GLACIER MASS BALANCE BULLETIN

Bulletin No. 9 (2004–2005)

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)

and the International Hydrological Programme (IHP, UNESCO)

Compiled by

the World Glacier Monitoring Service (WGMS)

ICSU (FAGS) – IUGG (IACS) – UNEP – UNESCO – WMO

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Edited by

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2007

Printed by

Staffel Druck AG
CH-8045 Zurich
Switzerland

ISSN 1997-9088 (printed issues)
ISSN 1997-9096 (online issues)

The cover page shows the East and West branches of Urumqihe S. No.1 of the Chinese Tien Shan.
Photo taken by T. Bolch in 2006.

PREFACE

Glaciers and ice caps are key indicators and unique demonstration objects of global climate change. The striking losses in length, area, thickness and volume of their firn and ice can be observed and – in principle – be understood by everybody. It is, therefore, a clearly recognisable reflection of rapid if not accelerating change in the energy balance of the earth's surface. This change has been taking place at a global scale and for more than a century now. While its initial phase following the cold centuries of the Little Ice Age was 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 become primarily forced by human impacts on the atmosphere. Measurements of glacier mass balance help to quantify such relations and to anticipate possible further evolution. The latter includes rather dramatic scenarios of complete deglaciation in many mountain regions of the world within the decades to come. In order to further document the evolution and to clarify the physical processes and relationships involved, the World Glacier Monitoring Service (WGMS) of the International Association for the Cryospheric Sciences (IACS/IUGG; former International Commission on Snow and Ice, ICSI/IAHS/IUGG) as one of the permanent services of the Federation of Astronomical, Geophysical and Data Analysis Services (FAGS/ ICSU) collects and publishes standardised glacier data. This long-term activity is a contribution to the Global Climate/Terrestrial Observing Systems (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).

Worldwide glacier monitoring was initiated more than a century ago and is now integrated into global climate-related observation systems. International assessments such as the periodical reports of the Intergovernmental Panel on Climate Change (IPCC) or various GCOS/GTOS reports (for instance, the 2nd report on the adequacy of the Global Observing Systems for Climate in support of the UNFCCC or the Implementation plan for the Global Observing System for Climate in support of the UNFCCC) clearly recognize glacier changes as high-confidence climate indicators and as a valuable element in early detection strategies. An integrated and multi-level strategy within the Global Terrestrial Network for Glaciers (GTN-G) of the Global Terrestrial Observing System (GTOS) aims at combining 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. 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 data compilation of the World Glacier Monitoring Service – a network of at present about 100 glaciers in 22 countries, 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. Such a sample of reference 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 based on the direct glaciological method, ideally in combination with decadal geodetic or photogrammetric surveys. In accordance with an agreement made with the international organization and countries involved, preliminary glacier mass balance values are made available one year after the end of the measurement period on the WGMS homepage (www.wgms.ch). This internet homepage also contains former issues of and the present Glacier Mass Balance Bulletin as well as explanations of the monitoring strategy. The following series of reports on the variations of glaciers in time and space has already been published by the World Glacier Monitoring Service and its predecessor, the Permanent Service on the Fluctuations of Glaciers:

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

The present Glacier Mass Balance Bulletin reporting the results of the balance years 2003/2004 and 2004/2005 is the ninth issue of a long-term series of publications. It is designed to speed up and facilitate access to information concerning 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 presentations rather than purely numerical data. The Glacier Mass Balance Bulletin complements the publication series Fluctuations of Glaciers where the full collection of digital data, including the more numerous observations of glacier length variation, can be found. It should also be kept in mind that this fast and somewhat preliminary reporting of mass balance measurements may require slight correction and update at a later time. Correspondingly corrected and updated information can be found in the Fluctuations of Glaciers series.

Special thanks are extended to all those who have helped to build up the database which, despite its many limitations, nevertheless remains an irreplaceable treasure of international snow and ice research, readily available to the scientific community as well as to a vast public.

Zurich, 2008

Wilfried Haeberli
Director, World Glacier Monitoring Service

CONTENTS

1 INTRODUCTION

Two main categories of data – basic information and detailed information – are being reported in the Glacier Mass Balance Bulletin. Basic information on specific net balance, cumulative specific balance, accumulation area ratio and equilibrium line altitude is given for 105 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 13 glaciers. These were selected for having a long and complete 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 information on glaciers from all regions worldwide, two glaciers with shorter measurement series have been included.

