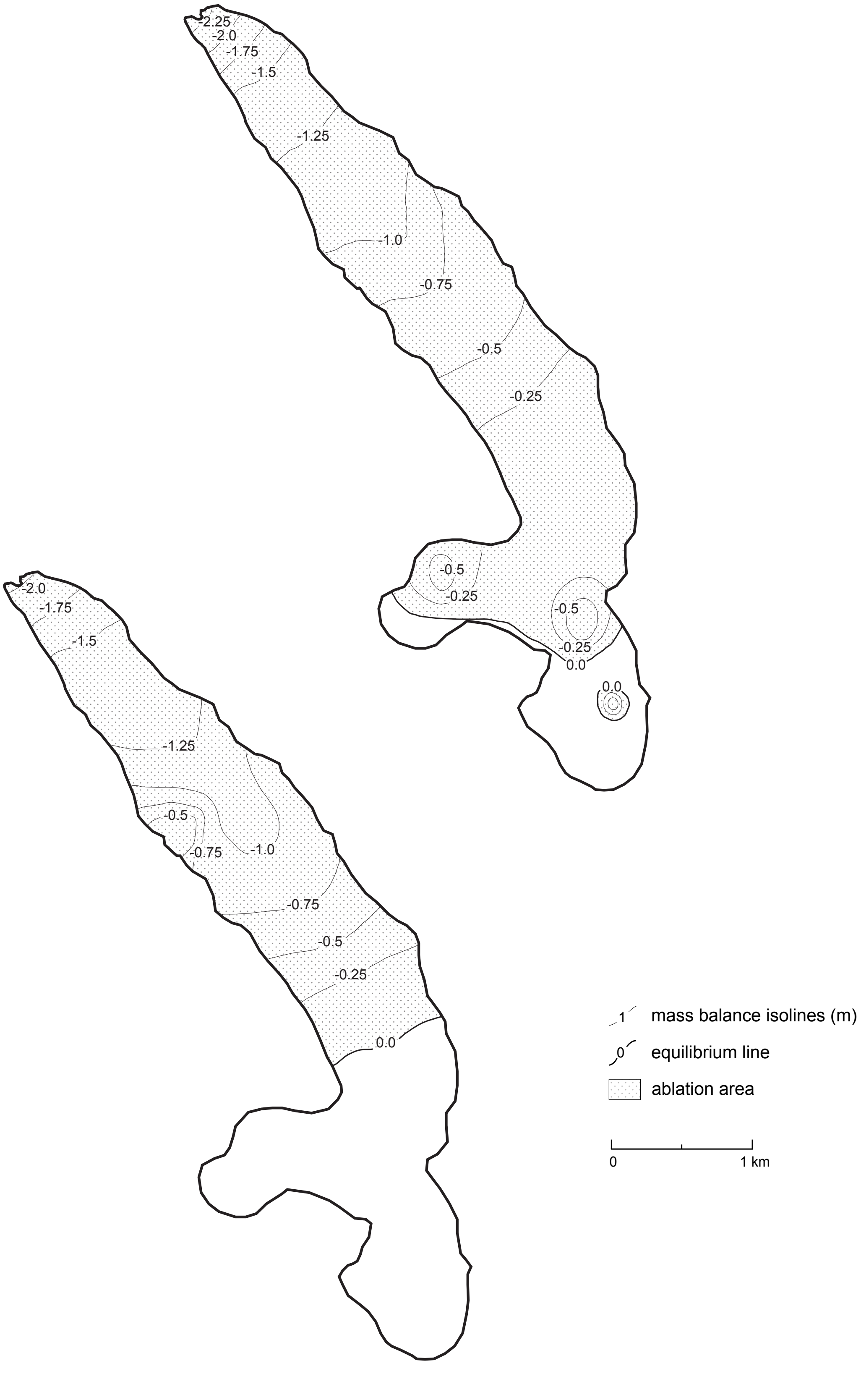


Freya (GREENLAND)

3.7.2 Mass balance maps 2007/08 and 2008/09

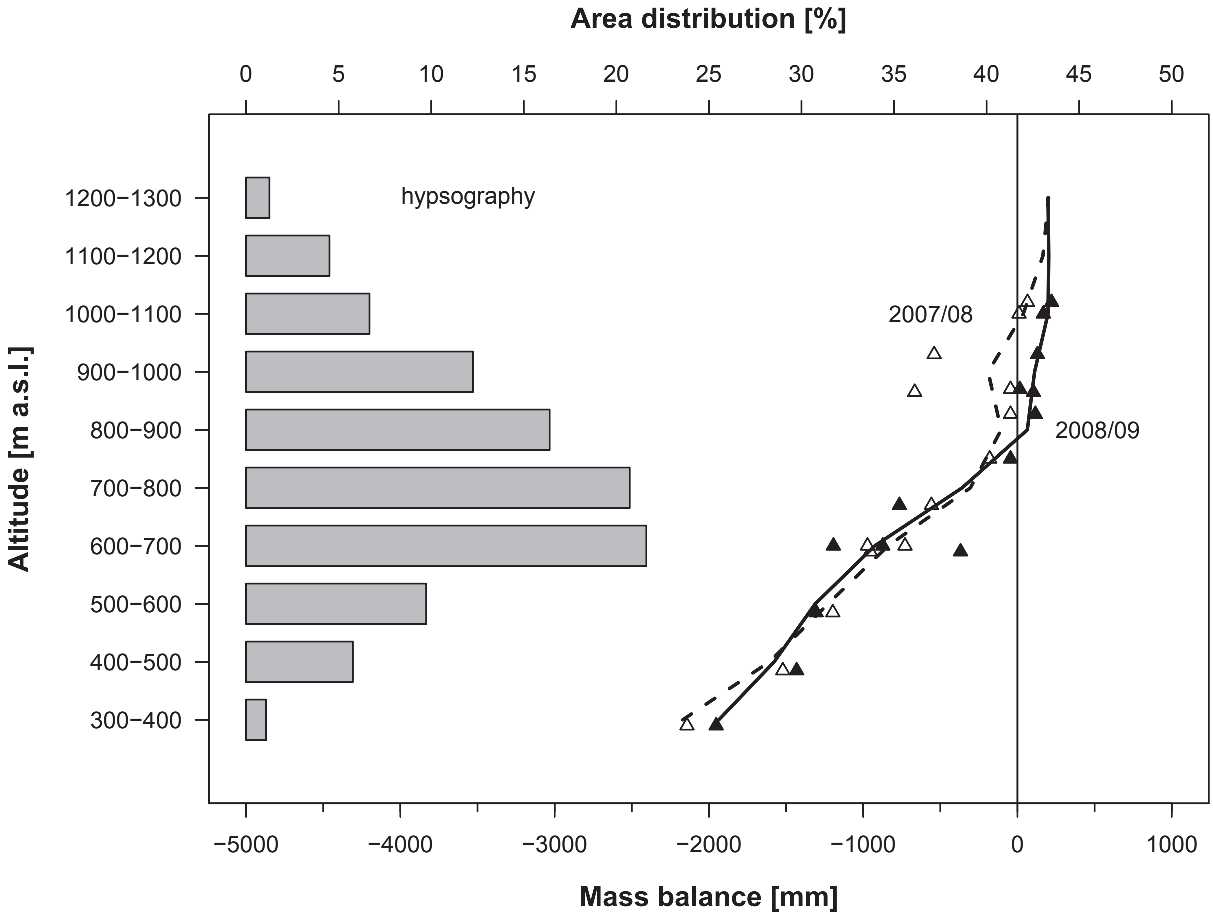
2007/08

2008/09

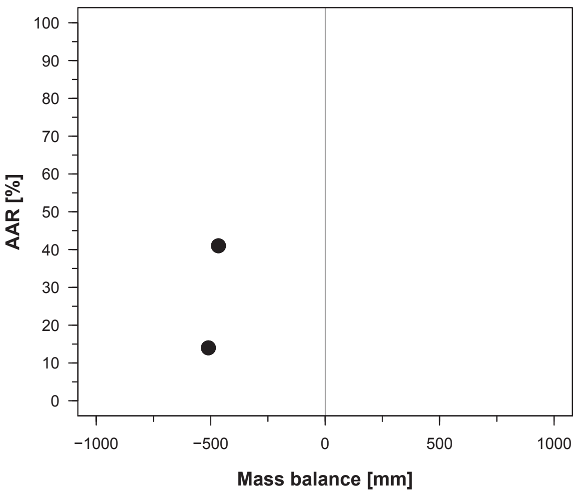


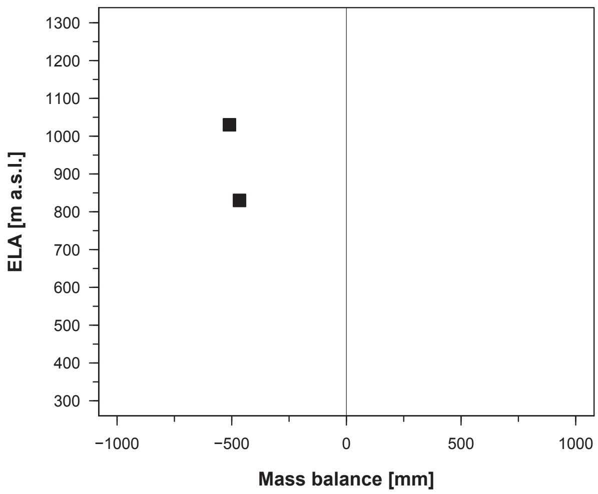
Freya (GREENLAND)

3.7.3 Mass balance versus altitude (2007/08 and 2008/09)



3.7.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Freya (GREENLAND)

3.8 CARESÈR (ITALY/CENTRAL ALPS)

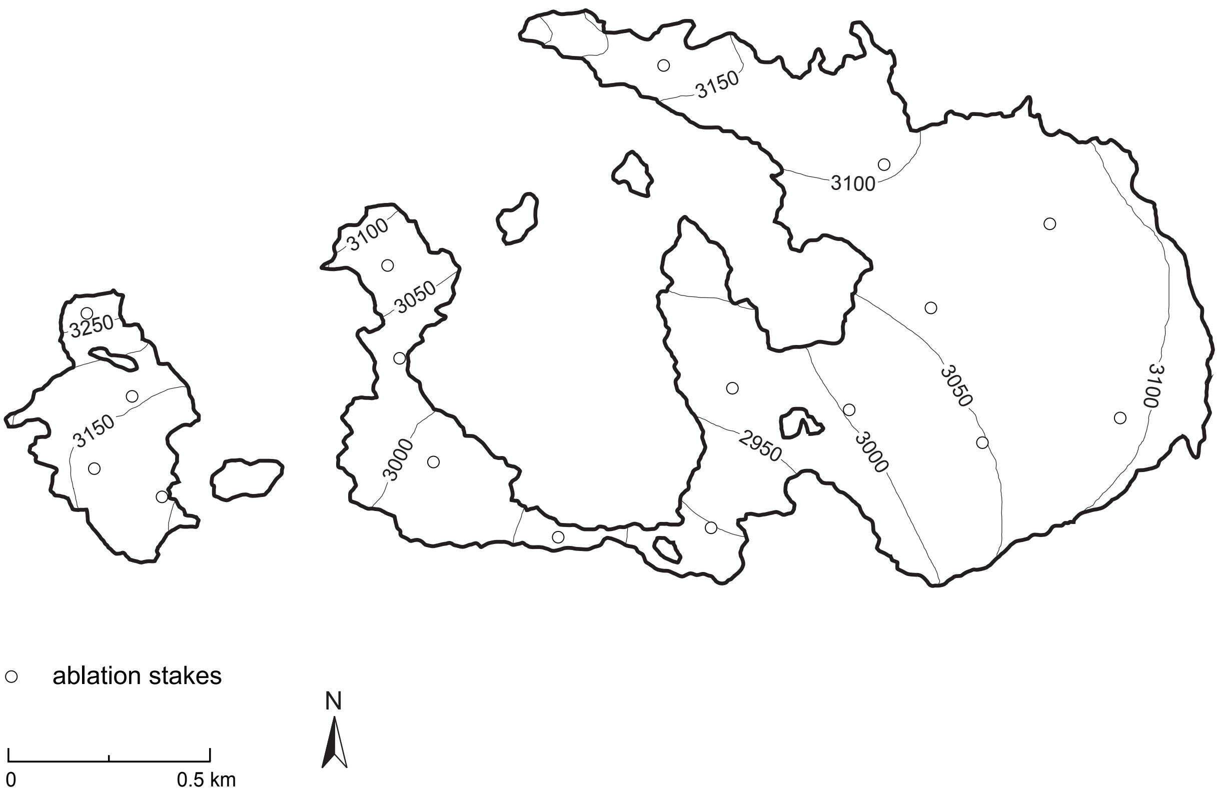
COORDINATES: 46.45° N / 10.70° E

Aerial view of Caresèr Glacier taken on 21 September 2010. Photo by G. Tognoni.

Caresèr Glacier is located in the eastern part of the Ortles-Cevedale group (European Alps, Italy). It occupies an area of 1.9 km^2 and extends from 3277 m to 2875 m a.s.l. The surface is exposed mainly to the south and quite flat. 75 % of the glacier area lies between 2900 and 3100 m a.s.l. and the median altitude is 3077 m a.s.l. The mean annual air temperature at this elevation is about −3 to −4 °C and precipitation averages 1450 mm, of which 80 % falls as snow. The mass balance investigations on Caresèr Glacier began in 1967 and continues until present without interruption. The glacier mass balance was near to equilibrium until 1980, but since then it has shown strong mass losses. In the last thirty years the ELA was mostly above the maximum altitude of the glacier, which became inactive. The mean value of the annual mass balance was −1200 mm w.e. from 1981 to 2002, but decreased to −2100 mm w.e. from 2003 to 2009. This is a result of both warmer ablation seasons and positive feedbacks (albedo and surface lowering). The repeated negative mass balances are causing huge changes in glacier morphology due to widespread bedrock emersion. The first remarkable event was the detachment of the western portion of the glacier from the main ice body in 2005. In the last three years the glacier was subjected to further fragmentation.

During the hydrological years 2007/08 and 2008/09, the mass balance of Caresèr Glacier was negative, at −1851 and −1236 mm w.e., respectively. The ablation seasons were warm and long, but in 2009 the high snow accumulation during winter (40 % above the long-term mean) led to a less negative mass balance.

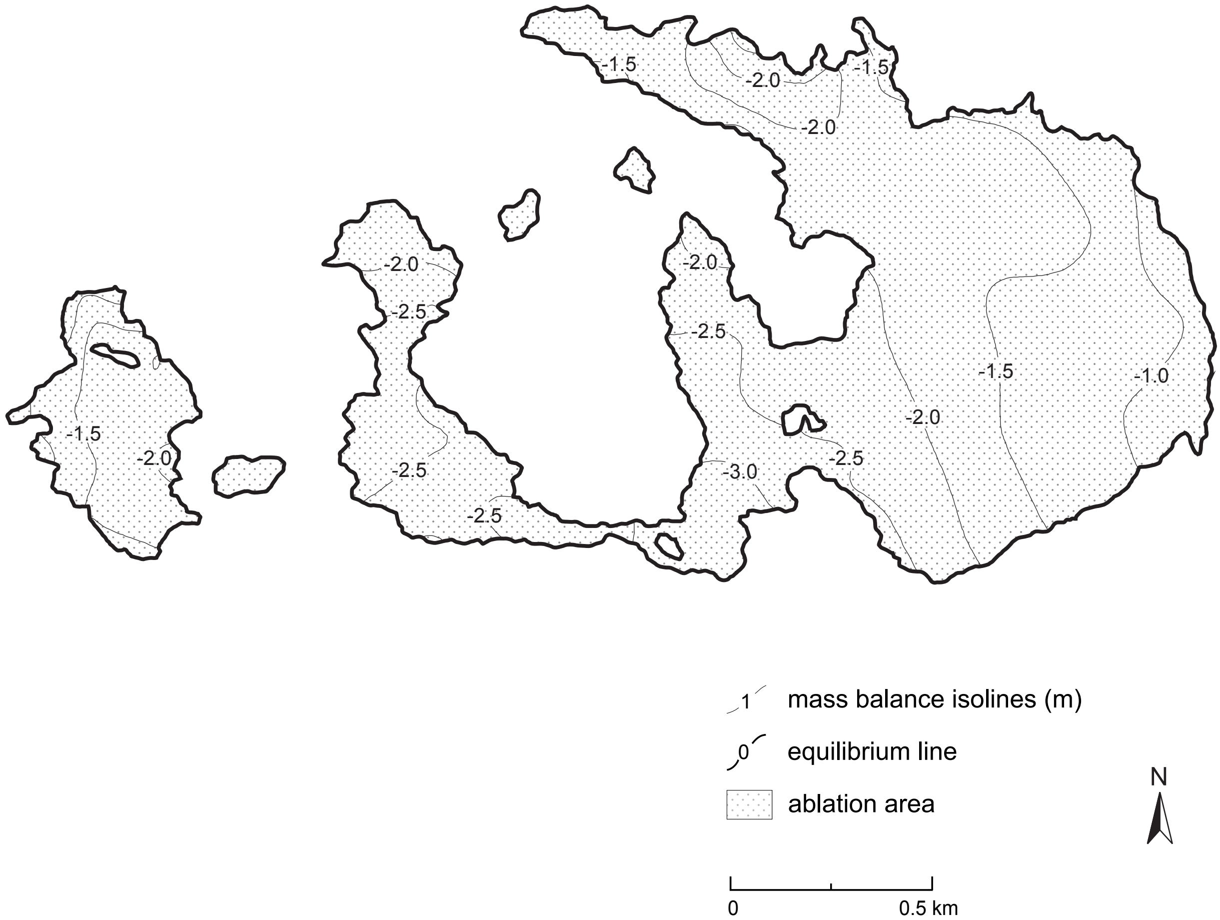
3.8.1 Topography and observation network



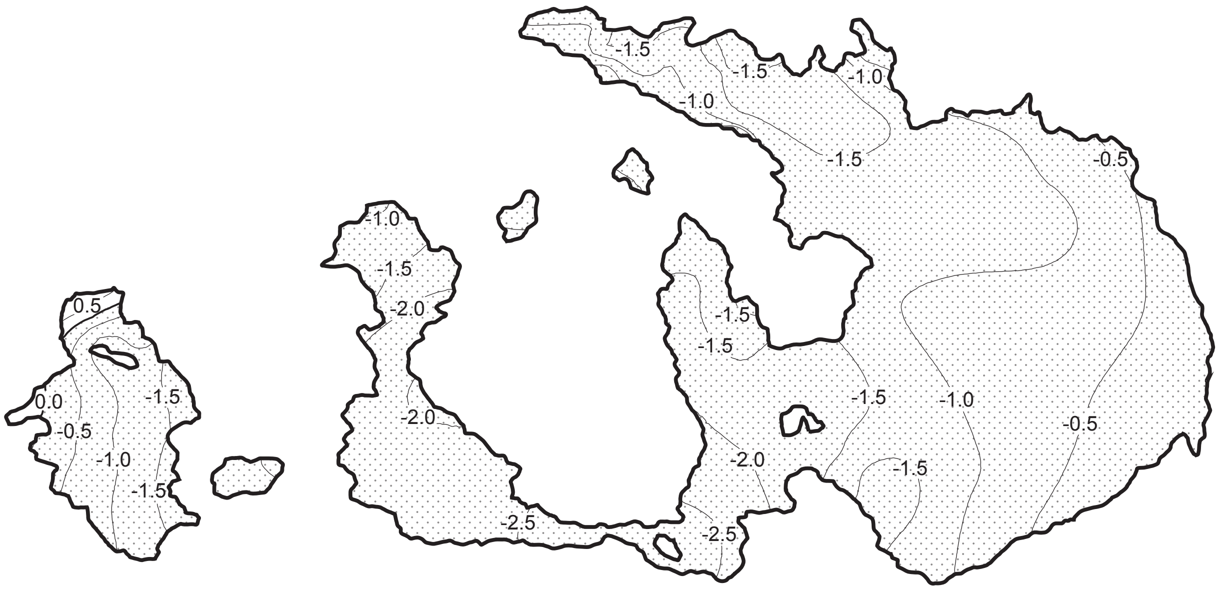
Caresèr (ITALY)

3.8.2 Mass balance maps 2007/08 and 2008/09

2007/08

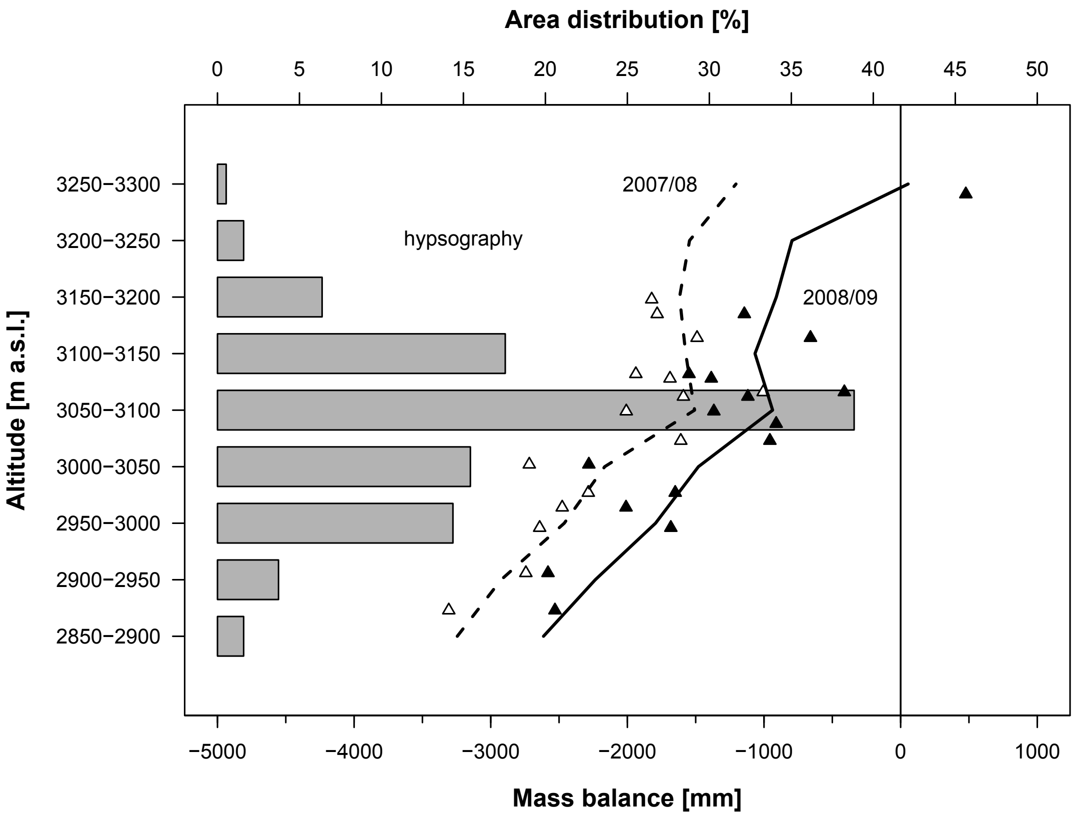


2008/09

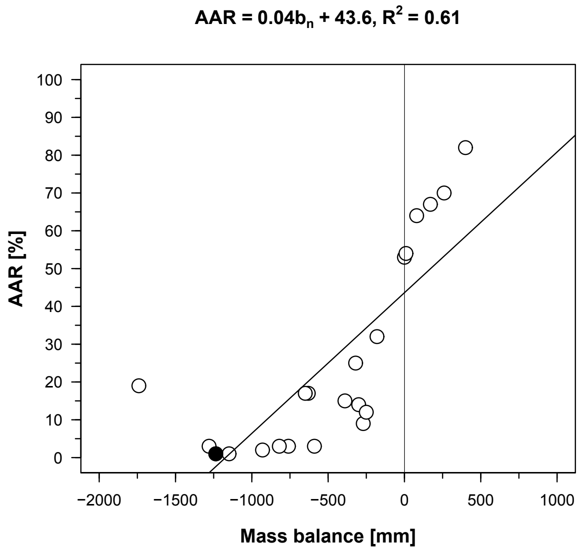


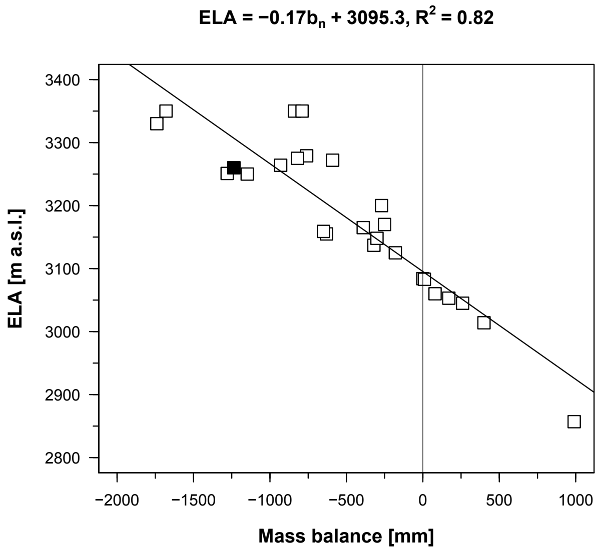
Caresèr (ITALY)