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

Table 1.1: General geographic information on the 105 glaciers for which basic information for the years 2004 and/or 2005 is reported. Additionally, 20 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	2002/2005	Antarctica	Antarctic Peninsula	63.82 S	57.43 W
2	Martial Este	2001/2005	Argentina	Andes Fueguinos	54.78 S	68.40 W
3	Filleckkees	1964/1980	Austria	Eastern Alps	47.13 N	12.60 E
4	Großer Goldbergkees	2001/2005	Austria	Eastern Alps	47.03 N	12.47 E
5	Hintereisferner	1953/2005	Austria	Eastern Alps	46.80 N	10.77 E
6	Jamtalferner	1989/2005	Austria	Eastern Alps	46.87 N	10.17 E
7	Kesselwandferner	1953/2005	Austria	Eastern Alps	46.83 N	10.79 E
8	Kleiner Fleisskees	2001/2005	Austria	Eastern Alps	47.05 N	12.95 E
9	Pasterzenkees	2005/2005	Austria	Eastern Alps	47.10 N	12.70 E
10	Sonnblickkees	1959/2005	Austria	Eastern Alps	47.13 N	12.60 E
11	Vernagtferner	1965/2005	Austria	Eastern Alps	46.88 N	10.82 E
12	Wurtenkees	1983/2005	Austria	Eastern Alps	47.03 N	13.00 E
13	Chacaltaya	1992/2005	Bolivia	Tropical Andes	16.35 S	68.12 W
14	Charquini Sur	2003/2005	Bolivia	Tropical Andes	16.17 S	68.09 W
15	Zongo	1992/2005	Bolivia	Tropical Andes	16.25 S	68.17 W
16	Baby Glacier	1960/2005	Canada	High Arctic	79.43 N	90.97 W
17	Devon Ice Cap	1961/2005	Canada	High Arctic	75.42 N	83.25 W
18	Helm	1975/2005	Canada	Coast Mountains	49.97 N	123.00 W
19	Meighen Ice Cap	1976/2000	Canada	High Arctic	79.95 N	99.13 W
20	Peyto	1966/2005	Canada	Rocky Mountains	51.67 N	116.53 W
21	Place	1965/2005	Canada	Coast Mountains	50.43 N	122.6 W
22	Sentinel	1966/1989	Canada	Coast Mountains	49.90 N	122.98 W
23	White	1960/2005	Canada	High Arctic	79.45 N	90.67 W