3.8.3 Mass balance versus altitude (2007/08 and 2008/09) for the entire glacier



3.8.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





3.9 TSENTRALNIY TUYUKSUYSKIY (KAZAKHSTAN/TIEN SHAN)

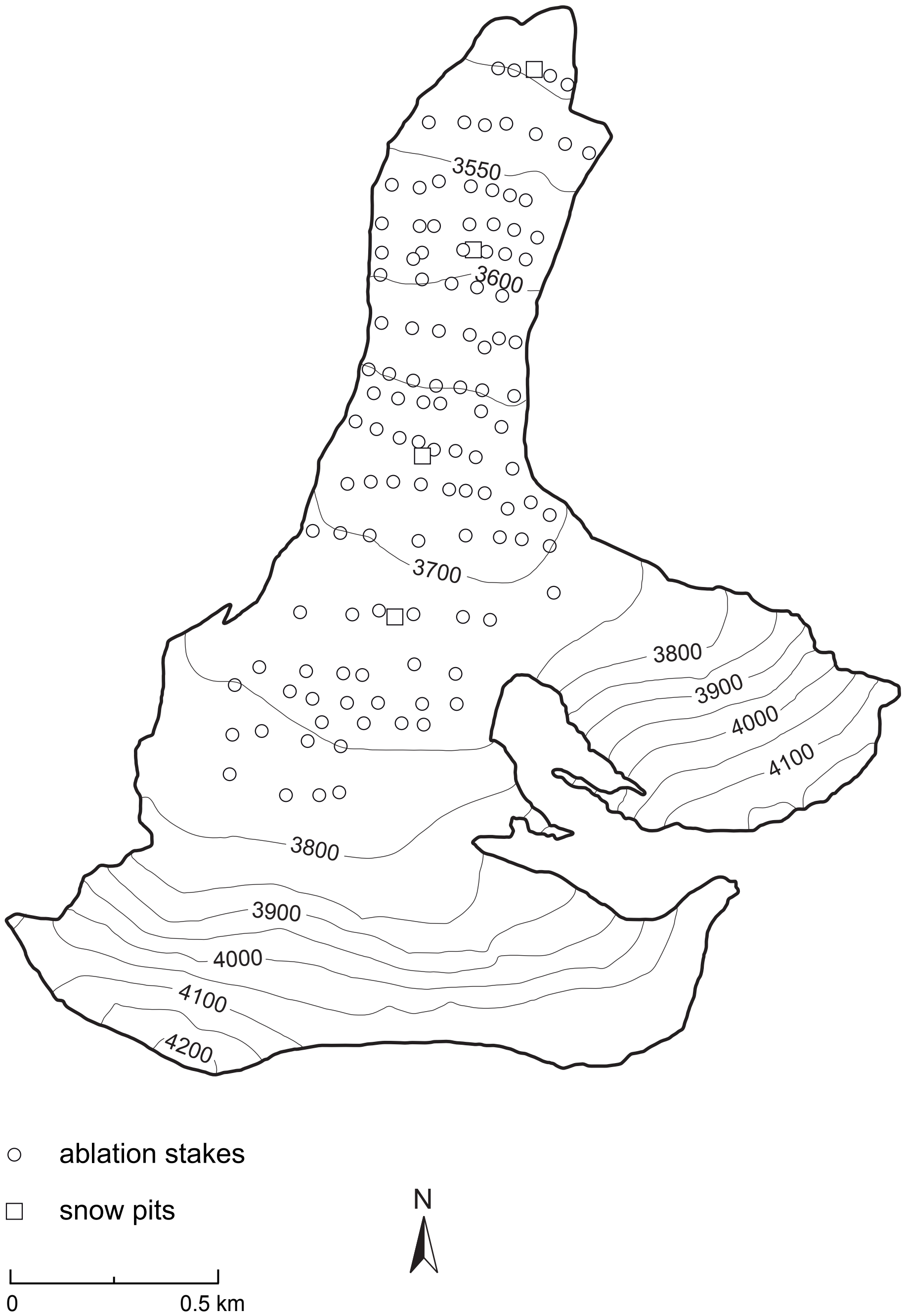
COORDINATES: 43.05° N / 77.08° E

Photo taken by V. P. Blagoveshensky, July 2007.

This valley glacier in the Zailiyskiy Alatau Range of Kazakh Tien Shan is also called the Tuyuksu Glacier. It extends from 4219 m to 3492 m a.s.l. and has a surface area of 2.451 km^2 (including debris-covered ice) with exposure to the north. Mean annual air temperature at the equilibrium line of the glacier in 2008 (around 3980 m a.s.l.) was –7 °C for balanced conditions, and –5 to –6 °C in 2009 (ELA around 3710 m a.s.l.). The glacier is considered to be cold to polythermal and surrounded by continuous permafrost.

Average annual precipitation as measured with 13 precipitation gauges for the balance year 2007/08 was equal to 858 mm. For the balance year 2008/09, it amounted to 1260 mm. The summer precipitation equaled 55 % of the annual sum in 2008, and 29 % in 2009. Annual precipitation at the meteorological station Tuyuksu (3450 m a.s.l.) equaled 741 mm (of which 492 mm summer precipitation) in 2007/08, and 996 mm in 2008/09 (375 mm in summer). The average summer temperature was 6.3 °C in 2008, and 4.4 °C in 2009. The summer season of 2008 was 1.4 °C warmer, but 0.6 °C colder than average (reference period 1972–2008), while precipitation was 98 mm less in 2008, and 39 mm less in 2009. As a result of these conditions the glacier mass balance was –1357 mm w.e. in 2007/08, and +206 mm w.e. in 2008/09.

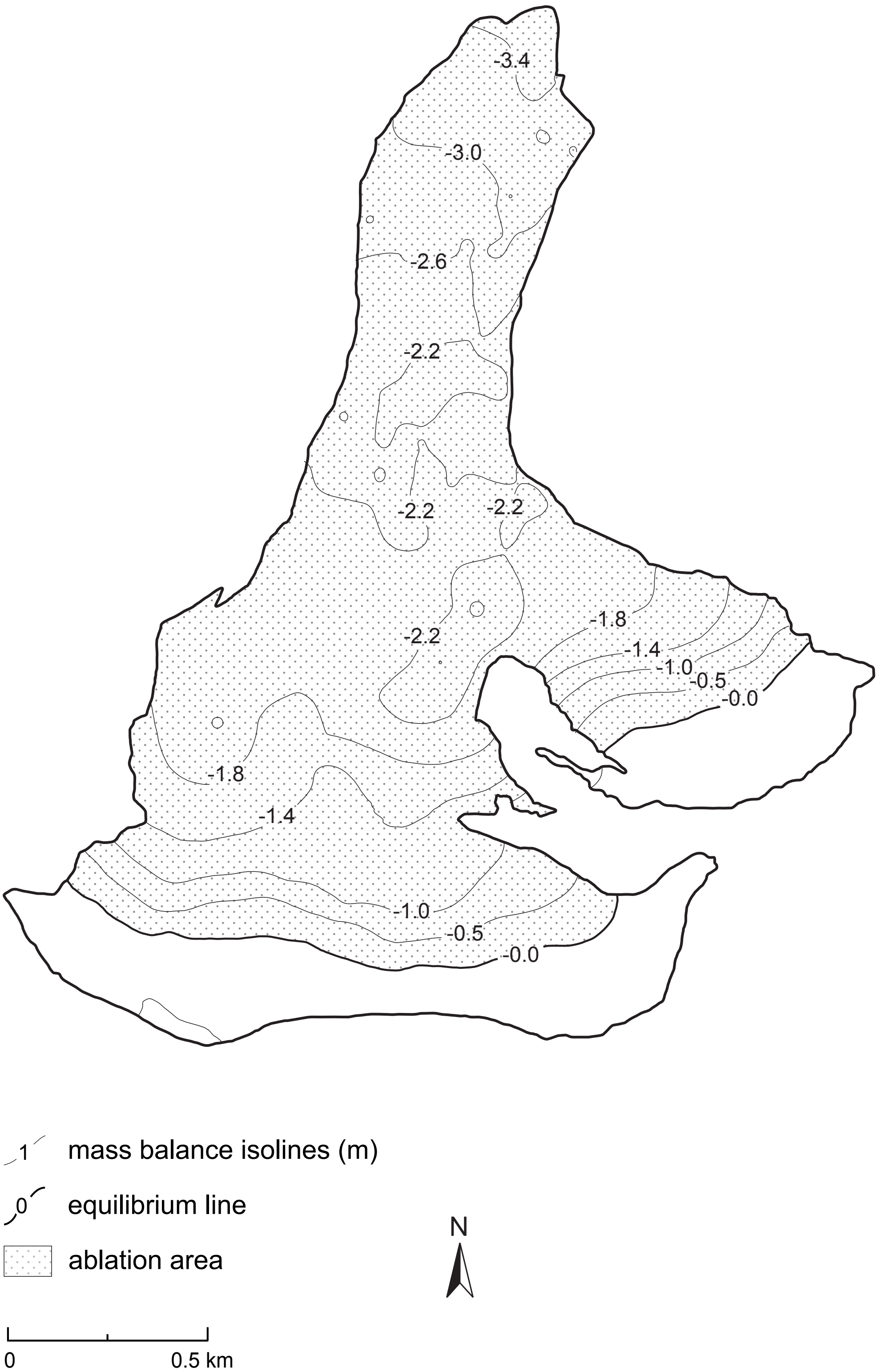
3.9.1 Topography and observation network



Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

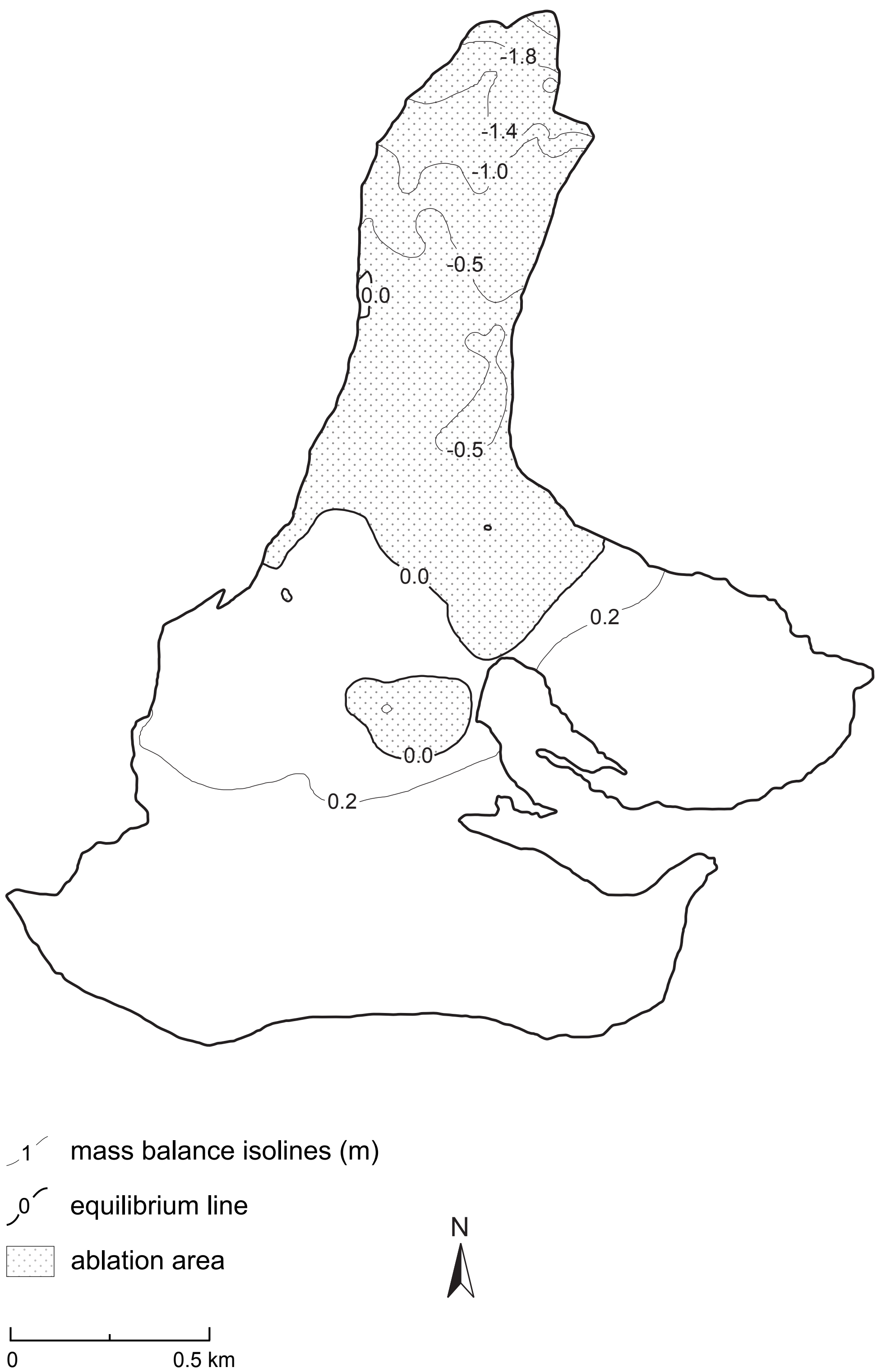
3.9.2 Mass balance maps 2007/08 and 2008/09

2007/08



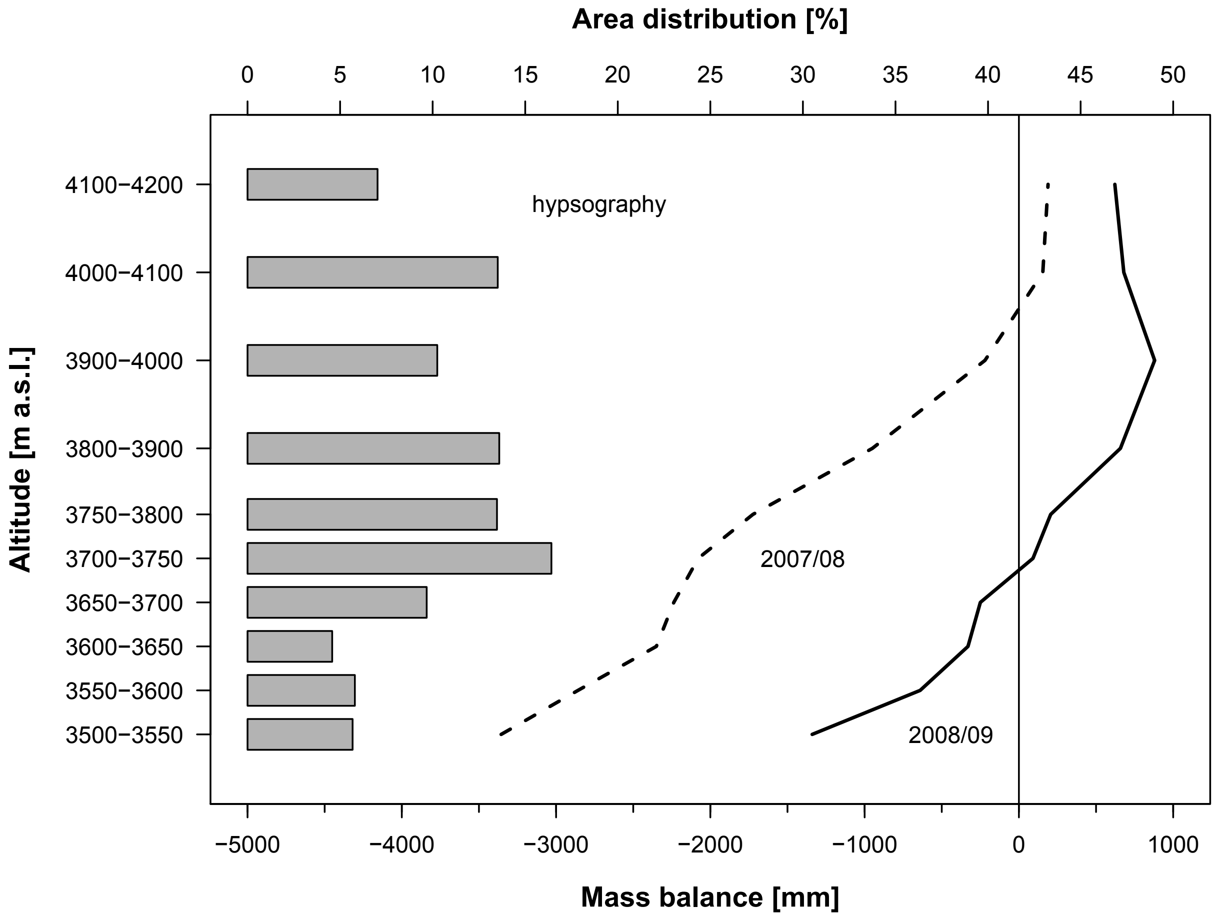
Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

2008/09

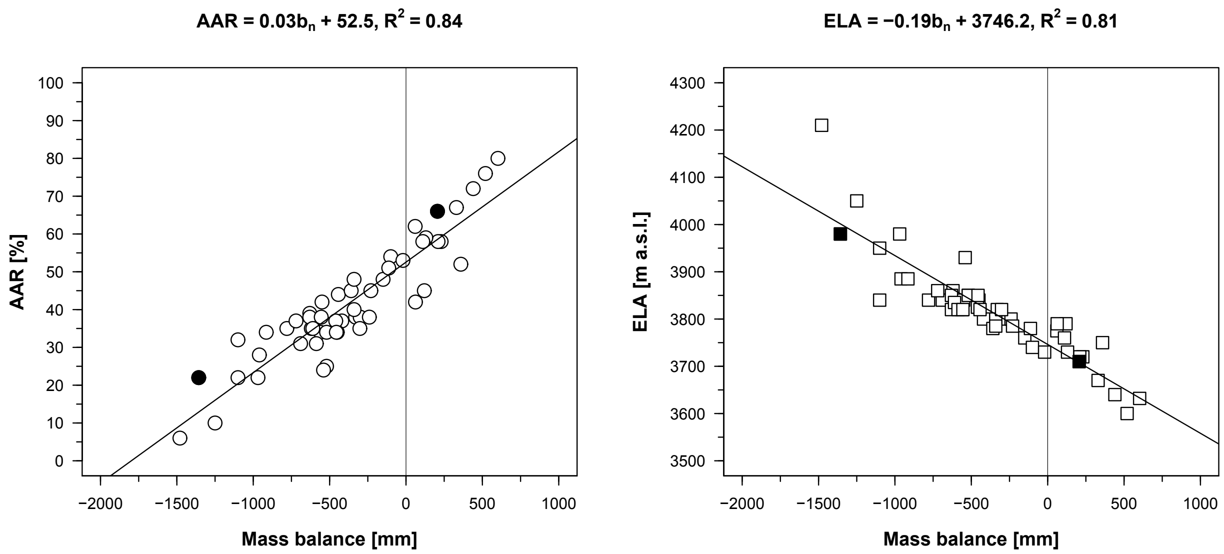


Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.9.3 Mass balance versus altitude (2007/08 and 2008/09)



3.9.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period



Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.10 BREWSTER (NEW ZEALAND/TITITEA MT ASPIRING NP)

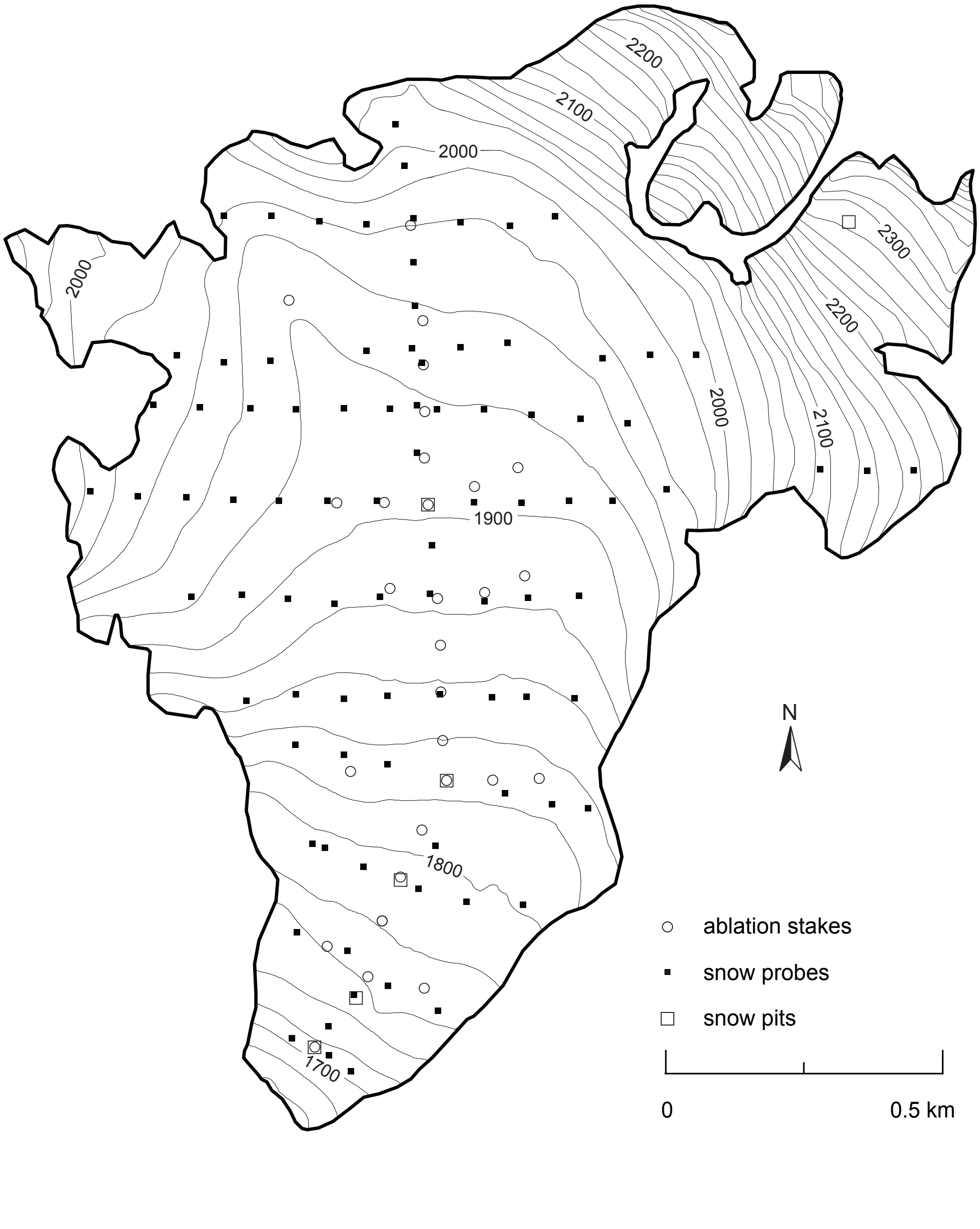
COORDINATES: 44.08° S / 169.44° E

Aerial view of Brewster Glacier taken by A. Willsman, 3 March 2009.

Brewster Glacier is a temperate glacier on the Main Divide of the Southern Alps of New Zealand and lies south of Mt Brewster (2515 m a.s.l.). The glacier has an area of about 2.5 km^2, is about 2.5 km long, and extends over an elevation range of 730 m, from 2390 m to 1660 m a.s.l. The major part of the glacier, up to about 2000 m a.s.l., faces south with an average slope of 11°, and the top 400 m have a south-westerly aspect with a mean slope of 31°. The maximum ice thickness is about 150 m, and a few hundred meters up the snout there is a bed overdeepening. On the western margin of the glacier the valley walls are not clearly confined. The glacier surface is very clean and there is little sedimentation in the glacier forefield. The exposed bedrock is polished and displays abrasion marks from the glacier. These observations, the very few debris delivering rockwalls surrounding Brewster Glacier and very low frequency surface-impedance measurements suggest minor subglacial sediments, with eroding rather than sedimenting glacier activities. Brewster Glacier is a maritime glacier type with an annual mean precipitation (1951–1980) between 3200–4800 mm and a mean annual air temperature at the ELA (ca. 1900 m a.s.l. for a balanced year) of about 1 °C.

In the years 2007/08 and 2008/09, the mass balances were negative (−1653 mm w.e. and −828 mm w.e., respectively) with an ELA above the glacier limits in 2008 and at 2034 m a.s.l. in 2009. More knowledge about the mass balance above 2000 m a.s.l. and new glacier outlines are needed. Updated glacier outlines would resolve the discrepancies between the mentioned altitude range and the topographical map.

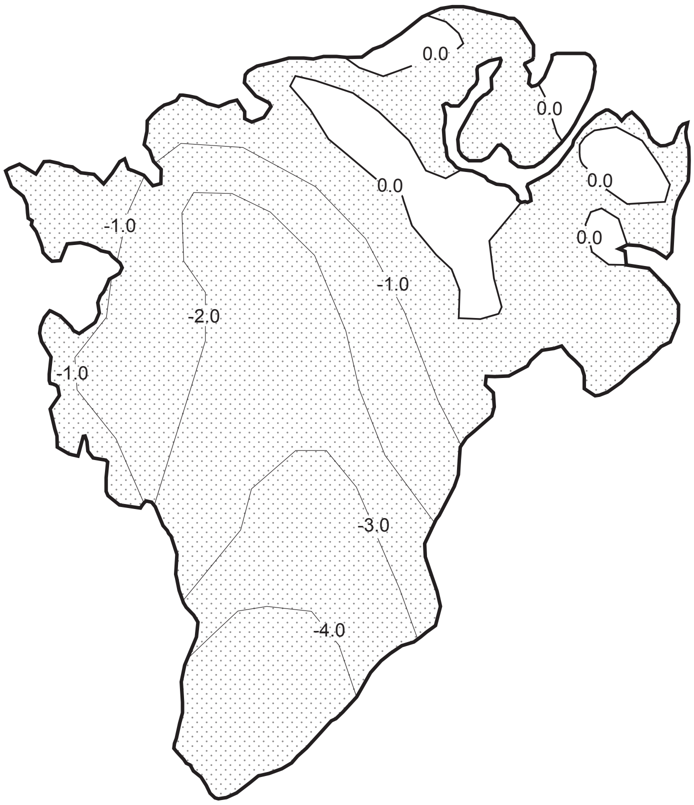
3.10.1 Topography and observation network



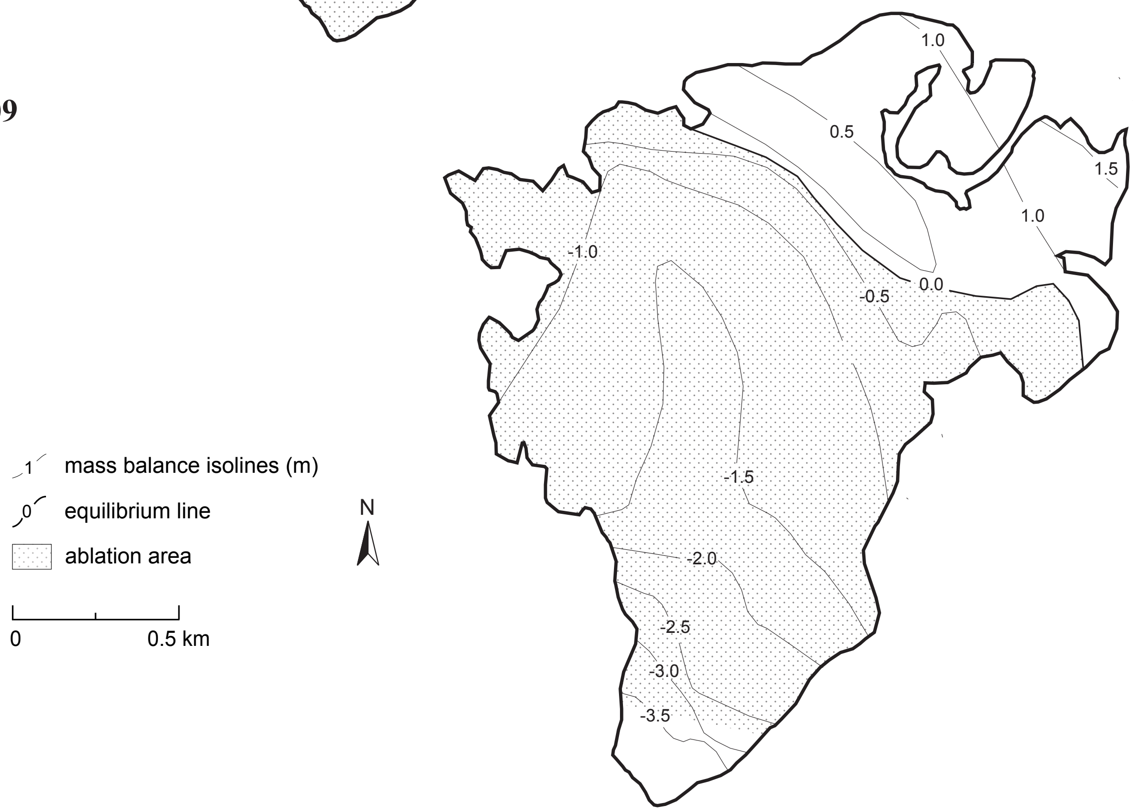
Brewster Glacier (NEW ZEALAND)

3.10.2 Mass balance maps 2007/08 and 2008/09

2007/08

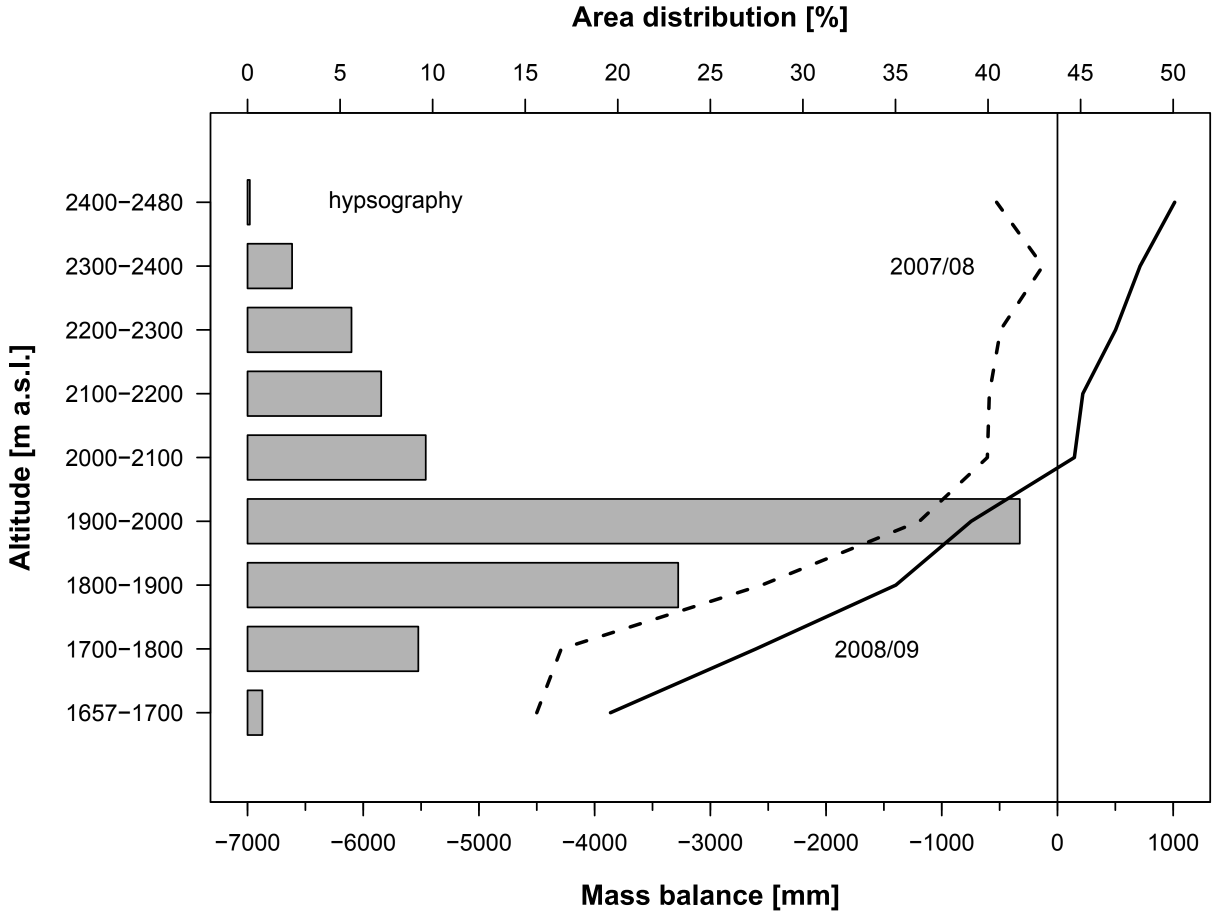


2008/09

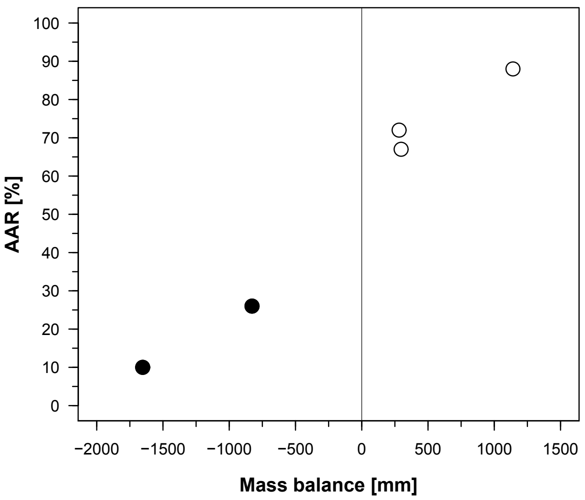


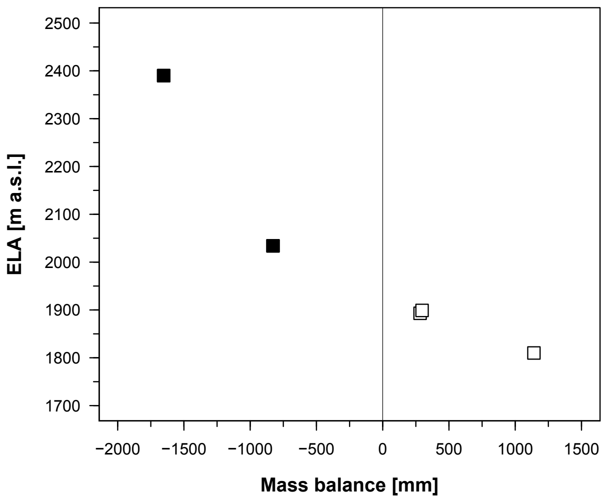
Brewster Glacier (NEW ZEALAND)

3.10.3 Mass balance versus altitude (2007/08 and 2008/09)



3.10.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Brewster Glacier (NEW ZEALAND)

3.11 WALDEMARBREEN (NORWAY/SPITSBERGEN)

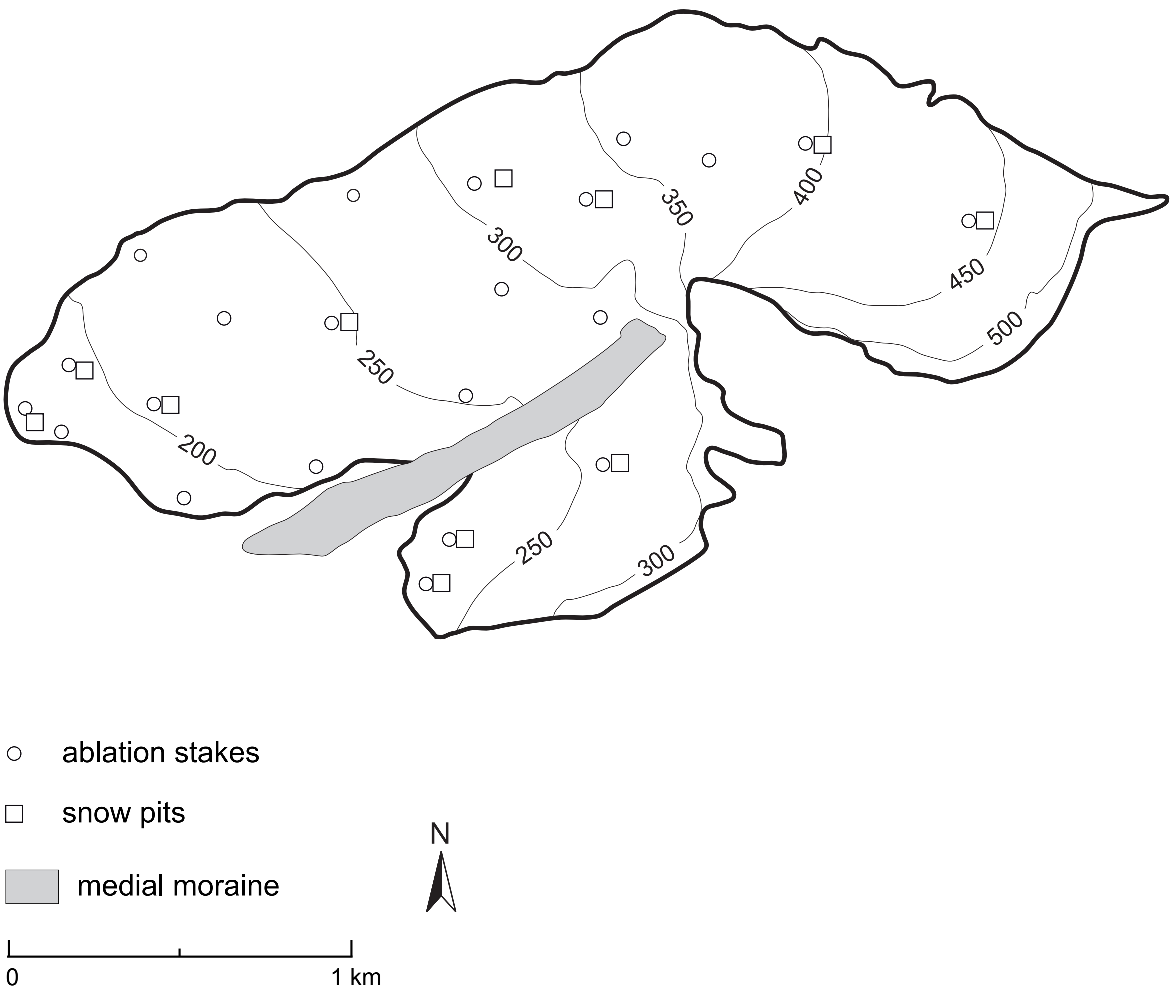
COORDINATES: 78.67° N / 12.00° E

Photo taken by I. Sobota in the summer of 2009.

Waldemarbreen is located in the northern part of the Oscar II Land, north-western Spitsbergen, and flows downvalley to the Kaffiøyra plane. Kaffiøyra is a coastal lowland situated on the Forlandsundet. The glacier is composed of two parts separated by a 1600 m long medial moraine. It occupies an area of 2.5 km^2 and extends from 500 m to 150 m a.s.l. with a general exposure to the west. Mean annual air temperature in this area is about –4 to –5 °C and annual precipitation is generally 300–400 mm. Since the 19th century the surface area of the Kaffiøyra glaciers has decreased by approximately 37 %. Recently Waldemarbreen has been retreating. Detailed mass balance investigations have been conducted since 1995.

The balance in 2007/08 showed a net mass loss of –322 mm w.e. In 2008/09 the mass balance was –649 mm w.e. The mean value of the mass balance for the period 1995–2009 is –572 mm w.e.

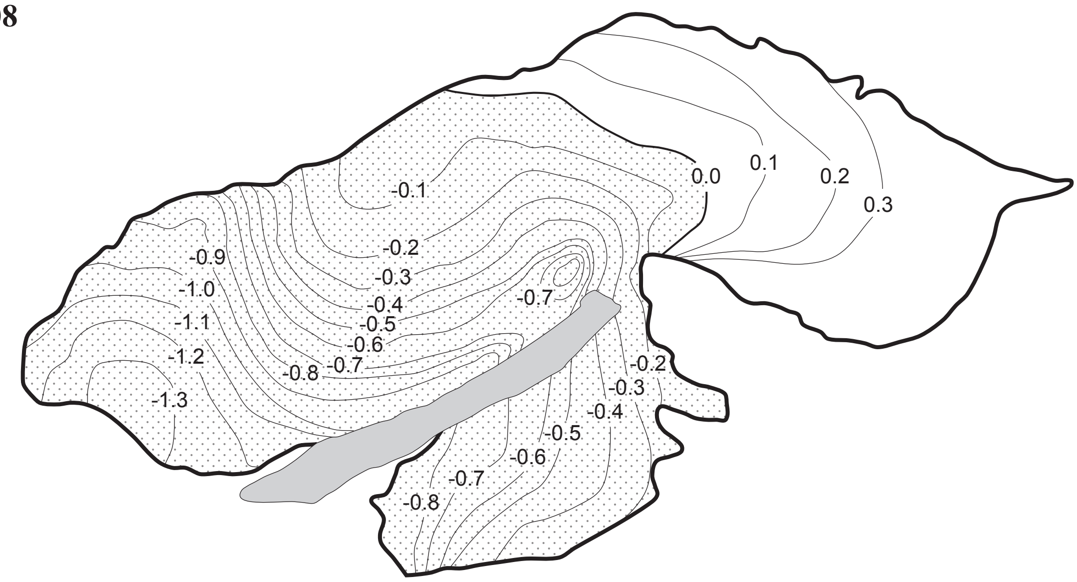
3.11.1 Topography and observation network



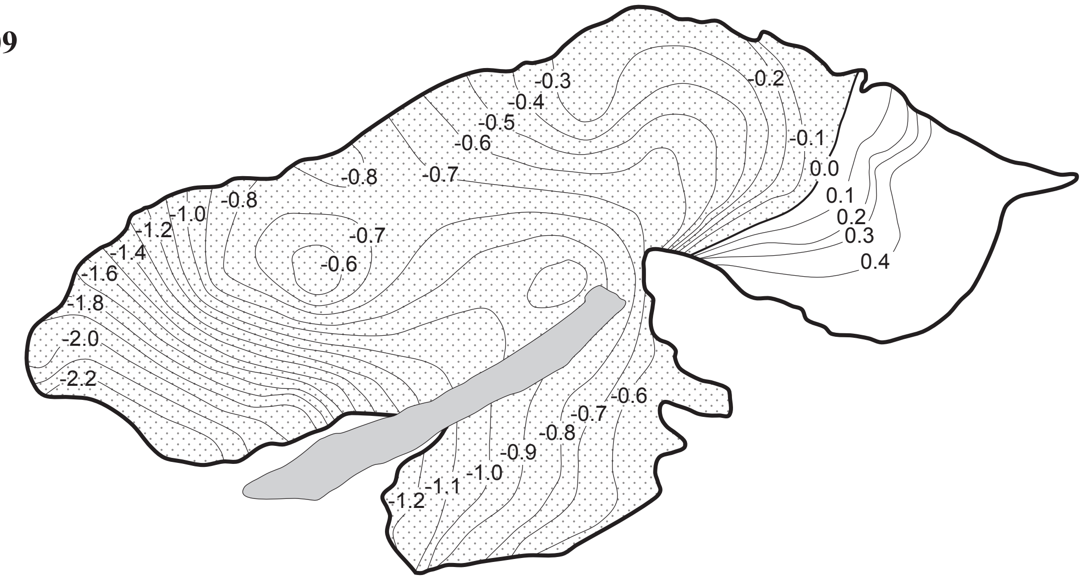
Waldemarbreen (NORWAY)

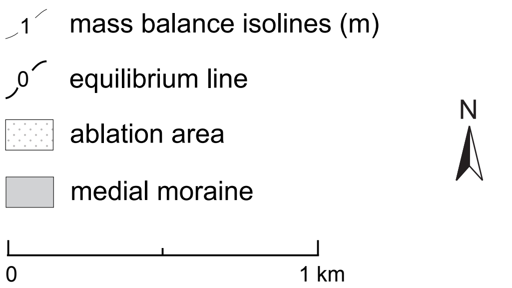
3.11.2 Mass balance maps 2007/08 and 2008/09