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
24	Echaurren Norte	1976/2005	Chile	Central Andes	33.58 S	70.13 W
25	Urumqihe E-Br.	1988/2005	China	Tien Shan	43.08 N	86.82 E
26	Urumqihe S.No.1	1959/2005	China	Tien Shan	43.08 N	86.82 E
27	Urumqihe W-Br.	1988/2005	China	Tien Shan	43.08 N	86.82 E
28	Antizana 15 Alpha	1995/2005	Ecuador	Eastern Cordillera	0.47 S	78.15 W
29	Argentière	1976/2005	France	Western Alps	45.95 N	6.98 E
30	Gebroulaz	2001/2005	France	Western Alps	45.29 N	6.62 E
31	Ossoue	2002/2005	France	Pyrenees	42.77 N	0.14 E
32	Saint Sorlin	1957/2005	France	Western Alps	45.16 N	6.15 E
33	Sarennes	1949/2005	France	Western Alps	45.13 N	6.13 E
34	Breidamerkurjök. E.B.	1998/2005	Iceland	South-eastern Iceland	64.22 N	16.33 W
35	Brúarjökull	1994/2005	Iceland	Eastern Iceland	64.67 N	16.17 W
36	Dyngjujökull	1994/2005	Iceland	Central Northern Iceland	64.67 N	17.00 W
37	Eyjabakkajökull	1994/2005	Iceland	Eastern Iceland	64.65 N	15.58 W
38	Hofsjökull E	1989/2005	Iceland	Central Iceland	64.80 N	18.58 W
39	Hofsjökull N	1988/2005	Iceland	Central Iceland	64.95 N	18.92 W
40	Hofsjökull SW	1990/2005	Iceland	Central Iceland	64.72 N	19.05 W
41	Koeldukvislarjökull	1995/2005	Iceland	Central Iceland	64.58 N	17.83 W
42	Langjökull S. Dome	1997/2005	Iceland	Central Iceland	64.62 N	20.30 W
43	Tungnaárjökull	1994/2005	Iceland	Central Iceland	64.32 N	18.07 W
44	Chhota Shigri	2003/2005	India	Western Himalaya	32.20 N	77.50 E
45	Hamtah	2001/2005	India	Himachal Pradesh	32.34 N	77.37 E
46	Calderone	2001/2005	Italy	Apennin	42.47 N	13.62 E
47	Caresèr	1967/2005	Italy	Central Alps	46.45 N	10.70 E
48	Ciardoney	1992/2005	Italy	Western Alps	45.52 N	7.39 E
49	Fontana Bianca	1983/2005	Italy	Central Alps	46.48 N	10.77 E
50	Lunga (Vedretta)	2004/2005	Italy	Central Alps	46.46 N	10.61 E
51	Malavalle	2002/2005	Italy	Central Alps	46.95 N	11.20 E
52	Pendente	1996/2005	Italy	Central Alps	46.96 N	11.23 E
53	Hamaguri Yuki[4)]	1981/2005	Japan	Northern Japan Alps	36.60 N	137.62 E
54	Igli Tuyuksu	1976/1990	Kazakhstan	Tien-Shan	43.00 N	77.10 E
55	Manshuk Mametov	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
56	Mayakovskiy	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
57	Molodezhniy	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
58	Ordzhonikidze	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
59	Partizan	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
60	Shumskiy	1967/1991	Kazakhstan	Dzhungarskiy	45.08 N	80.23 E
61	Ts. Tuyuksuyskiy	1957/2005	Kazakhstan	Tien Shan	43.05 N	77.08 E
62	Visyachiy-1-2	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
63	Zoya Kosmodemya	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
64	Lewis	1979/1996	Kenya	East Africa	0.15 S	37.30 E
65	Brewster	2005/2005	New Zealand	Wills-Burke	44.07 S	169.43 E
66	Ålfotbreen	1963/2005	Norway	Western Norway	61.75 N	5.65 E
67	Austdalsbreen	1987/2005	Norway	Western Norway	61.80 N	7.35 E
68	Austre Brøggerbreen	1967/2005	Norway	Spitsbergen	78.88 N	11.83 E
69	Breidablikkbrea	1963/2005	Norway	South-western Norway	60.10 N	6.40 E
70	Engabreen	1970/2005	Norway	Northern Norway	66.65 N	13.85 E
71	Gråfjellsbrea	1964/2005	Norway	South-western Norway	60.10 N	6.40 E
72	Gråsubreen	1962/2005	Norway	Southern Norway	61.65 N	8.60 E
73	Hansbreen	1989/2005	Norway	Spitsbergen	77.08 N	15.67 E
74	Hansebreen	1986/2005	Norway	Western Norway	61.75 N	5.68 E
75	Hardangerjøkulen	1963/2005	Norway	Central Norway	60.53 N	7.37 E
76	Hellstugubreen	1962/2005	Norway	Southern Norway	61.57 N	8.43 E
77	Irenebreen	2002/2005	Norway	NW-Spitsbergen	78.65 N	12.10 E
78	Kongsvegen	1987/2005	Norway	Spitsbergen	78.80 N	12.98 E
79	Langfjordjøkulen	1989/2005	Norway	Northern Norway	70.12 N	21.77 E
80	Midtre Lovénbreen	1968/2005	Norway	Spitsbergen	78.88 N	12.07 E
81	Nigardsbreen	1962/2005	Norway	Western Norway	61.72 N	7.13 E
82	Rundvassbreen	2002/2004	Norway	Northern Norway	67.30 N	16.10 E
83	Storbreen	1949/2005	Norway	Central Norway	61.57 N	8.13 E
84	Storglombreen	1985/2005	Norway	Northern Norway	66.67 N	14.00 E
85	Waldemarbreen	1995/2005	Norway	NW-Spitsbergen	78.67 N	12.00 E
86	Artesonraju	2005/2005	Peru	Cordillera Blanca	8.95 S	77.62 W
87	Yanamarey	2005/2005	Peru	Cordillera Blanca	9.65 S	77.27 W
88	Abramov	1968/1998	Russia	Pamir Alai	39.63 N	71.60 E
89	Djankuat	1968/2005	Russia	Northern Caucasus	43.20 N	42.77 E
90	Garabashi	1984/2005	Russia	Northern Caucasus	43.30 N	42.47 E
91	Golubin	1969/1994	Kirghizstan	Tien-Shan	42.47 N	74.50 E
92	Kara-Batkak	1957/1998	Kirghizstan	Tien-Shan	42.10 N	78.30 E
93	Kozelskiy	1973/1997	Russia	Kamchatka	53.23 N	158.82 E
94	Leviy Aktru	1977/2005	Russia	Altay	50.08 N	87.72 E
95	Maliy Aktru	1962/2005	Russia	Altay	50.08 N	87.75 E
96	No. 125 (Vodopadniy)	1977/2005	Russia	Altay	50.10 N	87.70 E
97	Maladeta	1992/2005	Spain	South Pyrenees	42.65 N	0.63 E
98	Mårmaglaciären	1990/2005	Sweden	Northern Sweden	68.83 N	18.67 E
99	Rabots Glaciär	1982/2005	Sweden	Northern Sweden	67.90 N	18.55 E
100	Riukojietna	1986/2005	Sweden	Northern Sweden	68.08 N	18.08 E
101	Storglaciären	1946/2005	Sweden	Northern Sweden	67.90 N	18.57 E
102	Tarfalaglaciären	1986/2005	Sweden	Northern Sweden	67.93 N	18.65 E
103	Basòdino	1992/2005	Switzerland	Western Alps	46.42 N	8.48 E
104	Findelen	2005/2005	Switzerland	Western Alps	46.00 N	7.87 E

No.	Glacier Name[1]	1st/last survey[2]	Country	Location	Coordinates[3]	
105	Gries	1962/2005	Switzerland	Western Alps	46.44 N	8.33 E
106	Limmern	1948/1985	Switzerland	Western Alps	46.82 N	8.98 E
107	Plattalva	1948/1989	Switzerland	Western Alps	46.83 N	8.98 E
108	Silvretta[5]	1960/2005	Switzerland	Eastern Alps	46.85 N	10.08 E
109	Blue Glacier	1956/1999	USA	Washington	47.82 N	123.68 W
110	Columbia (2057)	1984/2005	USA	North Cascades	47.97 N	121.35 W
111	Daniels	1984/2005	USA	North Cascades	47.57 N	121.17 W
112	Easton	1990/2005	USA	North Cascades	48.75 N	120.83 W
113	Foss	1984/2005	USA	North Cascades	47.55 N	121.20 W
114	Gulkana	1966/2005	USA	Alaska Range	63.25 N	145.42 W
115	Ice Worm	1984/2005	USA	North Cascades	47.55 N	121.17 W
116	Lemon Creek	1953/2005	USA	Coast Range	58.38 N	134.40 W
117	Lower Curtis	1984/2005	USA	North Cascades	48.83 N	121.62 W
118	Lynch	1984/2005	USA	North Cascades	47.57 N	121.18 W
119	Noisy Creek	1993/2005	USA	Washington	48.67 N	121.53 W
120	North Klawatti	1993/2005	USA	Washington	48.57 N	121.12 W
121	Rainbow	1984/2005	USA	North Cascades	48.80 N	121.77 W
122	Sandalee	1995/2005	USA	Washington	48.42 N	120.80 W
123	Sholes	1990/2005	USA	North Cascades	48.80 N	121.78 W
124	Silver	1993/2005	USA	Washington	48.98 N	121.25 W
125	South Cascade	1953/2005	USA	North Cascades	48.37 N	121.05 W
126	Wolverine	1966/2004	USA	Kenai Mtns	60.40 N	148.92 W
127	Yawning	1984/2005	USA	North Cascades	48.45 N	121.03 W

[1] Note: Countries and glaciers are listed in alphabetical order
[2] Note: Years of first and most recent survey available to the WGMS
[3] Note: Coordinates in decimal notation
[4] Note: Perennial snowfield or glacieret
[5] Note: The data series has been recalculated by the Principal Investigators and will be published in the next GMBB.