2007/08



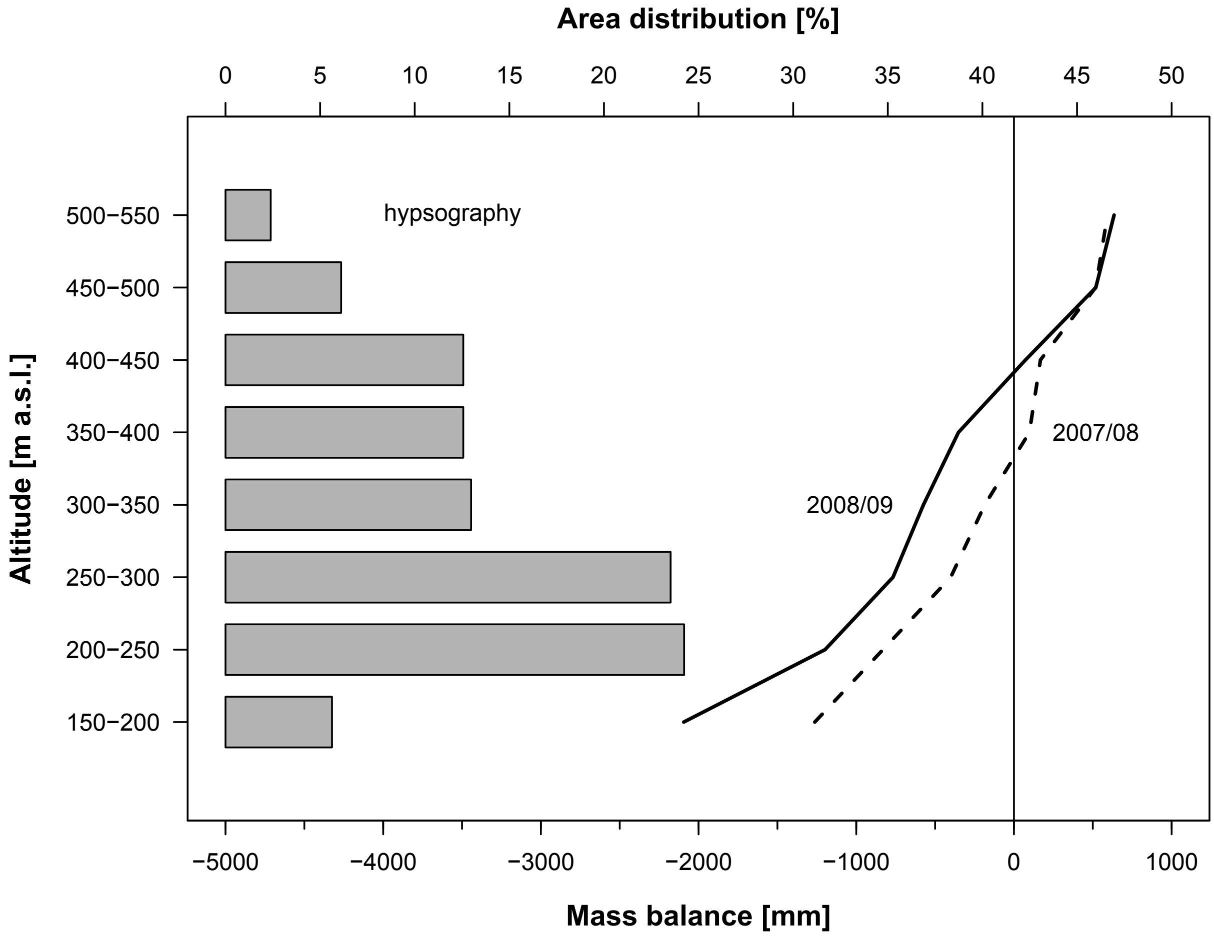
2008/09



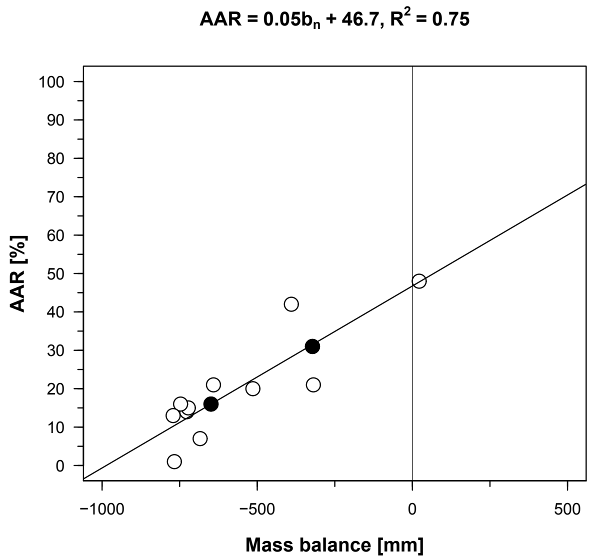


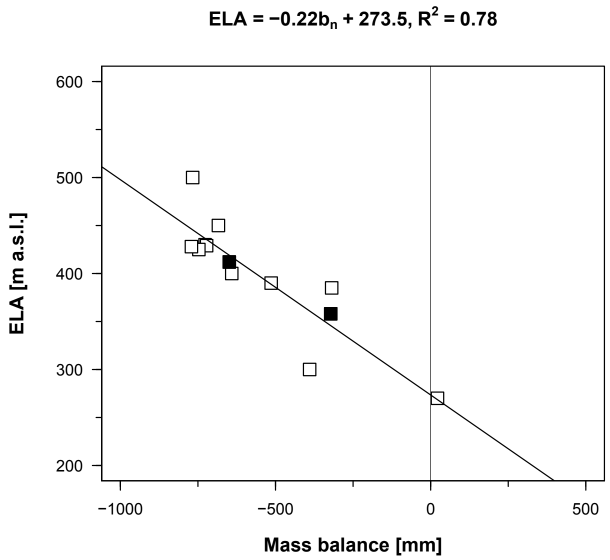
Waldemarbreen (NORWAY)

3.11.3 Mass balance versus altitude (2007/08 and 2008/09)



3.11.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Waldemarbreen (NORWAY)

3.12 NIGARDSBREEN (NORWAY/WESTERN NORWAY)

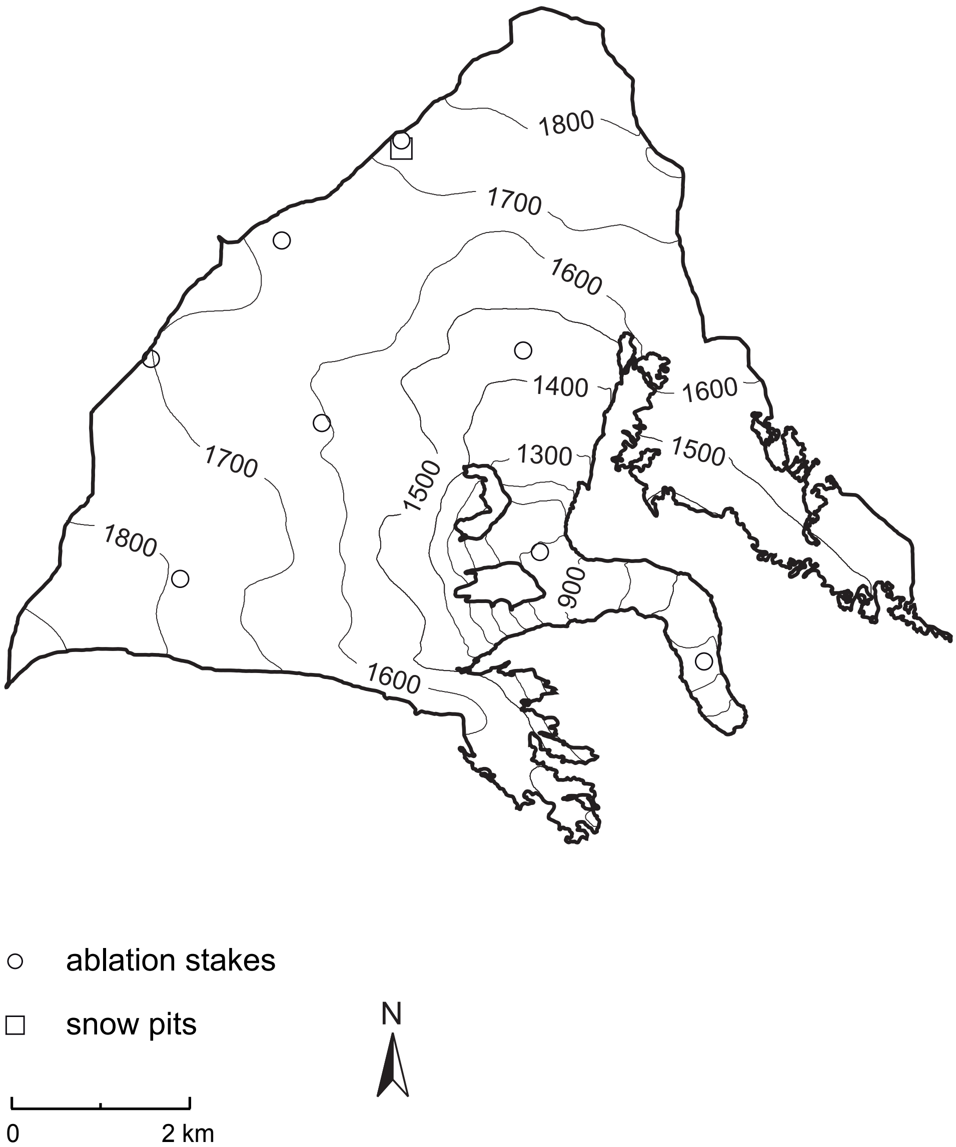
COORDINATES: 61.72° N / 07.13° E

Aerial view of Nigardsbreen taken by B. Kjøllmoen, 31 July 2002.

Nigardsbreen is one of the largest and best-known outlet glaciers from Jostedalsbreen ice cap in Southern Norway. It has an area of 47.2 km^2 (measured in 2009) 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 1957 m down to 315 m a.s.l. Its wide accumulation area discharges into a narrow tongue, both being generally exposed to the south-east. The glacier is assumed to be entirely temperate and the periglacial area to be predominantly free of permafrost. Average annual precipitation for the 1961–1990 period was 1380 mm and mean annual air temperature at the equilibrium line is estimated at −3° C. Nigardsbreen has been the subject of mass balance investigations since 1962.

In 2007/08, the winter balance was +3010 mm w.e. (126 % of the average for the period 1962–2007) and summer balance was −1920 mm w.e. (96 % of the average for 1962-2007). The resulting mass balance was +1100 mm w.e. The calculated equilibrium line altitude is about 1325 m a.s.l. In 2008/09, the winter balance was +2200 mm w.e. (90 % of the mean for the reference period 1971−2000) and summer balance was −1960 mm w.e. (102 % of the mean for the reference period 1971−2000). The resulting mass balance is +240 mm w.e. and the calculated equilibrium line altitude is about 1465 m a.s.l. The mean value for the reference period 1971−2000 is +540 mm w.e., while the average for last ten years (1999−2008) is 140 mm w.e. Since 1962, the cumulative mass balance has been calculated as 19,340 mm w.e.

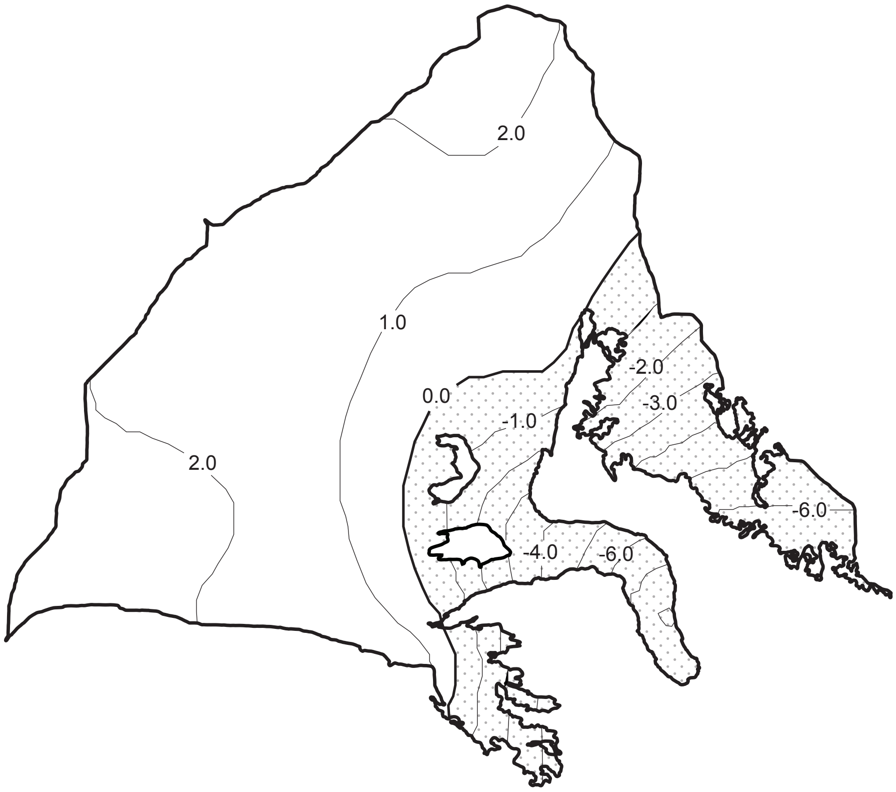
3.12.1 Topography and observation network



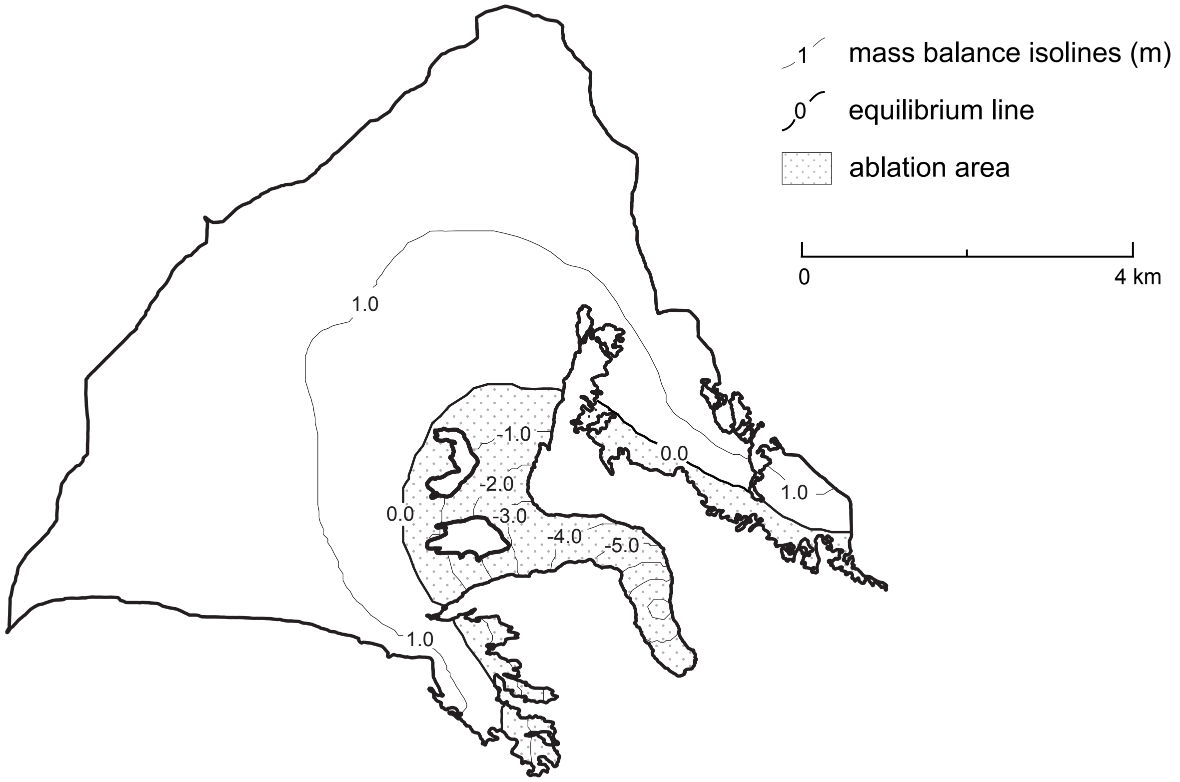
Nigardsbreen (NORWAY)

3.12.2 Mass balance maps 2007/08 and 2008/09

2007/08

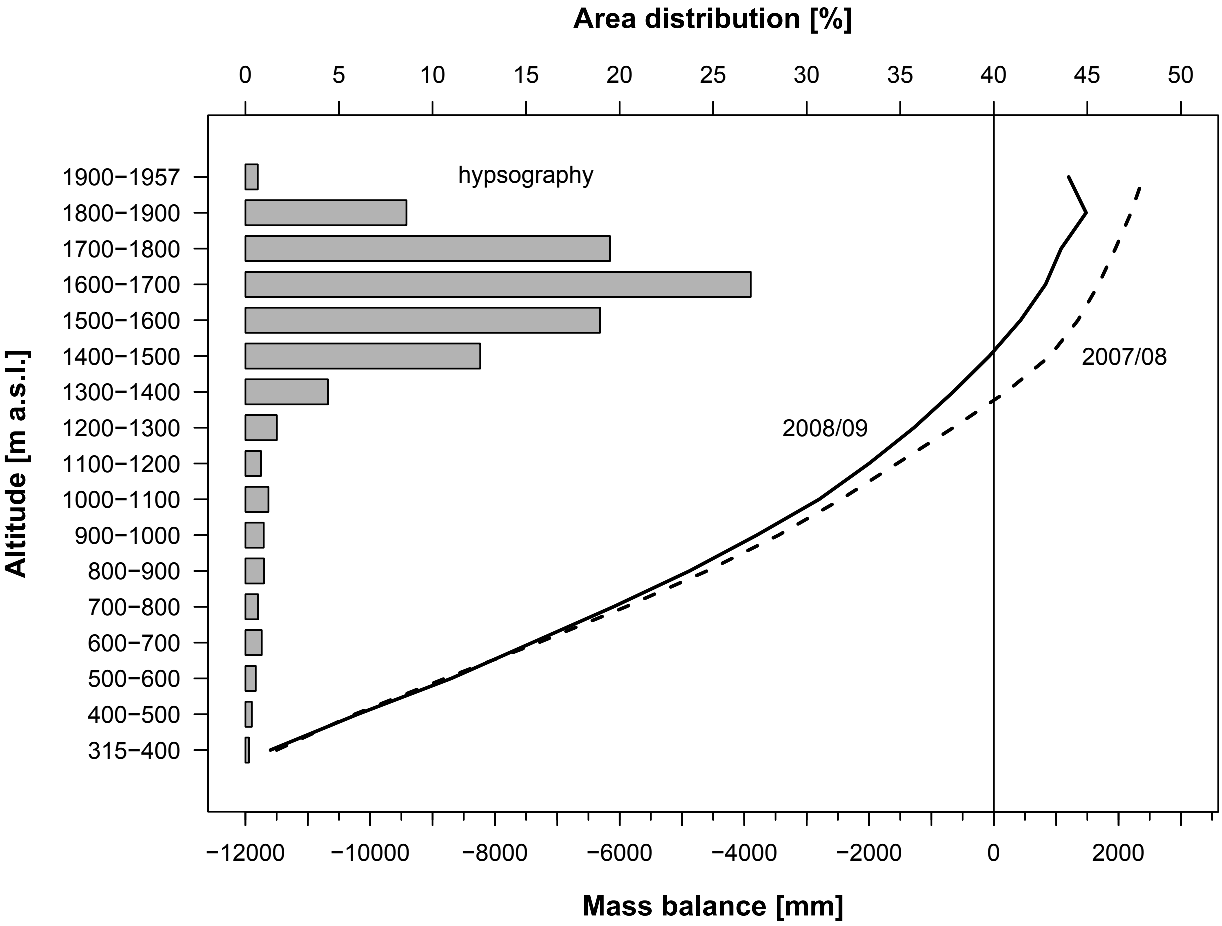


2008/09

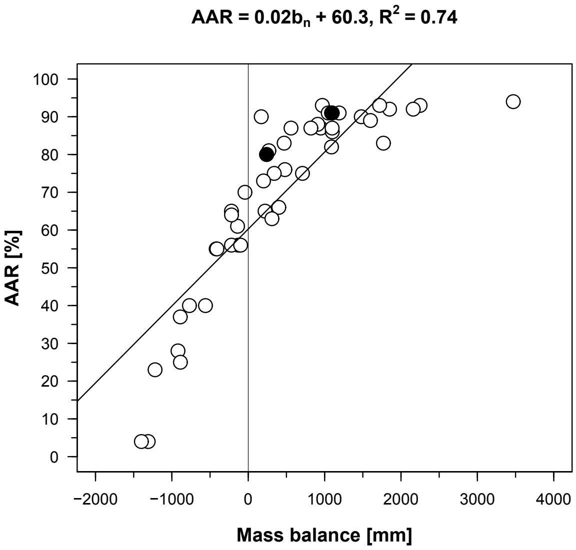


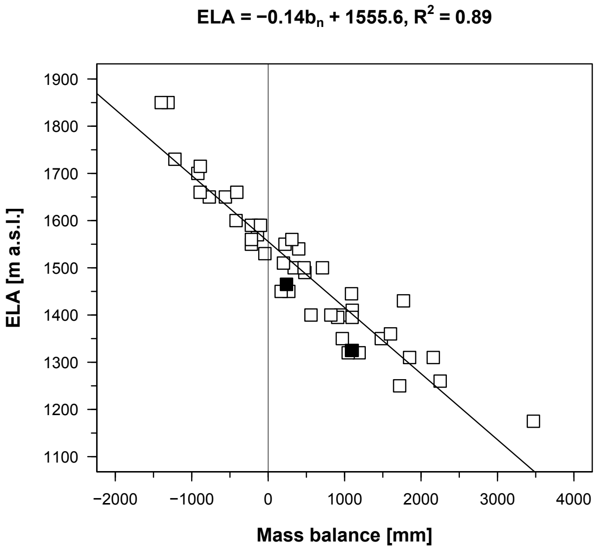
Nigardsbreen (NORWAY)

3.12.3 Mass balance versus altitude (2007/08 and 2008/09)



3.12.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period

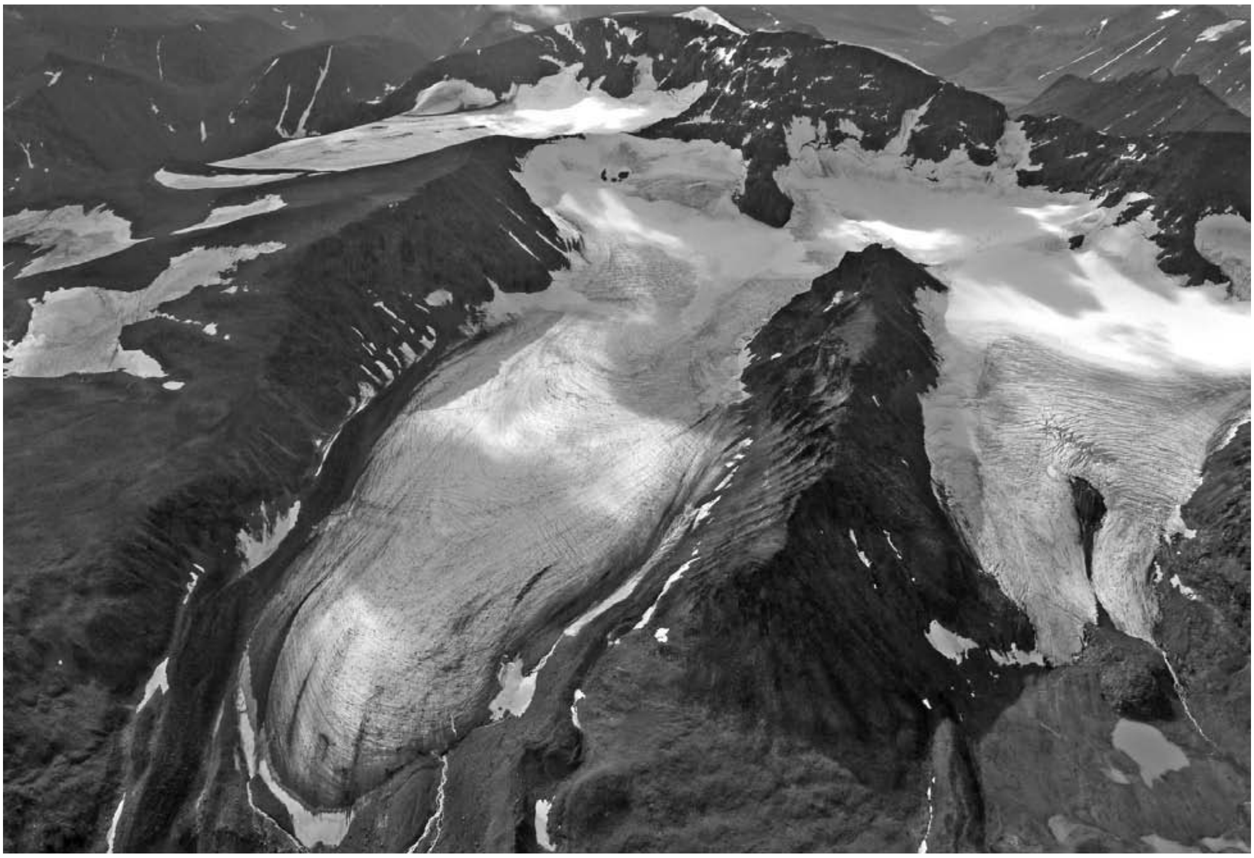




Nigardsbreen (NORWAY)