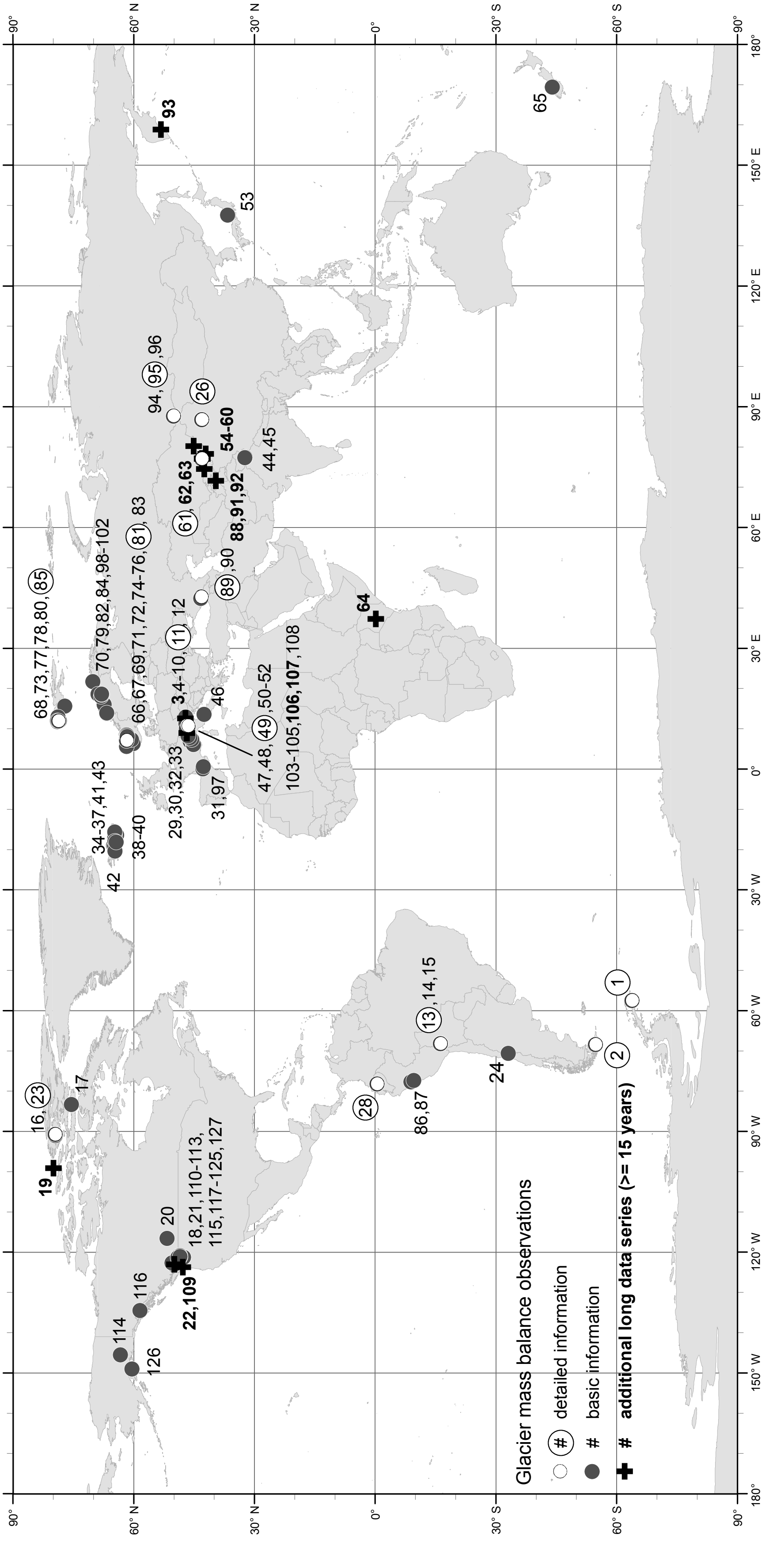


Figure 1.1: Location of the 105 glaciers for which basic information is reported. Additionally, 20 glaciers with interrupted long-term measurment series are marked (i.e. 15 or more years).

2 BASIC INFORMATION

Specific net balance (b), equilibrium line altitude (ELA) and accumulation area ratio (AAR) from the balance years 2003/04 and 2004/05 are presented in Part 2.1. The AAR values are given as integer values only.

Values for ELA_0 and AAR_0 are given in addition. They represent the calculated ELA and AAR values for a zero net balance, i.e., a hypothetical steady state. All values since the beginning of mass balance measurements 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 net balance) are given in Chapter 3.

The graphs in the second part present the development of cumulative specific net balance over the whole observation period for each glacier where three or more net balances were reported and the years 2003/04 or 2004/05 are included. 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 read out from the cumulative specific net balance graphs and has to be determined with the help of other means, such as geodetic or photogrammetric methods.