3.13 STORGLACIÄREN (SWEDEN/NORTHERN SWEDEN)

COORDINATES: 67.90° N / 18.57° E

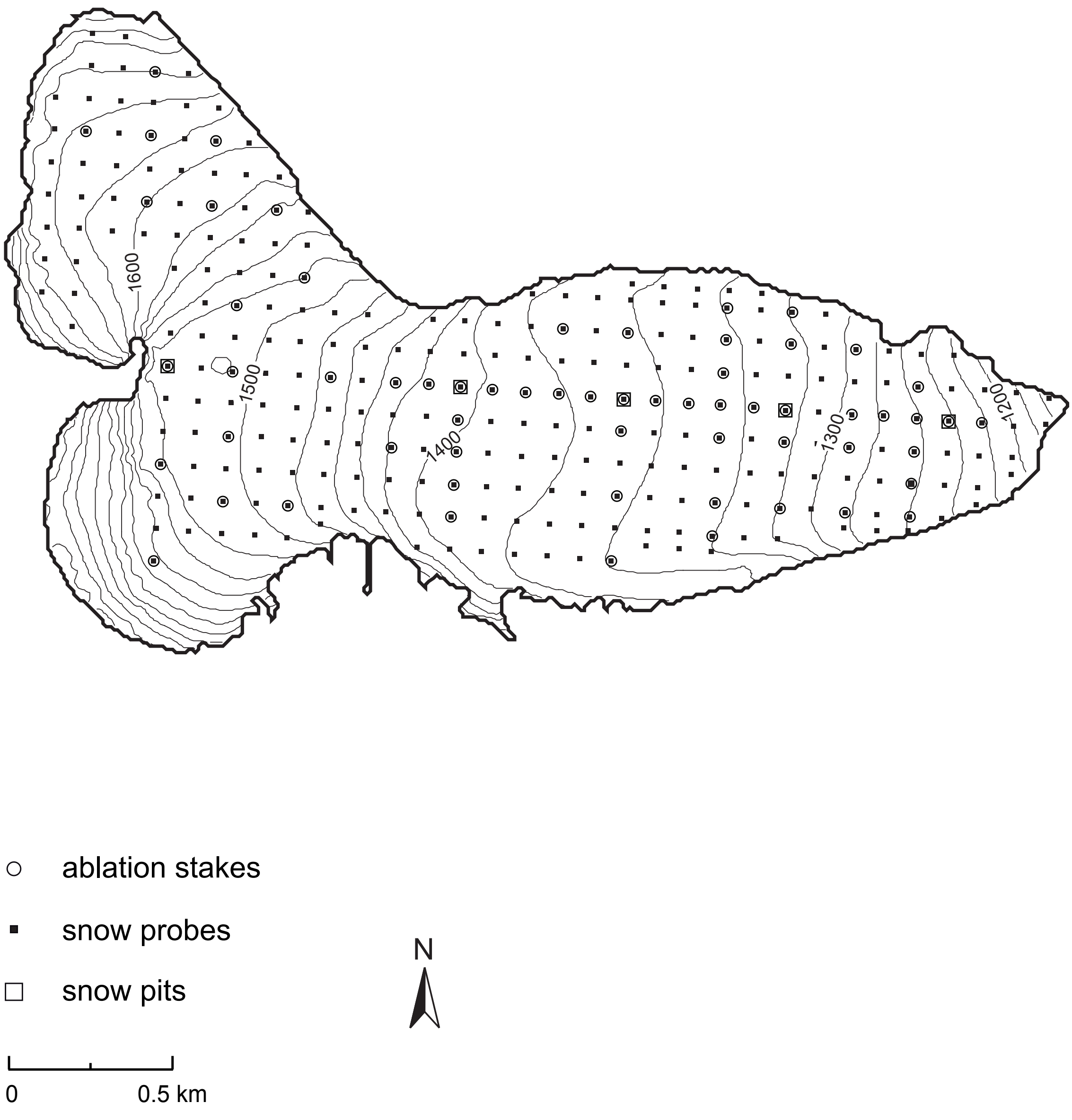


Aerial view of Storglaciären (left) and Isfallsglaciären (right) taken by P. Holmlund, 8 August 2010.

Storglaciären in the Kebnekaise Mountains of northern Sweden is a small valley glacier with a divided accumulation area and a smooth longitudinal profile. It is exposed to the east, maximum and minimum elevations are 1750 m and 1130 m a.s.l., surface area is 3.12 km^2, and average thickness is 95 m (with a maximum thickness of 250 m). Mean annual air temperature at the equilibrium line of the glacier (around 1450 m a.s.l. for balanced conditions) is about −6 °C. Approximately 85 % of the glacier is temperate with a cold surface layer in its lower part (ablation area), and its tongue lying in discontinuous permafrost. Average annual precipitation is about 1000 mm at the nearby Tarfala Research Station.

The mass balance in 2007/08 was positive (+580 mm w.e.) with an ELA at 1410 m a.s.l. and an AAR of 53 %. In 2008/09, the mass balance was negative (−530 mm w.e.), which was reflected in the ELA at 1495 m a.s.l. and the AAR of 37 %. Aerial photographs and corresponding glaciological maps are available for the years 1949/59/69/80/90/99. Recently, diapositives of the original photographs were reprocessed using uniform photogrammetric methods. A comparison of the glaciological mass balance with these new volume changes showed that the mean annual differences between glaciological and volumetric mass balance are less than the uncertainty of the in-situ stake reading and, hence, do not require an adjustment of the glaciological data series.

3.13.1 Topography and observation network

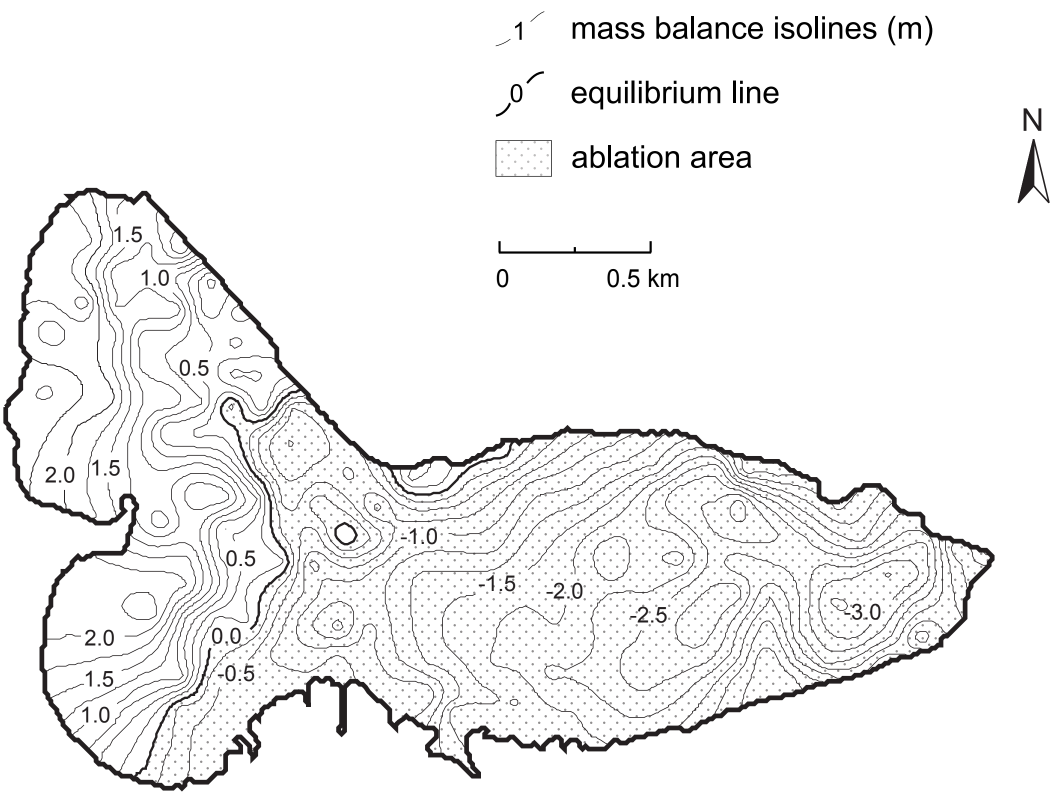


Storglaciären (SWEDEN)

3.13.2 Mass balance maps 2007/08 and 2008/09

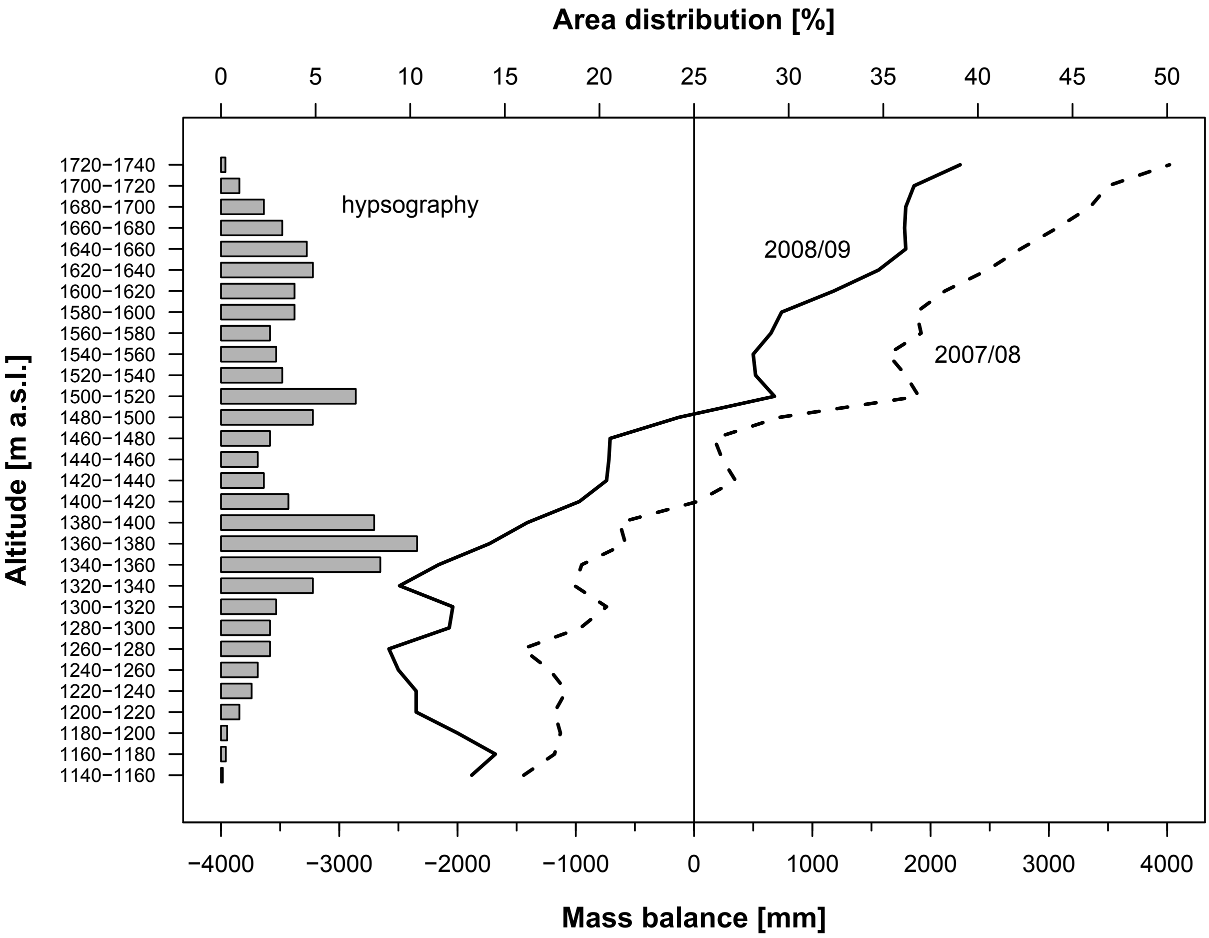
2007/08

2008/09

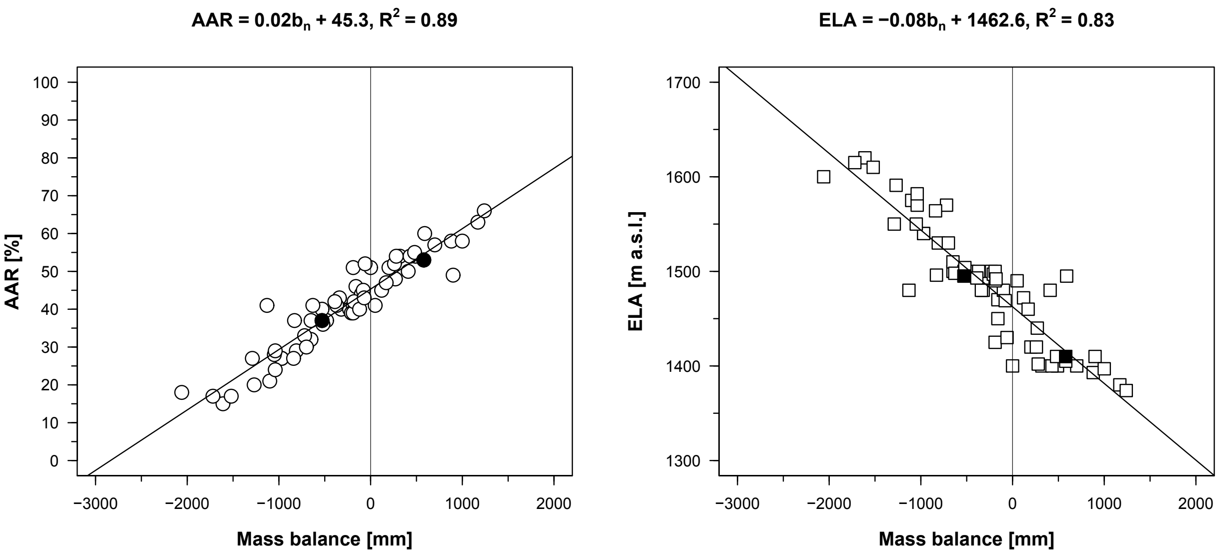


Storglaciären (SWEDEN)

3.13.3 Mass balance versus altitude (2007/08 and 2008/09)



3.13.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period



Storglaciären (SWEDEN)

3.14 GULKANA (USA/ALASKA RANGE)

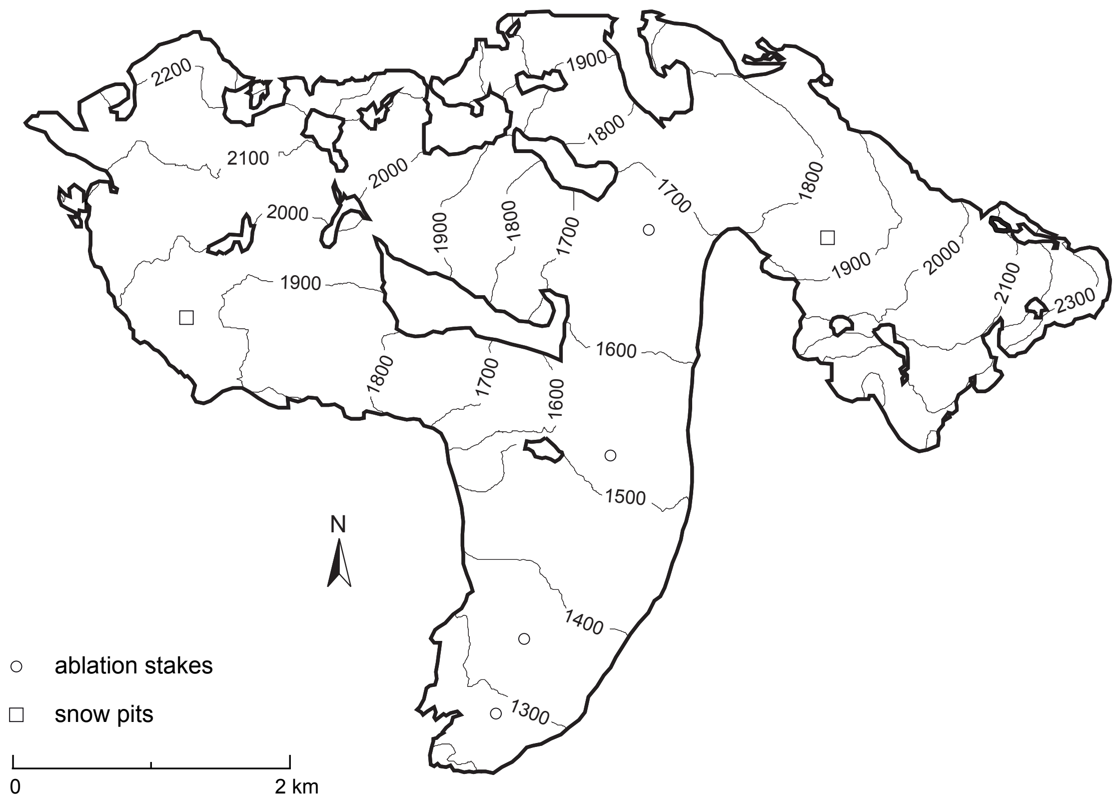
COORDINATES: 63.25° N / 145.42° W

Aerial view looking west at Gulkana Glacier on 4 August 1994, photo by R. March.

Gulkana Glacier is a 7.5 km long, multi-branched valley glacier located in a continental climate regime on the south flank of the eastern Alaska Range in central Alaska. The accumulation area consists of four adjacent cirques with east, south, and west exposures that reach altitudes as high as 2470 m a.s.l. The ablation area flows south-southwestward to a terminus at about 1160 m. The near terminus area is lightly covered with rock debris. The mass balance has been measured seasonally with glaciological methods since 1965/66. Geodetic surveys have been made in 1974, 1993, and 1999. Glacier area has shrunk from an estimated 19.59 km^2 in 1965 to measured values of 18.37 km^2, 18.11 km^2, and 17.05 km^2 in 1974, 1993, and 1999 respectively, and to an estimated value of 15.28 km^2 in 2009 for a 22 % loss in area since the start of the balance measurements. Ice thickness at about 1670 m altitude (a little below the ELA) was about 270 m in the mid 1970s and further reduced by about 15 m to 255 m in 2009. Ice thickness in the lower ablation zone has decreased by almost 60 m over the same period from about 150 m thick to 90 m. The mean annual air temperature at the long-term ELA of 1770 m altitude is −5.0 °C, as estimated from the Gulkana weather station at 1480 m altitude on a lateral moraine adjacent to the glacier. Annual average precipitation on the glacier is about 1600 mm, as estimated from the same weather station after taking into account an estimated precipitation catch efficiency of 60 %.

In 2007/08 the mean air temperature was 0.8 °C below the long-term mean; in 2008/09 it was 0.7 °C below the long-term mean. The specific mass balance was −180 mm w.e. in 2007/08 and −720 mm w.e. in 2008/09. These balance differences are largely due to summer temperatures that were 2 °C higher in 2009 than in 2008.

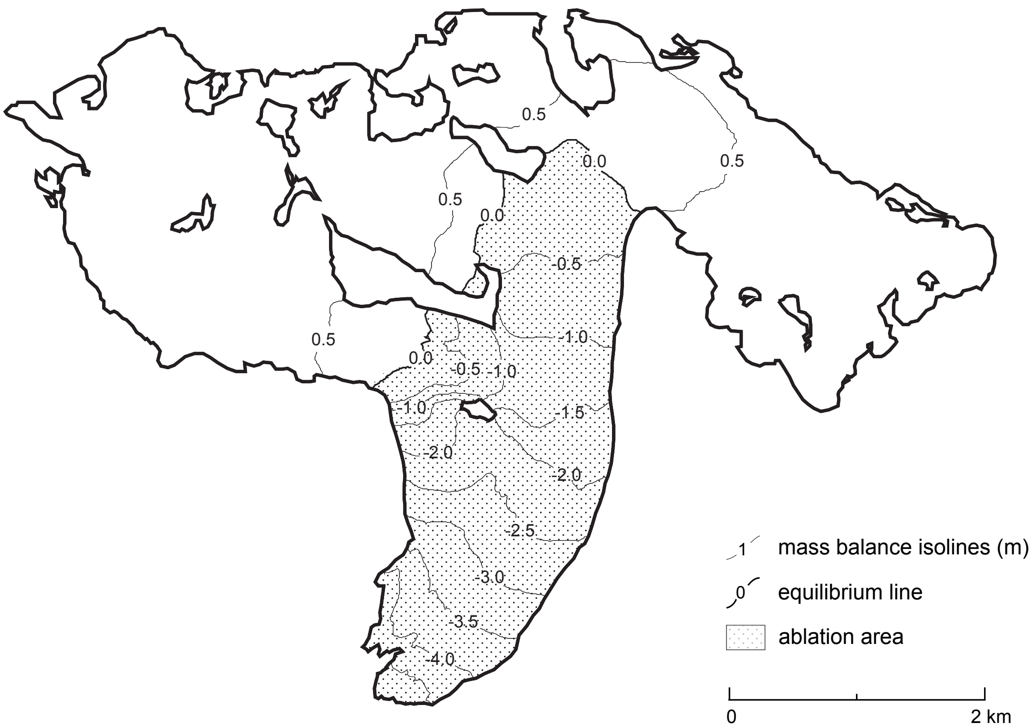
3.14.1 Topography and observation network



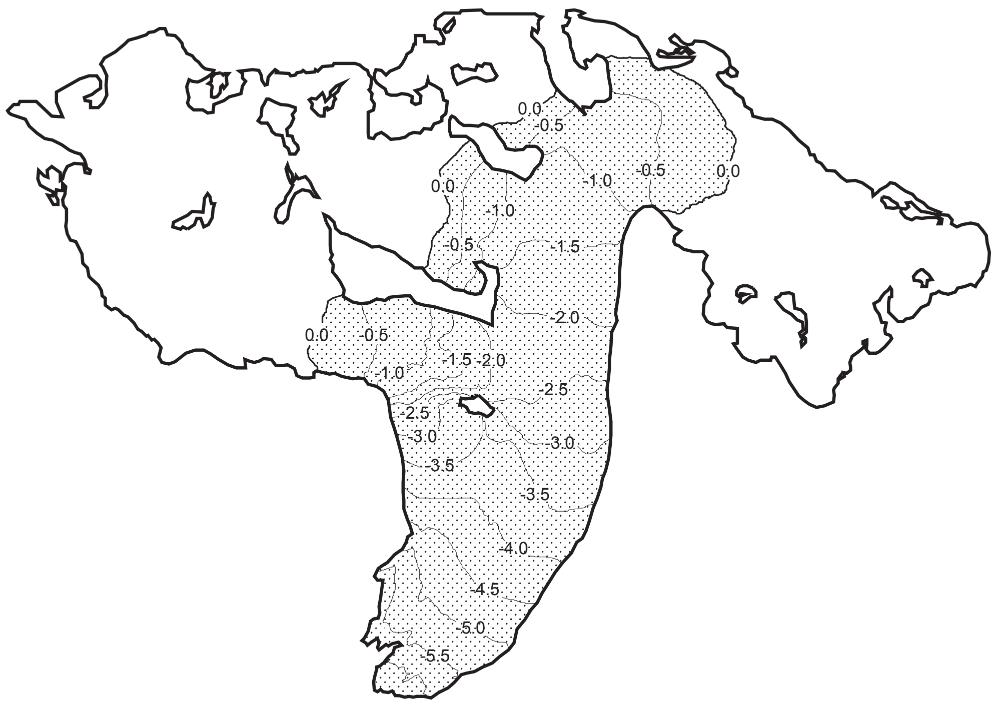
Gulkana (USA)

3.14.2 Mass balance maps 2007/08 and 2008/09

2007/08

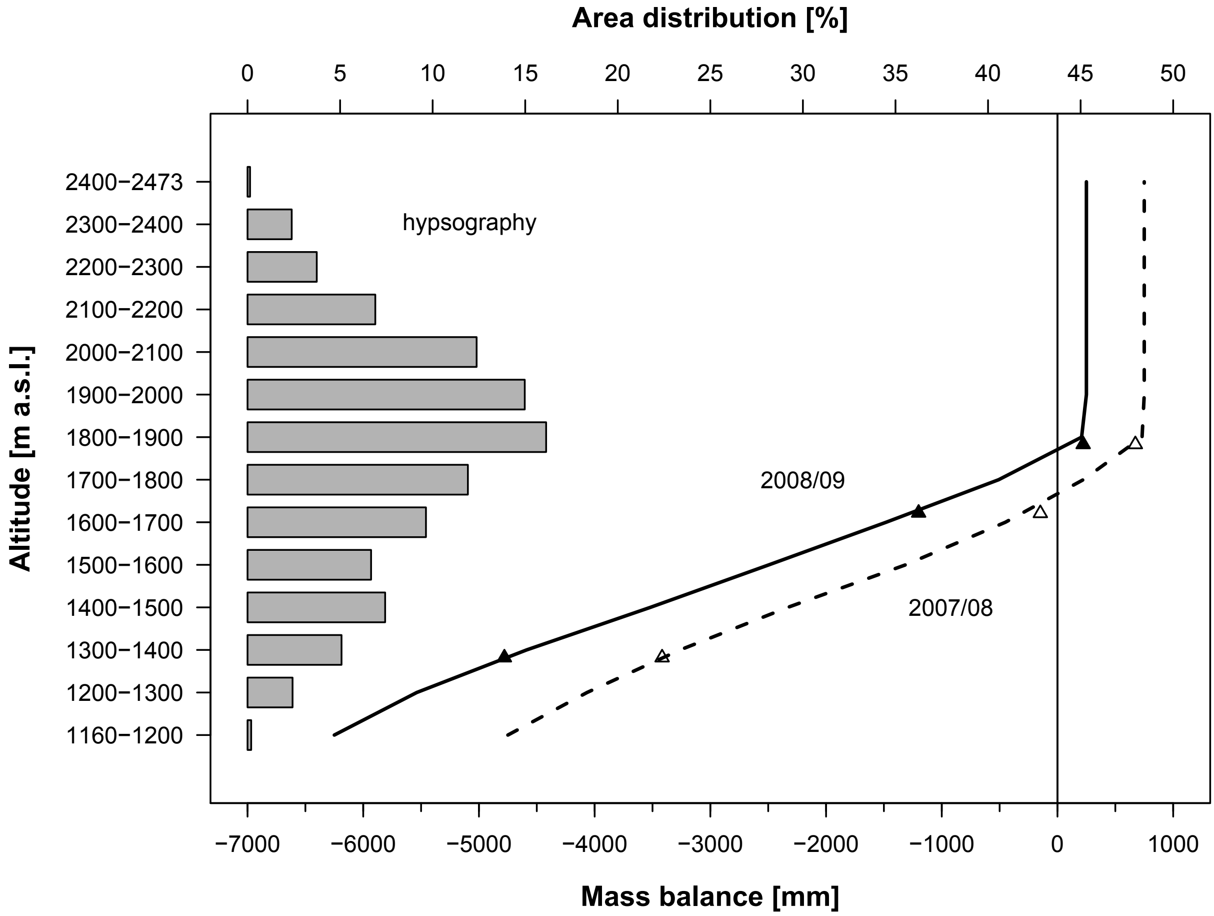


2008/09

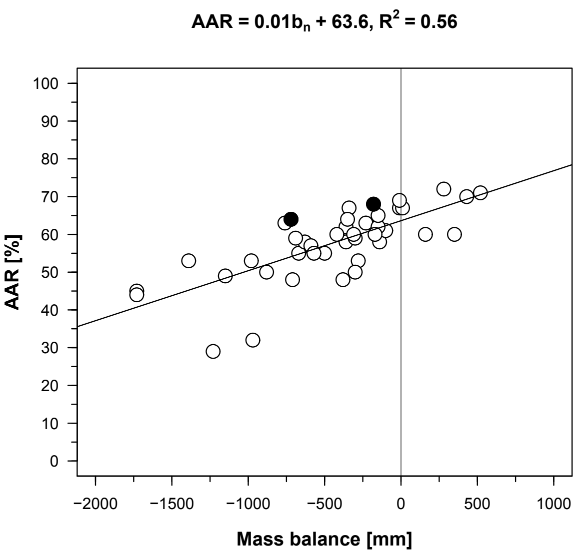


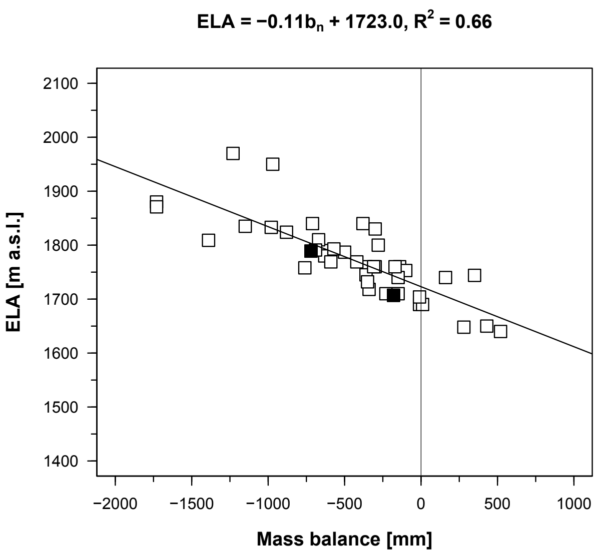
Gulkana (USA)

3.14.3 Mass balance versus altitude (2007/08 and 2008/09)



3.14.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Gulkana (USA)

3.15 WOLVERINE (USA/KENAI MOUNTAINS)

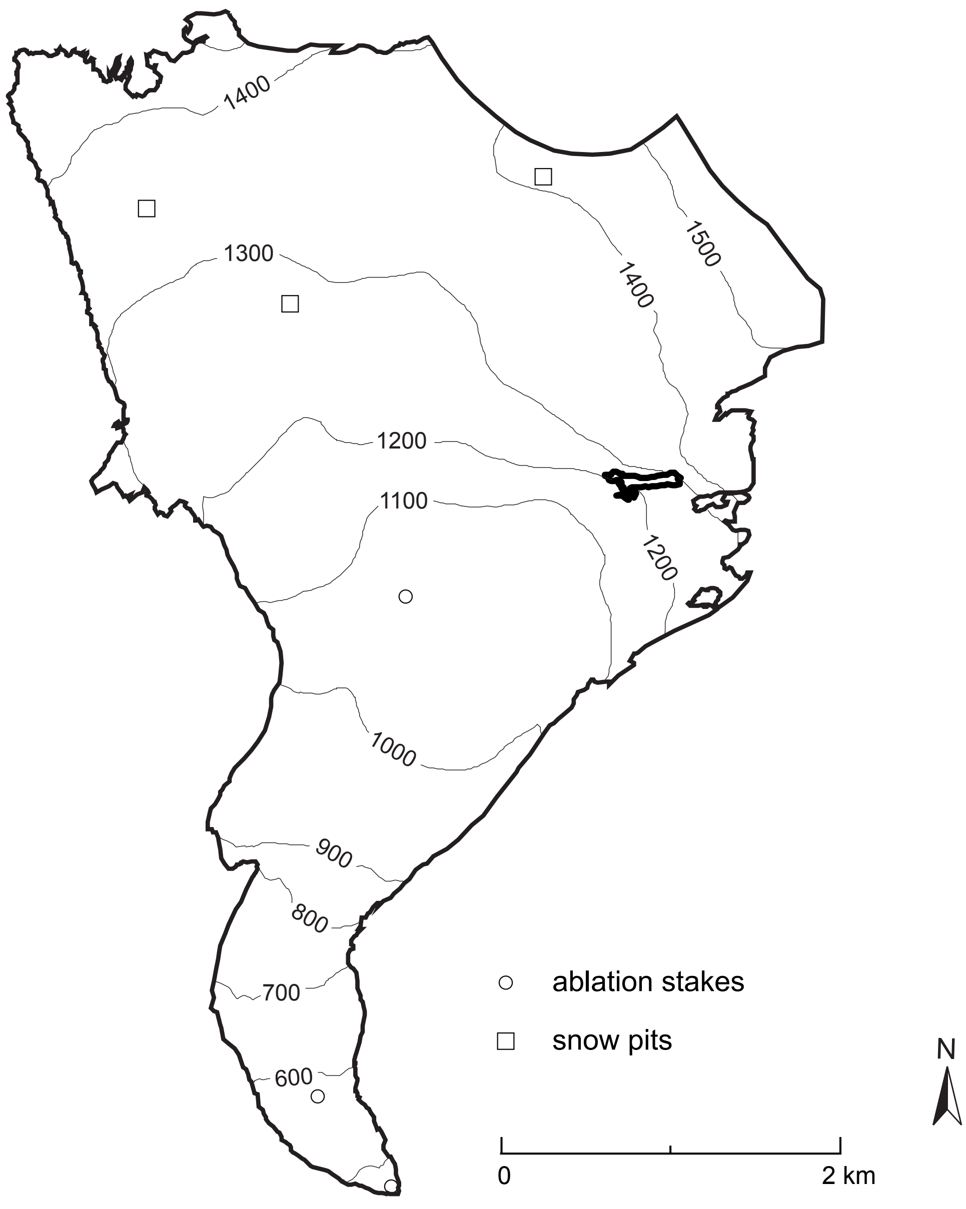
COORDINATES: 60.40° N / 148.92° W

Aerial view looking north at Wolverine Glacier on 24 August 1987, photo by B. Krimmel.

Wolverine Glacier is an 8 km long valley glacier in the coastal mountains of south-central Alaska's Kenai Peninsula that experiences a maritime climate with high precipitation rates. This south-facing glacier spans altitudes from 1680 m to 400 m a.s.l. The mass balance has been measured seasonally with the glaciological method since 1965/66. Geodetic surveys have been made in 1979, 1995, 1998, and 2002. Glacier area has shrunk from an estimated 17.24 km^2 in 1965 to measured values of 16.98 km^2, 16.86 km^2, and 16.79 km^2, and 16.75 km^2 in 1979, 1995, 1998, and 2002 respectively, and to an estimated value of 16.68 km^2 in 2009 for a 3 % loss in area since the start of the balance measurements. Ice at 1060 m (a little below the ELA) that was about 310 m thick in mid 1970s thinned by 17 m to a thickness of 293 m in 2009. Ice in the lower ablation zone has thinned by almost 70 m over the same period from 150 m to 80 m thick. The mean annual air temperature at the long-term ELA of 1170 m is −1.5 °C, as estimated from the Wolverine weather station at 990 m altitude about 0.5 km west of the glacier. Annual average precipitation catch at the weather station is 930 mm and precipitation on the glacier is estimated at about 2800 mm.

In 2007/08 the mean air temperature was 1.1 °C below the long-term mean; in 2008/09 it was 0.6 °C below the long-term mean. The specific mass balance was +880 mm w.e. in 2007/08 and −1780 mm w.e. in 2008/09. These balance differences are largely due to a significantly higher winter balance in 2007/08 than in 2008/09.

3.15.1 Topography and observation network

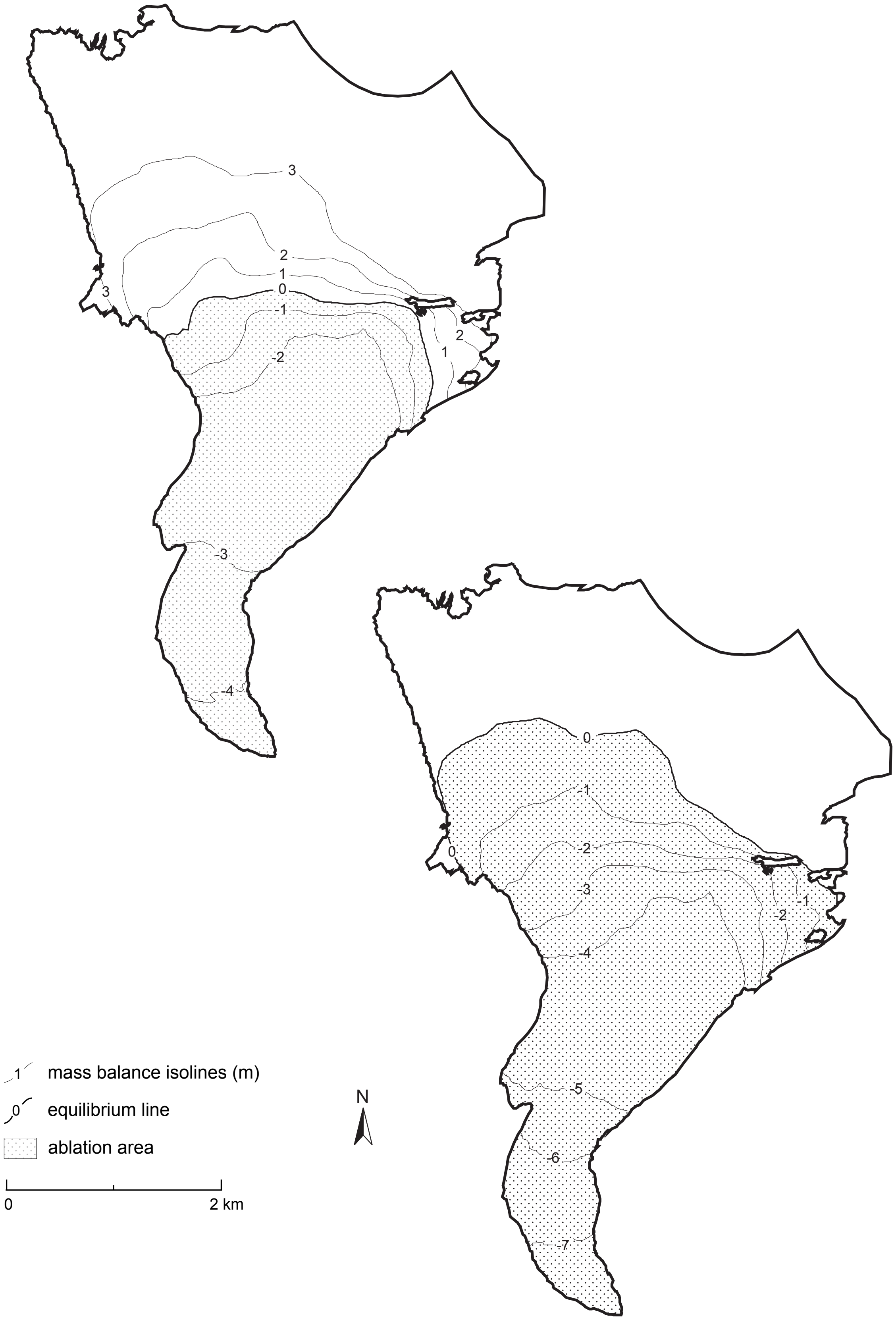


Wolverine (USA)

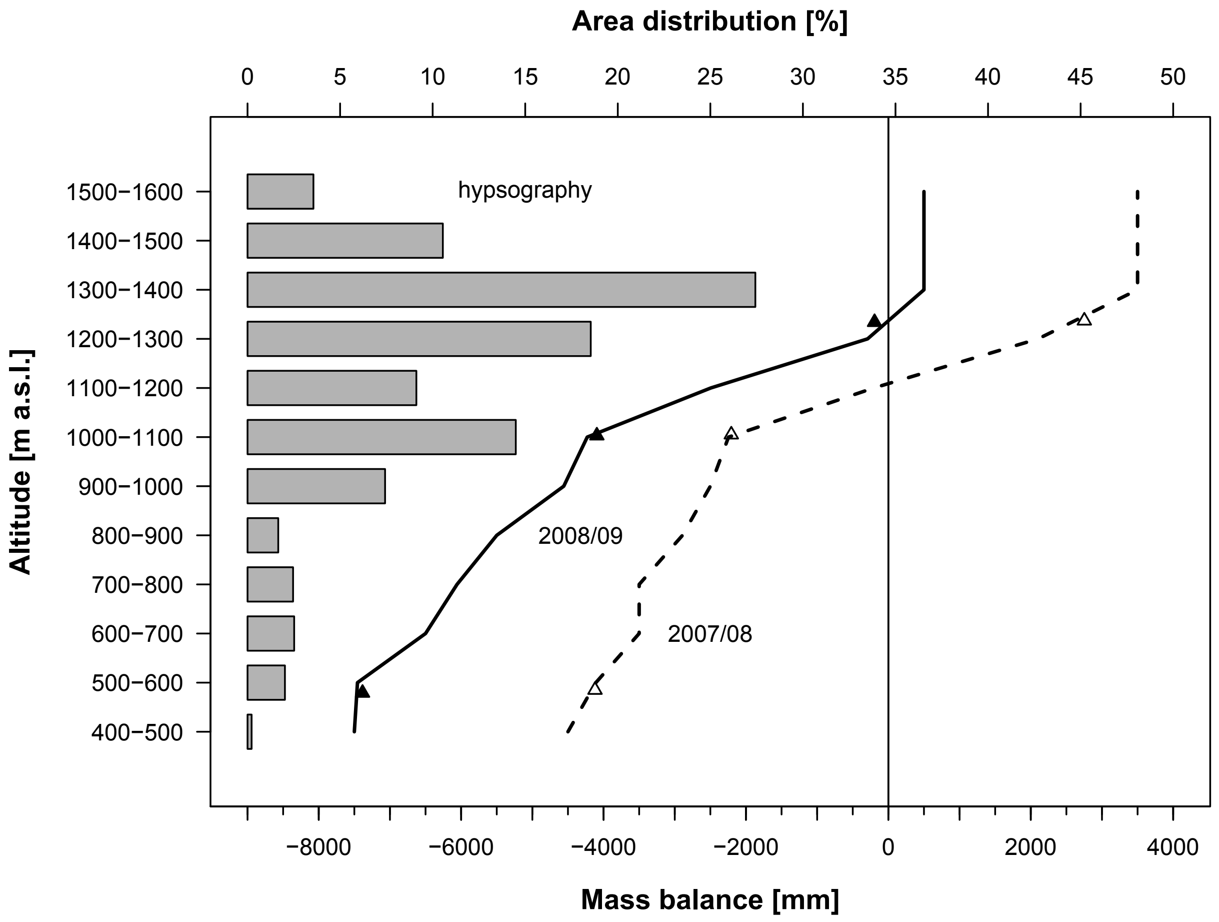
3.15.2 Mass balance maps 2007/08 and 2008/09

2007/08

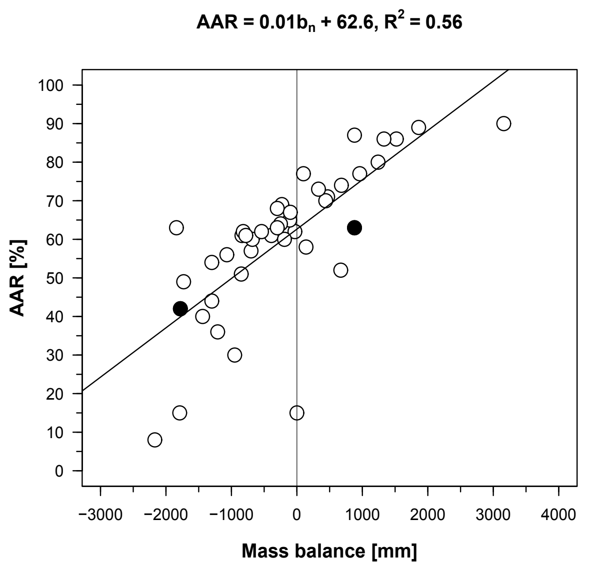
2008/09

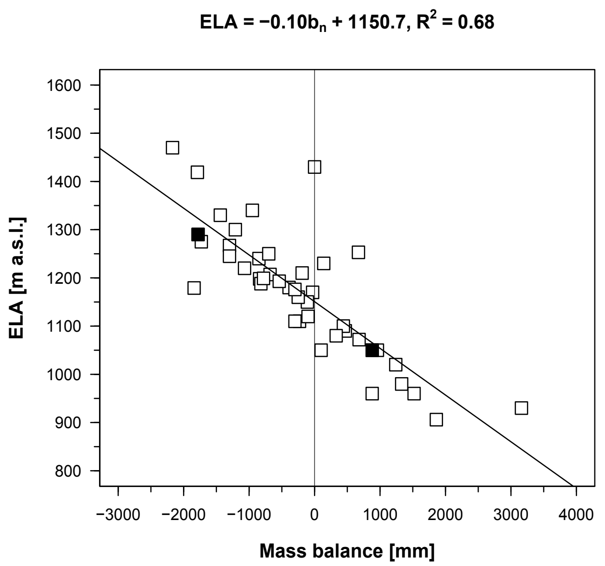


3.15.3 Mass balance versus altitude (2007/08 and 2008/09)



3.15.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Wolverine (USA)