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

Name	Country	b04 [mm]	b05 [mm]	ELA04 [m a.s.l.]	ELA05 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR04 [%]	AAR05 [%]	AAR_0 [%]
Bahía del Diablo	Antarctica	- 110	- 230	380	400	—	44	38	—
Martial Este	Argentina	- 1318	- 991	> 1180[1)]	1140	—	0	13	—
Goldbergkees	Austria	+ 137	- 260	2925	2880	—	52	51	—
Hintereisferner	Austria	- 667	- 1061	3185	3225	2906	32	29	66
Jamtalferner	Austria	- 288	- 975	2870	> 3200[1)]	2863	40	15	52
Kesselwandferner	Austria	- 189	- 59	3157	3136	3118	61	66	70
Kleinfleisskees	Austria	+ 125	- 111	2820	2850	—	75	63	—
Pasterzenkees	Austria	—	- 899	—	2920	—	—	60	—
Sonnblickkees	Austria	+ 8	- 323	2755	2810	2740	62	44	60
Vernagtferner	Austria	- 407	- 523	3205	3224	3082	34	40	66
Wurtenkees	Austria	- 313	- 448	2980	3020	2896	28	16	36
Chacaltaya	Bolivia	- 1822	- 2057	> 5599[1)]	> 5431[1)]	5258	0	0	—
Charquini Sur	Bolivia	- 1486	- 2499	5315	> 5393[1)]	—	4	0	—
Zongo	Bolivia	- 521	- 1559	5422	5515	5237	48	37	67
Baby Glacier	Canada	—	- 370[2)]	—	—	967	—	—	65
Devon Ice Cap	Canada	+ 46	- 262	1090	1328	—	—	—	
Helm	Canada	- 1995	- 2765	> 2200[1)]	> 2200[1)]	2008	0	0	39
Peyto	Canada	- 550	- 810	2680	2730	2609	29	21	53
Place	Canada	- 2210	- 1295	2610	2405	2080	0	1	50
White	Canada	37	- 612	921	1291	904	75	33	72
Echaurren Norte	Chile	- 570	- 850	—	—	—	—	—	—
Urumqihe E-Br.	China	- 706	- 480	4066	4096	3948	42	48	65
Urumqihe S. No.1	China	- 755	- 488	4074	4123	4025	41	51	56
Urumqihe W-Br.	China	- 844	- 503	4089	4173	4023	40	54	65
Antizana 15 Alpha	Ecuador	- 572	- 789	5145	5150	4023	56	55	65
Argentière	France	- 1310	- 1930	—	—	—	—	—	—
Gebroulaz	France	- 790	- 1510	3100	3200	—	—	—	—
Ossoue	France	- 1220	- 2490	—	—	—	—	—	—
Saint Sorlin	France	- 2450	- 2500	3230	3200	2863	—	—	—
Sarennes	France	- 2820	- 3280	—	—	—	—	—	—
Breidamerkurjökull E.B.	Iceland	- 1330	- 1530	1175	1230	924	50	38	74
Brúarjökull	Iceland	- 800	- 1557	1280	1445	1200	49	24	60
Dyngjujökull	Iceland	—	- 1327	—	1540	—	—	37	—
Eyjabakkajökull	Iceland	- 1310	- 2202	1180	1255	1074	37	25	56
Hofsjökull E	Iceland	- 1500	- 20	—	—	—	—	—	—
Hofsjökull N	Iceland	- 1370	- 430	—	—	—	—	—	—
Hofsjökull SW	Iceland	- 1500	- 570	—	—	—	—	—	—
Koeldukvislarjökull	Iceland	- 776	- 627	1454	1470	1289	46	46	60
Langjökull S. Dome	Iceland	- 1487	- 894	1130	1060	975	33	41	57
Tungnaárjökull	Iceland	- 1699	- 1757	1290	1320	1147	40	38	61
Chhota Shigri	India	- 1227	+ 144	5165	4855	—	31	74	—
Hamtah	India	- 1857	- 1856	—	—	—	7	—	—
Calderone	Italy	+ 252	- 194	2630	2730	—	100	21	—
Caresèr	Italy	- 1562	- 2005	> 3430[1)]	> 3391[1)]	3100	0	0	44