3.16 LEMON CREEK (USA/COAST MOUNTAINS)

COORDINATES: 58.38° N / 134.36° W

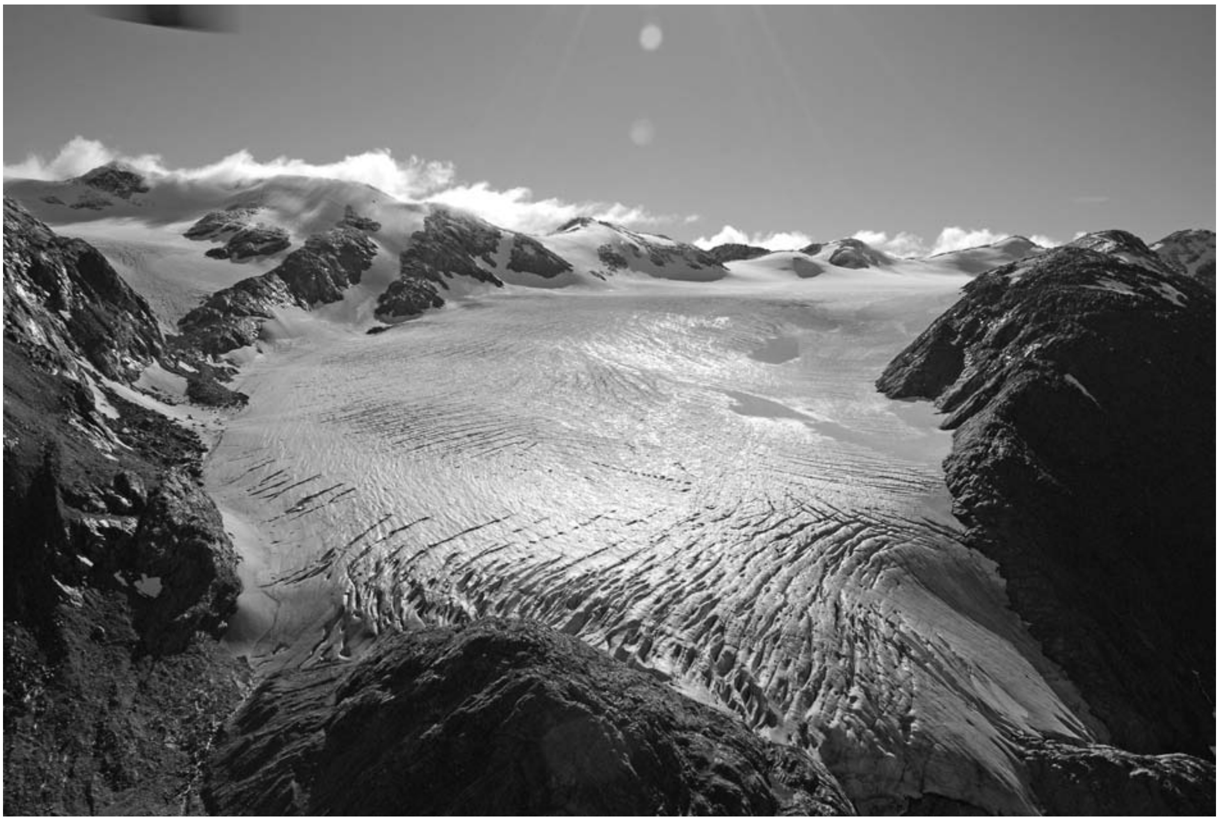
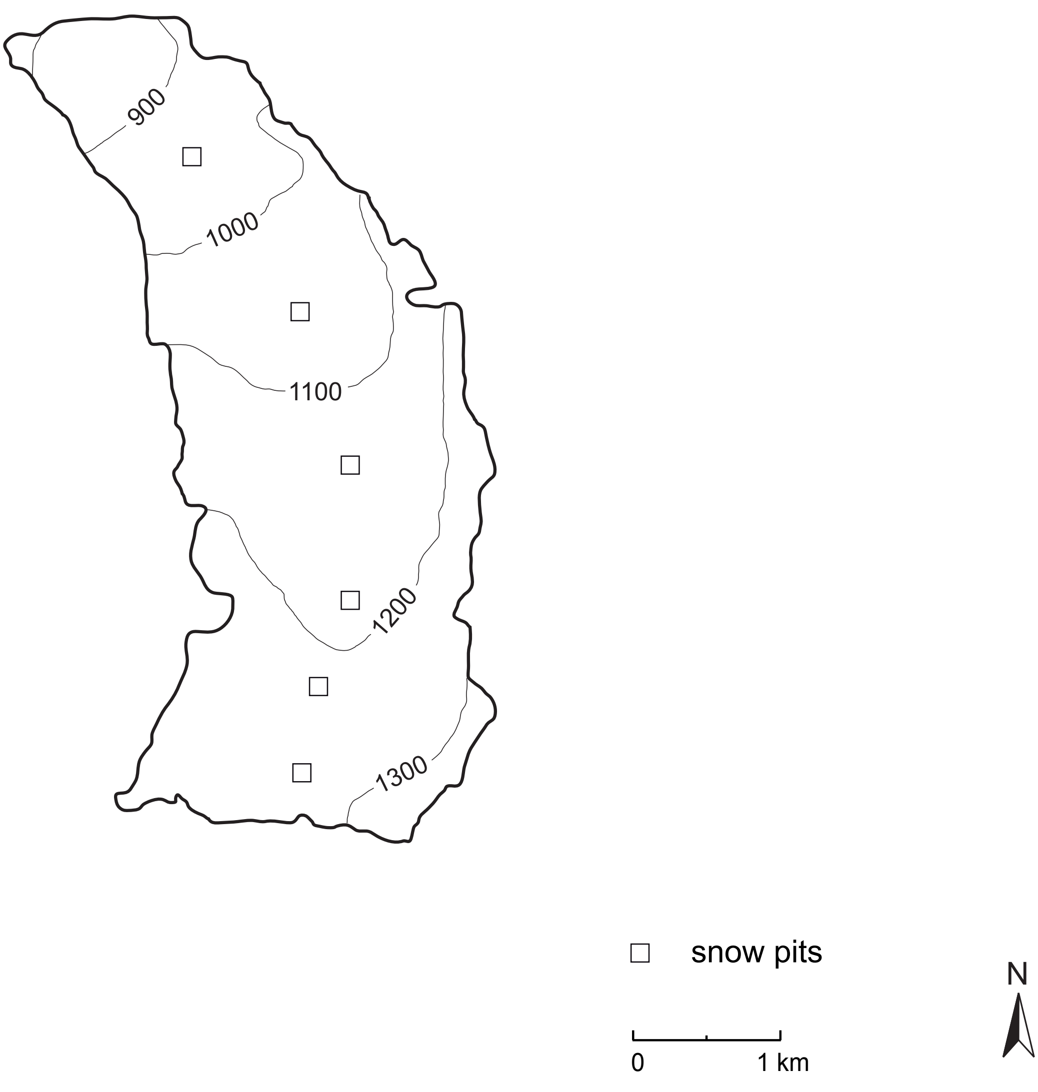


Photo taken L. Bernier, 17 September 2007.

This temperate valley glacier is part of the Juneau Icefield in the Coast Range of Southeast Alaska. The equilibrium line is at 1020 m. The glacier extends from 1400 m to 820 m a.s.l. and has a surface area of 11.6 km^2. The terminus of the glacier is currently steep and continuing a long-term retreat averaging 10−13 m per year, from 1998−2009. Mass balance measurements were initiated on this glacier in 1953 and have been conducted continuously since. A combined fixed date/stratigraphic method is employed, and only annual balance is determined.

Accumulation season precipitation October−April was 2.75 m and 2.65 m respectively in 2007/08 and 2008/09 at the snow telemetry measuring site at Long Lake 35 km from the glacier. During July and August, the primary ablation period on the Lemon Creek Glacier, average temperature at Camp-17 adjacent to the glacier was 3.5 °C in 2008 and 6.5 °C in 2009. The mass balance was positive 778 mm w.e. in 2007/08, with an ELA of 900 m. In 2008/09 the mass balance was negative −700 mm w.e., with an ELA of 1060 m. The more negative mass balance in 2008/09 was mainly the result of exceptionally high ablation in July and August, as winter snowfall had been comparatively high.

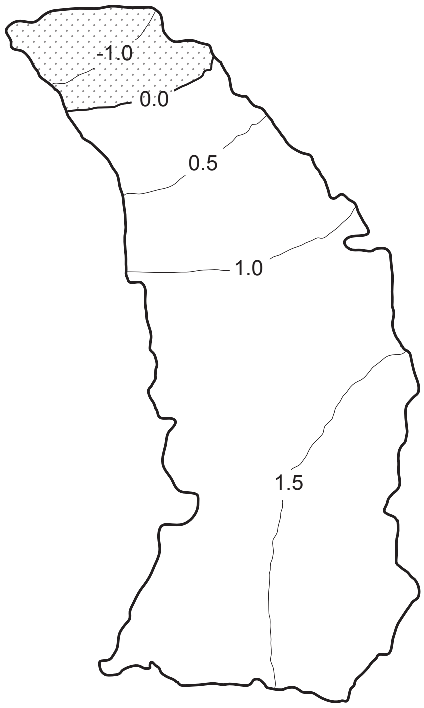
3.16.1 Topography and observation network



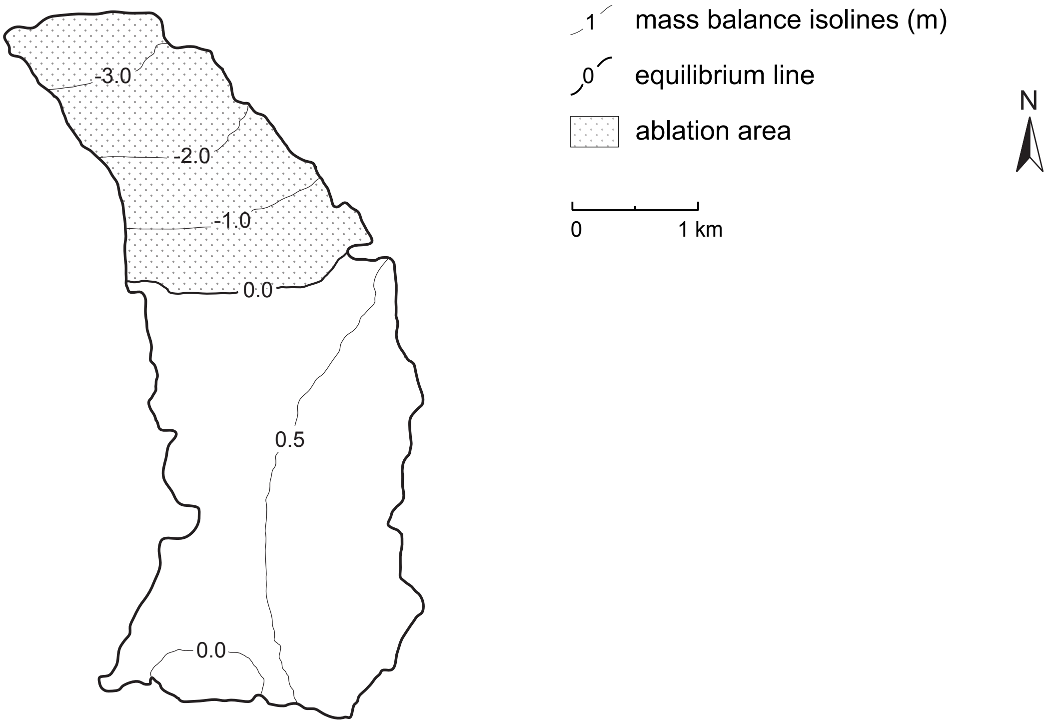
Lemon Creek (USA)

3.16.2 Mass balance maps 2007/08 and 2008/09

2007/08

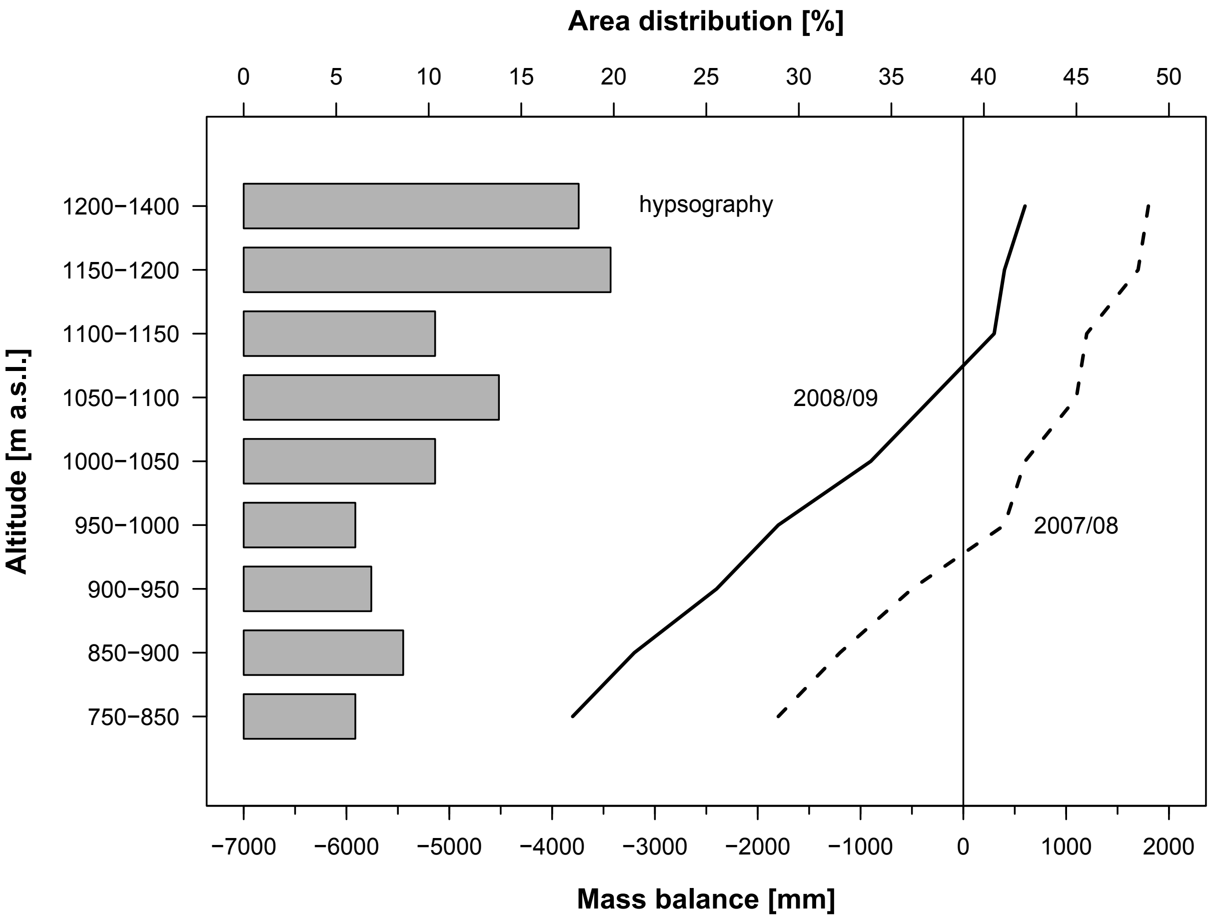


2008/09

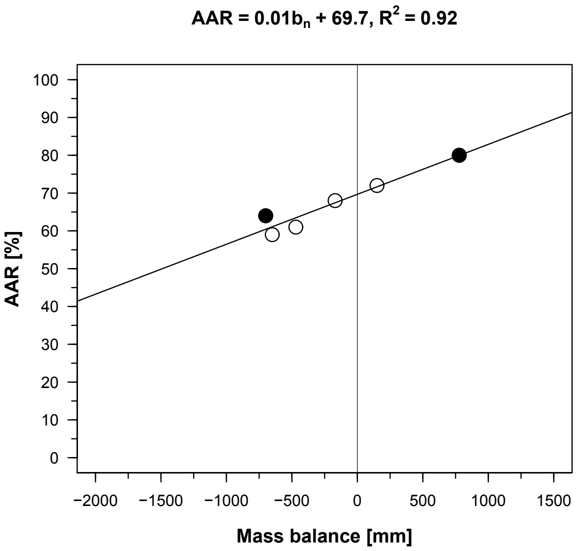


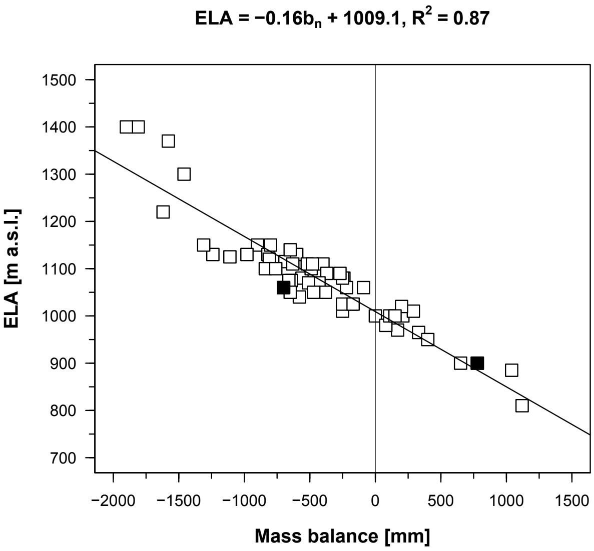
Lemon Creek (USA)

3.16.3 Mass balance versus altitude (2007/08 and 2008/09)



3.16.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





Lemon Creek (USA)

3.17 SOUTH CASCADE (USA/NORTH CASCADES)

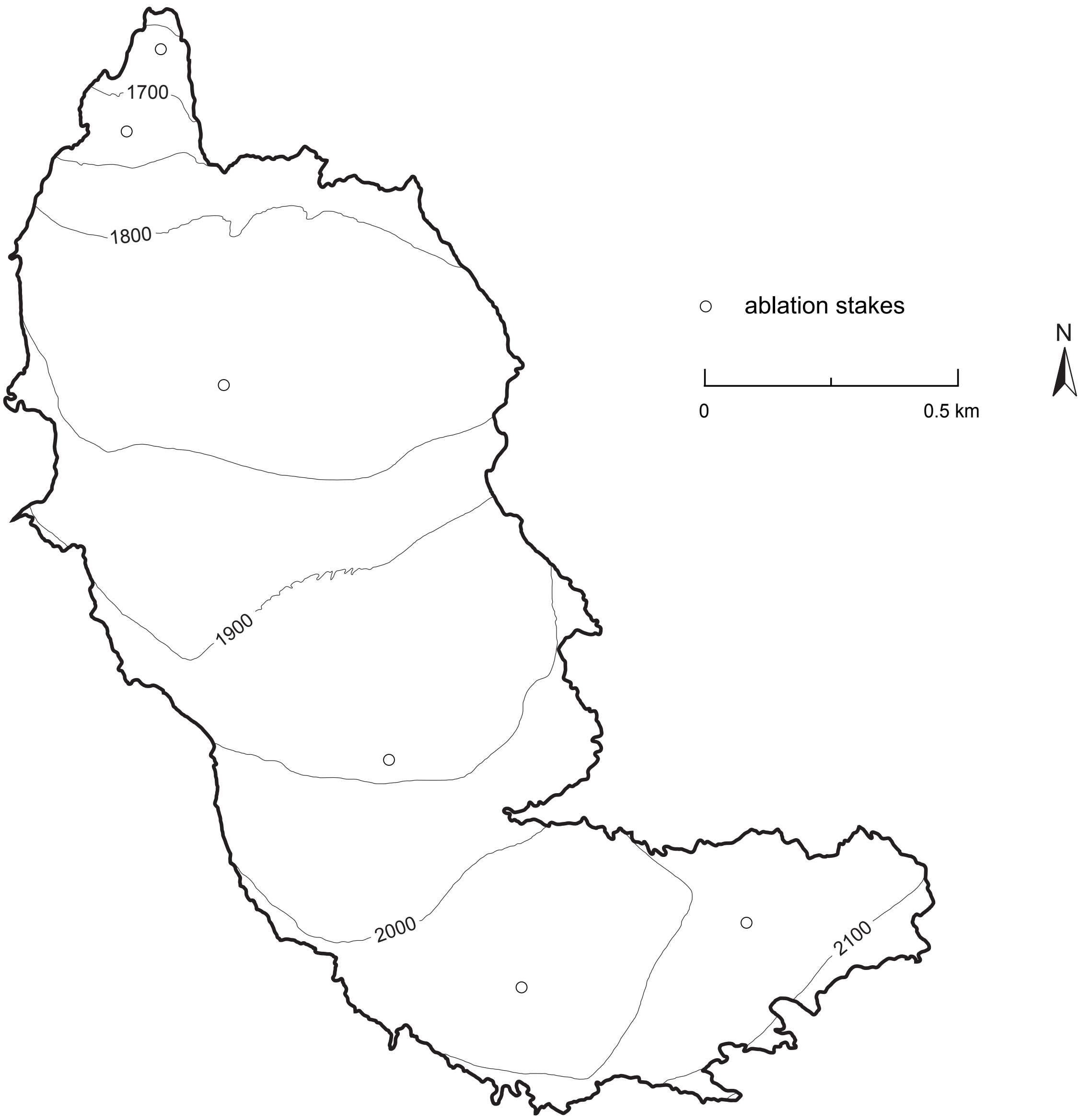
COORDINATES: 48.37° N / 121.05° W

Photo taken by V. Potts, for the U.S. Geological Survey, September 2009

The U.S. Geological Survey has closely monitored this temperate mountain glacier since the late 1950s. During 1958−2007, the glacier retreated about 0.7 km and shrank in area from 2.71 to 1.73 km^2, although part of the area change was due to separation of contributing ice bodies from the main glacier. Maximum and average glacier thicknesses are about 170 and 80 m, respectively. Year-to-year variations in snow accumulation on the glacier are largely attributable to the regional maritime climate and fluctuating climate conditions of the North Pacific Ocean. Long-term-average precipitation is about 4500 mm and most of that falls as snow during October through May. Average annual air temperature at 1900 m altitude (the approximate ELA_0) was estimated to be 1.6 °C during 2000−2009. Mass balances are computed yearly by the direct glaciological method. Mass balances measured at selected locations are used in an interpolation and extrapolation procedure that computes the mass balance at each point in the glacier surface altitude grid. The resulting mass balance grid is averaged to obtain glacier mass balances. Additionally, the geodetic method has been applied to compute glacier mass balances in 1970, 1975, 1977, 1979−1980, and 1985−1997.

Winter snow accumulation on the glacier during 2007/08 and 2008/09 was greater than the long-term (1959−2009) average. The 2007/08 preliminary summer balance (−3510 mm w.e.) was slightly more negative than the long-term average and this yielded a preliminary 2007/08 mass balance (−290 mm w.e.), which was less negative than the average for the period of record (−600 mm w.e.). Summer 2009 was uncommonly warm and the preliminary 2008/09 summer balance (−4980 mm w.e.) was more negative than any on record for the glacier. The 2008/09 glacier mass balance (−1860 mm w.e.) was among the 10 most negative for the period of mass balance record (1953−2009).

3.17.1 Topography and observation network

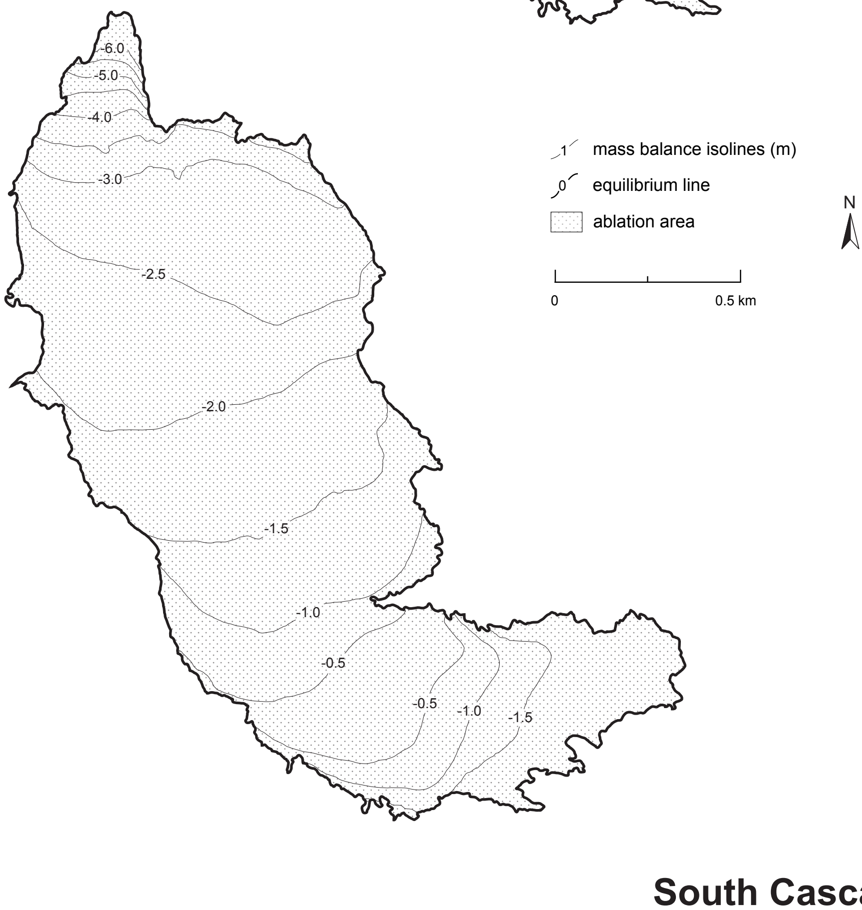


South Cascade (USA)

3.17.2 Mass balance maps 2007/08 and 2008/09

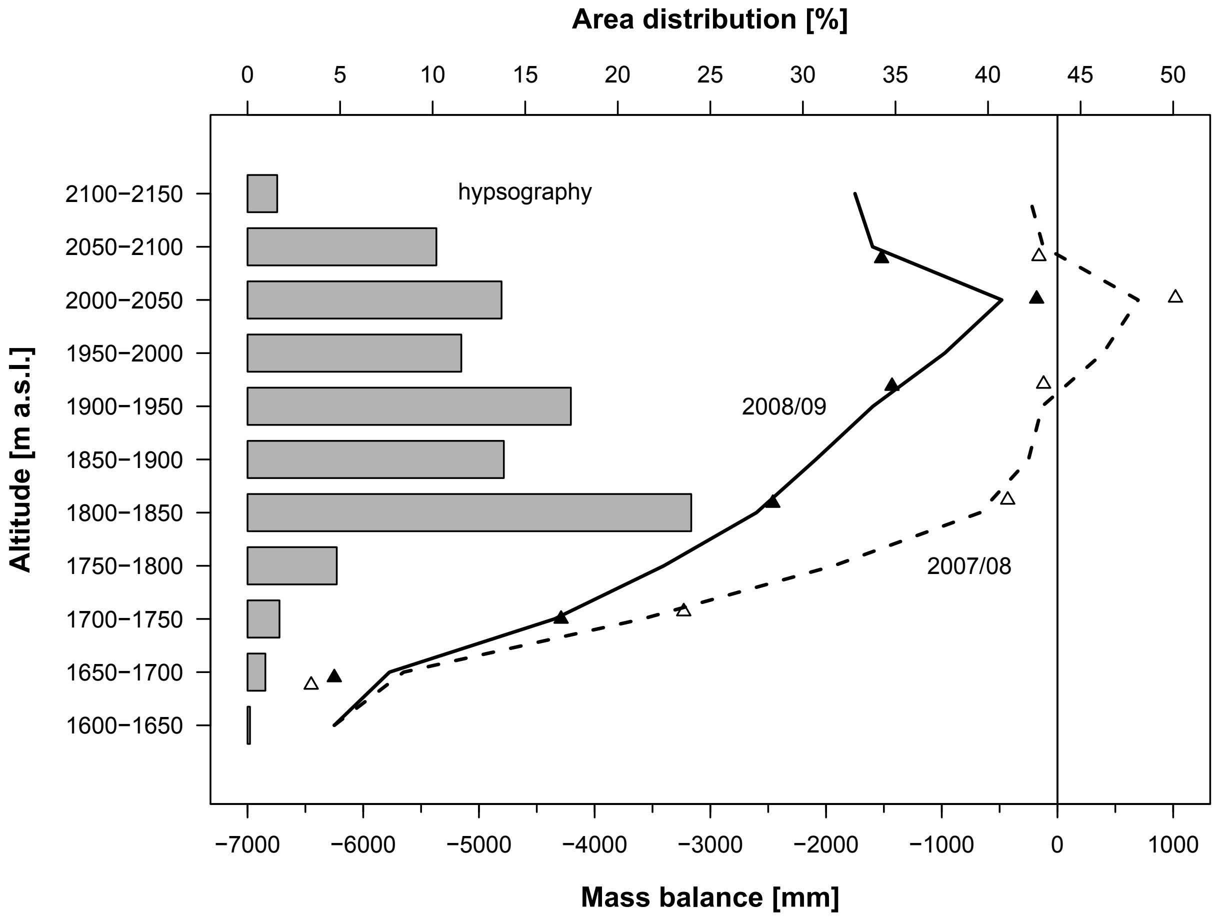
2007/08

2008/09

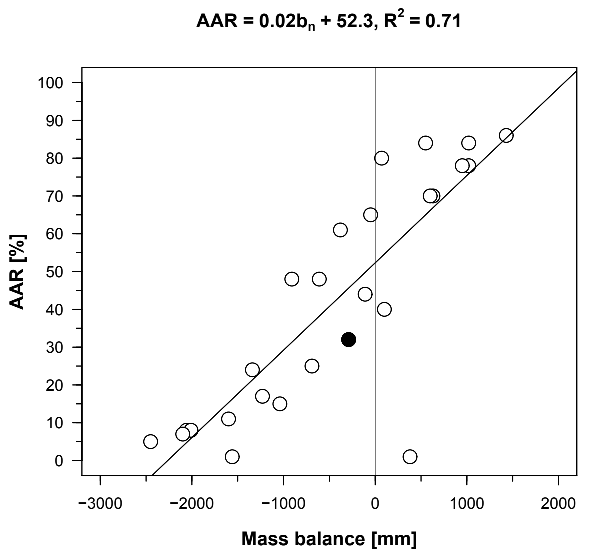


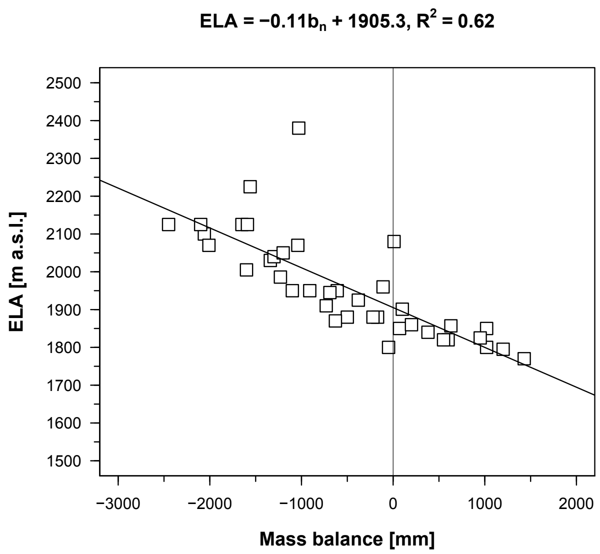
South Cascade (USA)

3.17.3 Mass balance versus altitude (2007/08 and 2008/09)



3.17.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific mass balance for the whole observation period





South Cascade (USA)

4 FINAL REMARKS

Pioneer surveys of accumulation and ablation of snow, firn and ice at isolated points date back to the end of the 19th century and beginning of the 20th century in Switzerland (Mercanton 1916). In the 1920s and 1930s, short-term observations (up to one year) were carried out at various glaciers in Nordic countries. Continuous, modern series of annual/seasonal measurements of glacier-wide mass balance were started in the late 1940s in Sweden, Norway, and in western North America, followed by a growing number of glaciers in the European Alps, North America and other glacierized regions. Meanwhile, glacier mass balance measurements have been carried out on more than 300 glaciers worldwide (Kaser et al. 2006, Zemp et al. 2009), of which about 250 series are available from the World Glacier Monitoring Service.

Climate (change)-related trend analysis is ideally based on long-term measurement series. Continuous glacier mass balance records for the period 1980−2009 are now available for a set of 37 'reference' glaciers in ten mountain ranges (cf. Zemp et al. 2009). These glaciers have well-documented and independently calibrated, long-term mass balance programmes based on the direct glaciological method (cf. Østrem and Brugman 1991) and are not dominated by non-climatic drivers such as calving or surge dynamics. Corresponding results from this sample of glaciers in North and South America and Eurasia are summarized in Table 4.1 (all values in mm water equivalent):

Table 4.1: Summarized mass balance data. The mean specific (annual) mass balance of 37 glaciers averaged for the years 1980–1989, 1990–1999 and 2000–2009 is shown in the upper table. A statistical overview of the 37 glaciers during the two reported years is given in the lower table.

	1980–1989		1990–1999		2000–2009	
mean specific (annual) mass balance	− 222 mm		− 437 mm		− 667 mm	
standard deviation of means	± 210 mm		± 204 mm		± 361 mm	
minimum mean value	− 545 mm	(1986)	− 824 mm	(1998)	− 1224 mm	(2003)
maximum mean value	+ 3 mm	(1983)	− 185 mm	(1993)	− 30 mm	(2000)
range	538 mm		795 mm		1233 mm	
positive mean balances	10 %		0 %		0 %	
positive balances	33 %		26 %		20 %	
mean AAR	49 %		45 %		38 %	

	2007/08		2008/09	
mean specific (annual) mass balance	− 503 mm		− 676 mm	
standard deviation	± 853 mm		± 943 mm	
minimum value	− 2340 mm	Sarennes	− 3900 mm	Sarennes
maximum value	+ 1090 mm	Nigardsbreen	+ 590 mm	Maliy Aktru
range	3430 mm		4490 mm	
positive balances	27 %		22 %	
mean AAR	40 %		41 %	

Taking the two years of this reporting period together, the mean mass balance was −590 mm w.e. per year. This is slightly less negative than the mean mass balance for the first decade since the turn of the century (2000−2009: −667 mm w.e. per year) but still exceeds the mean mass balances of the 1980s and 1990s by about 165 % and 35 %, respectively. During the first decade of the century, the maximum loss of the 1980−1999 time period (−824 mm w.e. per year in 1998) was exceeded twice (in 2003 and 2006), the percentage of positive glacier mass balances decrease from 33 % in the 1980s to 20 %, and there were no more years with a positive mean balance in the past two reporting decades. The melt rate and cumulative loss in glacier thickness continues to be extraordinary. Furthermore, the analyses of mean AAR values show that the glaciers are in strong and increasing imbalance with the climate and, hence, will continue to melt even without further warming.

The mean of the 37 glaciers included in the analysis is influenced by the large proportion of Alpine and Scandinavian glaciers. A mean value is therefore also calculated using only one single value (averaged) for each of the ten mountain ranges concerned (Table 4.2). Furthermore, a mean was calculated for all mass balances available, independent of record length. Figure 4.1 shows the number of reported observation series (a) as well as annual (b) and cumulative (c) results for all three means. In their general trend and magnitude, all three averages rather closely relate to each other and are in good agreement with the results from a moving-

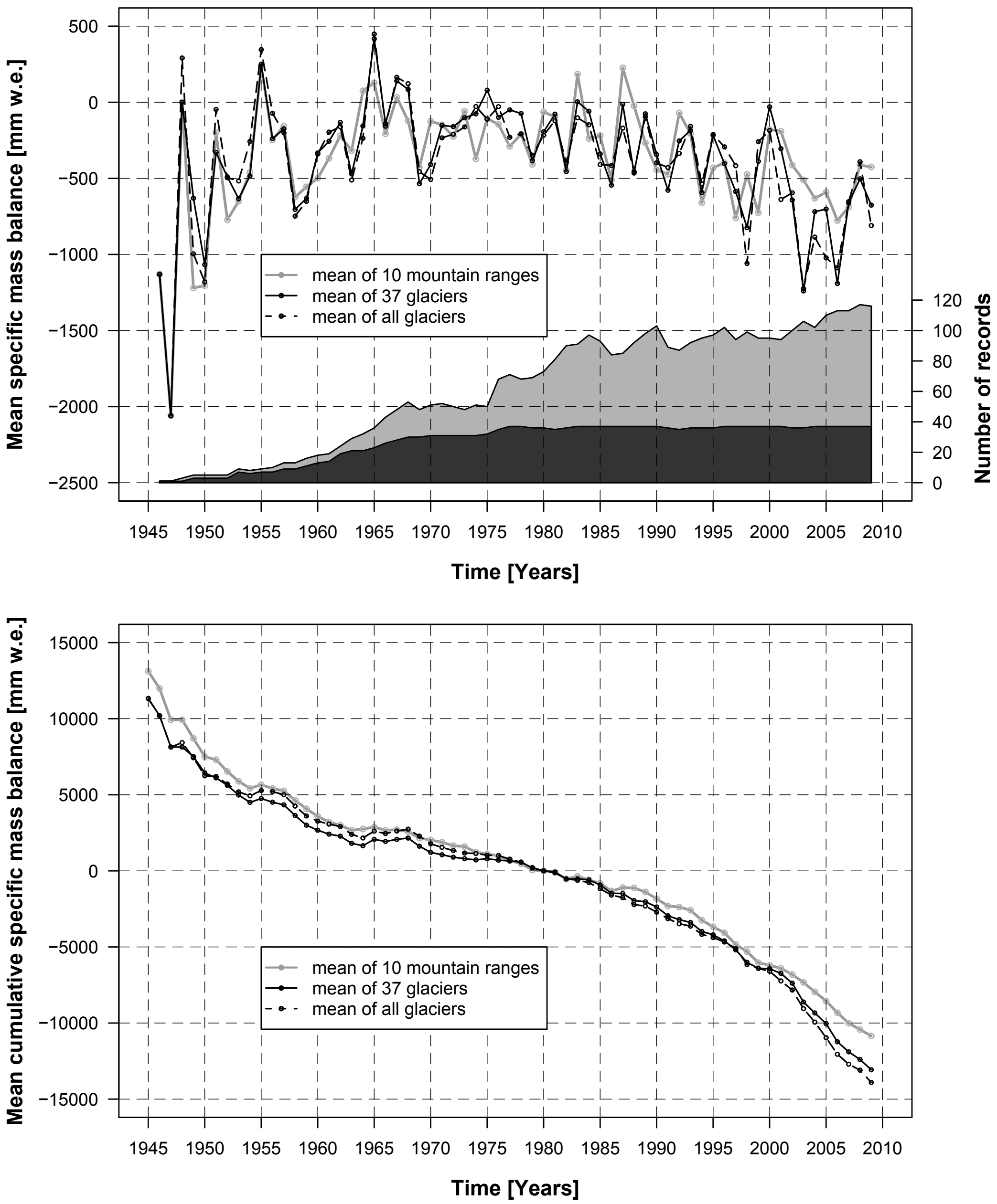


Figure 4.1: Mean specific mass balance (top) and mean cumulative specific mass balance (down) since 1945/46. The proportion of the 37 'reference' glaciers is also given (top).

Table 4.2: Mass balance data for 37 glaciers in 10 mountain regions 1980–2009.

Year	Alaska	Pacific Coast Ranges	Andes	Canadian High Arctic	Svalbard	Scandinavia	Alps	Caucasus	Altai	Tien Shan	Mean
1980	+1105	−747	+300	−88	−475	−1055	+441	+380	−10	−482	−63
1981	+1575	−968	+360	−182	−505	+194	−43	−910	−213	−271	−96
1982	−235	−401	−2420	+11	−10	−185	−841	+420	−460	−338	−446
1983	−200	−686	+3700	−73	−220	+756	−434	−970	+197	−220	+185
1984	−335	−273	−1240	+16	−705	+194	+111	+210	+307	−666	−238
1985	+620	−1058	+340	−50	−515	−451	−312	−380	+200	−581	−219
1986	−45	−847	−1700	+55	−265	−249	−1031	−500	+73	−594	−510
1987	+590	−1031	+950	−251	230	+925	−614	+1540	+183	−258	+226
1988	+355	−668	+2300	−129	−505	−1215	−604	+520	+333	−626	−24
1989	−1055	−1090	−1260	+83	−345	+1911	−889	+40	+117	−177	−267
1990	−1400	−938	−1300	−275	−585	+1196	−1128	+340	+107	−454	−444
1991	−5	−951	−860	−204	+115	+80	−1209	−310	−480	−903	−473
1992	−250	−1564	+1740	−100	−120	+1161	−1198	−130	−127	−108	−70
1993	−1215	−1609	−290	−271	−955	+1174	−517	+1100	+227	+286	−207
1994	−715	−1510	−1860	−173	−140	+171	−886	−840	−240	−410	−660
1995	−1360	−1250	−950	−254	−785	+589	+6	+40	+60	−408	−431
1996	−900	−272	−1180	+49	−75	−642	−448	−150	−140	−207	−397
1997	−1760	−792	−2530	−43	−570	−470	−423	+270	−123	−1160	−760
1998	+55	−2166	+2400	−202	−725	+221	−1640	−1000	−1110	−574	−474
1999	−915	+604	−4280	−354	−350	−122	−661	−560	−113	−510	−726
2000	+330	+416	−750	−404	−25	+988	−748	−1140	−230	−222	−179
2001	−180	−690	+1790	−233	−404	−787	+113	−620	−190	−698	−190
2002	−760	+81	−220	+30	−547	−1141	−916	+430	−357	−568	−413
2003	−320	−1591	+1900	−258	−841	−1392	−2510	+280	−363	−12	−511
2004	−2355	−1411	−550	121	−1058	−161	−1066	+730	−210	−346	−631
2005	−1245	−1558	−780	−418	−860	+309	−1422	+390	+87	−414	−591
2006	−585	−1612	+480	−114	−606	−2025	−1441	−800	−197	−872	−777
2007	−1085	−456	−130	−542	−354	+395	−1627	−2010	−297	−778	−688
2008	+350	−506	−540	−639	−68	+406	−1286	+100	−800	−1144	−413
2009	−1250	−1118	+80	−593	−192	−134	−1534	−120	+480	+134	−425
Mean	−440	−894	−217	−183	−415	+21	−825	−122	−110	−453	−364

Alaska	Gulkana, Wolverine
Pacific Coast Ranges	Place, South Cascade, Helm, Lemon Creek, Peyto
Andes	Echaurren Norte
Canadian High Arctic	Devon Ice Cap NW, Meighen Ice Cap, White
Svalbard	Austre Brøggerbreen, Midtre Lovénbreen
Scandinavia	Engabreen, Ålfotbreen, Nigardsbreen, Gråsubreen, Storbreen, Hellstugubreen, Hardangerjøkulen, Storglaciären
Alps	Saint Sorlin, Sarennes, Argentière, Silvretta, Gries, Stubacher Sonnblickkees, Vernagtferner, Kesselwandferner, Hintereisferner, Caresèr
Caucasus	Djankuat
Altai	No. 125 (Vodopadniy), Maliy Aktru, Leviy Aktru
Tien Shan	Ts. Tuyuksuyskiy, Urumqi Glacier No. 1

sample averaging of all available data (cf. Kaser et al. 2006; Zemp et al. 2009). The global average cumulative mass balance indicates a strong mass loss in the first decade after the start of measurements in 1946 (though based on few observation series only), slowing down in the second decade (1956–1965; based on observations above 30°N only), followed by a moderate ice loss between 1966 and 1985 (with data from the Southern Hemisphere only since 1976) and a subsequent acceleration until the present (2009).

With their dynamic response to changes in climatic conditions – growth/reduction in area mainly through the advance/retreat of glacier tongues – glaciers readjust to equilibrium conditions of ice geometry with a zero mass balance. Recorded mass balances document the degree of imbalance between glaciers and climate due to the delay in dynamic response caused by the characteristics of ice flow (deformation and sliding); over longer time intervals they depend on the rate of climatic forcing. With constant climatic conditions (no forcing), balances would tend towards and become finally zero. Long-term non-zero balances are, therefore, an expression of ongoing climate change and sustained forcing. Trends towards increasing non-zero balances are caused by accelerated forcing. In the same way, comparison between present-day and past values of mass balance must take the changes of glacier area into account, which have occurred in the meantime (Elsberg et al. 2001). Many of the relatively small glaciers, measured within the framework of the present mass balance observation network, have lost large percentages of their area during the past decades. The recent increase in the rates of ice loss over diminishing glacier surface areas, as compared with earlier losses related to larger surface areas, becomes even more pronounced and leaves no doubt about the accelerating change in climatic conditions, even if a part of the observed acceleration trend is likely to be caused by positive feedback processes.

Further analysis requires detailed consideration of aspects such as glacier sensitivity and the mentioned feedback mechanisms. The balance values and curves of cumulative mass balances reported for the individual glaciers (Chapter 2) not only reflect regional climatic variability but also mark differences in the sensitivity of the observed glaciers. This sensitivity has a (local) topographic component: the hypsographic distribution of glacier area with altitude and a (regional) climatic component: the change in mass balance with altitude or the mass balance gradient. The latter component tends to increase with increasing humidity and leads to stronger reactions by maritime rather than by continental glaciers. For the same reason, the mean balance values calculated above are predominantly influenced by maritime glaciers rather than by continental ones. Maritime glaciers are those found in the coastal mountains of Norway or USA/Alaska, where effects from changes in precipitation may predominate over the influence of atmospheric warming. The modern tool of differencing repeat digital elevation models (DEM) provides excellent possibilities to assess how representative long time series of local mass balance measurements are with respect to large glacier samples (Paul and Haeberli 2008) and to analyze spatial patterns of glacier thickness/volume changes in entire mountain ranges: DEM differencing, for instance, revealed that average thickness losses in southern Alaska (Larsen et al. 2007) are far higher than the averages reported here from in-situ observations on various continents.

Rising snowlines and cumulative mass losses lead to changes in the average albedo and to a continued surface lowering. Such effects cause pronounced positive feedbacks with respect to radiative and sensible heat fluxes. Albedo changes are especially effective in enhancing melt rates and can also be caused by input of dust (Oerlemans et al. 2009). The cumulative length change of glaciers is the result of all effects combined, and constitutes the key to a global intercomparison of decadal to secular mass losses. Surface lowering, thickness loss and the resulting reduction in driving stress and flow, however, increasingly replace processes of tongue retreat with processes of downwasting, disintegration or even collapse of entire glaciers. Moreover, the thickness of most glaciers regularly observed for their mass balance is measured in (a few) tens of meters. From the measured mass losses and thickness reductions, it is evident that several network glaciers with important long-term observations may not survive for many more decades. A special challenge therefore consists in developing a strategy for ensuring the continuity of adequate mass balance observations under such extreme conditions (Zemp et al. 2009).

The terms used in this publication follow the new *Glossary of Glacier Mass Balance and Related Terms* published by Cogley et al. (2011). This new glossary aims to update and revise Anonymous (1969) which has long been the actual standard of mass balance terminology. Key tasks for the future of glacier mass balance monitoring include the continuation of (long-term) measurement series, the extension of the presently available dataset, especially in under-represented regions, and the quantitative assessment of uncertainties related to mass balance measurements.

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