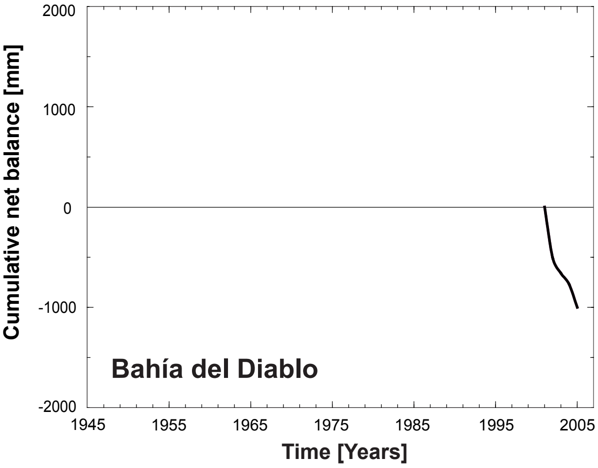
Name	Country	b04 [mm]	b05 [mm]	ELA04 [m a.s.l.]	ELA05 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR04 [%]	AAR05 [%]	AAR_0 [%]
Ciardoney	Italy	- 1060	- 2230	3150	3150	3050	0	0	54
Fontana Bianca	Italy	- 994	- 1471	> 3355 1)	> 3355 1)	3283	0	0	55
Lunga (Vedretta)	Italy	- 1524	- 1233	> 3390 1)	> 3390 1)	—	0	0	—
Malavalle	Italy	- 208	- 800	2990	3036	3060	47	37	50
Pendente	Italy	- 427	- 963	2935	2985	2830	9	2	37
Hamaguri Yuki 3)	Japan	- 1196	- 181	—	—	—	—	—	—
Ts. Tuyuksuyskiy	Kazakhstan	+ 62	- 340	3790	3785	3746	42	48	52
Brewster	New Zealand	—	+ 1141	—	1810	—	—	88	—
Ålfotbreen	Norway	- 100	+ 668	1225	1135	1187	53	78	57
Austdalsbreen	Norway	- 960	+ 190	1495	1385	1440	46	78	65
Austre Brøggerbreen	Norway	- 1120	- 1000	695	558	437	0	0	21
Breidablikkbrea	Norway	- 940	- 280	1605	1500	1475	17	48	—
Engabreen	Norway	+ 817	+ 897	1040	1060	1172	83	80	60
Gråfjellsbrea	Norway	- 820	+ 10	1565	1460	1457	24	67	—
Gråsubreen	Norway	- 492	- 493	2210	2180	2132	7	13	28
Hansbreen	Norway	- 577	+ 47	390	250	299	25	65	55
Hansebreen	Norway	- 500	- 90	1220	1150	1156	31	53	55
Hardangerjøkulen	Norway	+ 80	+ 723	1670	1590	1679	75	84	68
Hellstugubreen	Norway	- 843	- 287	1980	1930	1837	23	39	59
Irenebreen	Norway	- 605	- 862	405	480	—	27	10	—
Kongsvegen	Norway	- 740	- 440	703	631	550	5	19	45
Langfjordjøkulen	Norway	- 1920	- 1250	> 1050 1)	940	727	0	28	65
Midtre Lovénbreen	Norway	- 970	- 740	571	467	409	0	5	29
Nigardsbreen	Norway	- 43	+ 1098	1530	1395	1565	70	87	61
Rundvassbreen	Norway	- 210	—	1260	—	—	31	—	—
Storbreen	Norway	- 585	- 63	1855	1795	1716	22	43	59
Storglombreen	Norway	+ 110	+ 330	1075	1060	1156	78	79	64
Waldemarbreen	Norway	- 641	- 722	400	429	273	21	15	48
Artesonraju	Peru	—	- 761	—	4959	—	—	77	—
Yanamarey	Peru	—	- 1955	—	4912	—	—	35	—
Djankuat	Russia	+ 730	+ 390	3070	3080	3189	43	43	56
Garabashi	Russia	+ 250	+ 200	3750	3750	3797	66	66	60
Leviy Aktru	Russia	- 260	+ 40	3250	3190	3160	57	62	61
Maliy Aktru	Russia	- 150	+ 160	3240	3200	3152	63	72	70
No. 125 (Vodopadniy)	Russia	- 220	+ 60	3250	3210	3203	66	71	68
Maladeta	Spain	- 1516	- 1479	> 3200 1)	3150	3060	0	0	40
Mårmaglaciären	Sweden	- 580	- 790	—	—	1595	—	—	34
Rabots Glaciär	Sweden	—	- 1170	—	—	1368	—	—	51
Riukojietna	Sweden	—	- 350	—	—	1329	—	—	55
Storglaciären	Sweden	- 190	- 70	—	—	1462	—	—	45
Tarfalaglaciären	Sweden	- 380	- 920	—	—	1524	—	—	—
Basòdino	Switzerland	- 490	- 1172	2950	3100	2880	33	5	50
Findelen	Switzerland	—	- 200	—	3200	—	—	62	—
Gries	Switzerland	- 1330	- 1670	> 3400 1)	3153	2838	0	4	59
Silvretta	Switzerland	+ 119	- 651	2738	2835	2763	62	45	54

Name	Country	b04 [mm]	b05 [mm]	ELA04 [m a.s.l.]	ELA05 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR04 [%]	AAR05 [%]	AAR_0 [%]
Columbia (2057)	USA	- 1830	- 3210	—	—	—	—	—	68
Daniels	USA	- 2130	- 2900	—	—	—	—	—	69
Easton	USA	- 1060	- 2450	—	—	—	—	—	—
Foss	USA	- 1940	- 3120	—	—	—	—	—	65
Gulkana	USA	- 2290	- 260	—	1758	1727	—	63	63
Ice Worm	USA	- 2000	- 2850	—	—	—	—	—	69
Lemon Creek	USA	- 650	- 470	1100	1080	—	59	61	—
Lower Curtis	USA	- 1510	- 2750	—	—	—	—	—	63
Lynch	USA	- 1980	- 2620	—	—	—	—	—	69
Noisy Creek	USA	- 1575	- 2410	2043 [1)]	2100 [1)]	1771	0	0	62
North Klawatti	USA	- 1272	- 2060	2300	2360	2070	19	3	72
Rainbow	USA	- 1670	- 2650	—	—	—	—	—	67
Sandalee	USA	- 1232	- 2293	2330 [1)]	— [1)]	2150	0	0	62
Sholes	USA	- 1860	- 2840	—	—	—	—	—	—
Silver	USA	- 563	- 1490	2435	2555	2300	14	8	62
South Cascade	USA	- 1650	- 2450	—	> 2125 [1)]	1899	—	5	53
Wolverine	USA	- 2280	—	—	—	1151	—	—	63
Yawning	USA	- 1780	- 3020	—	—	—	—	—	—

[1)] Above glacier maximum elevation
[2)] Net balance measured over the period 01.09.2003 - 31.08.2005
[3)] Note: Perennial snowfield or glacieret

2.2 CUMULATIVE SPECIFIC NET BALANCE GRAPHS

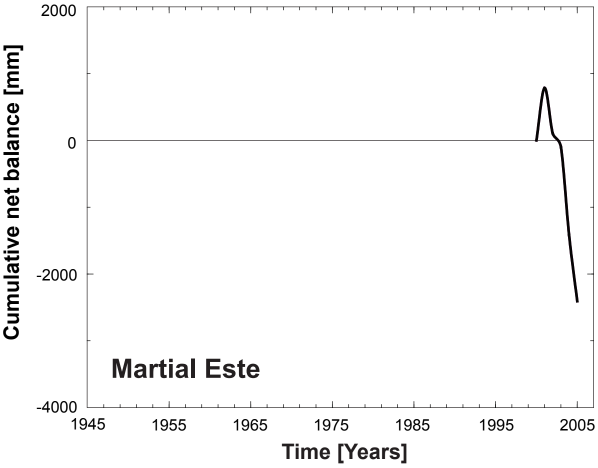
ANTARCTICA



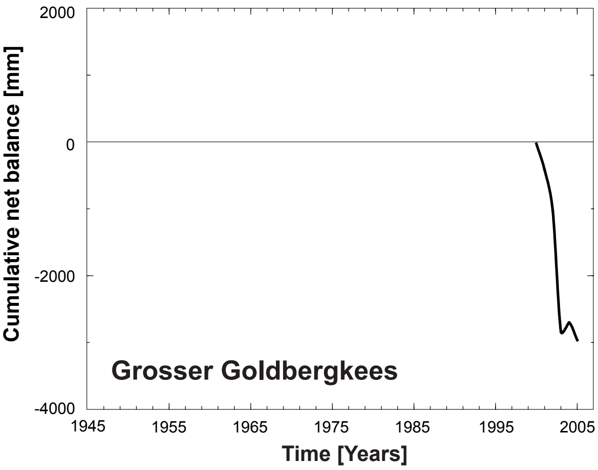
Notes:

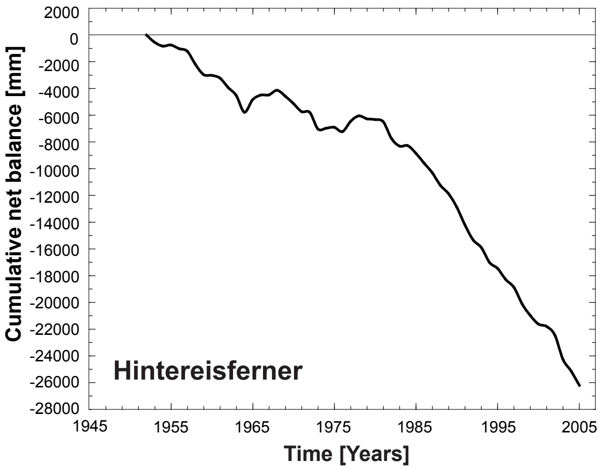
- missing values are marked with gaps in the plotted data series with graphs restarting with the value of the previous available data point
- y-axis are scaled according to the data range of the cumulative net balance graph

ARGENTINA

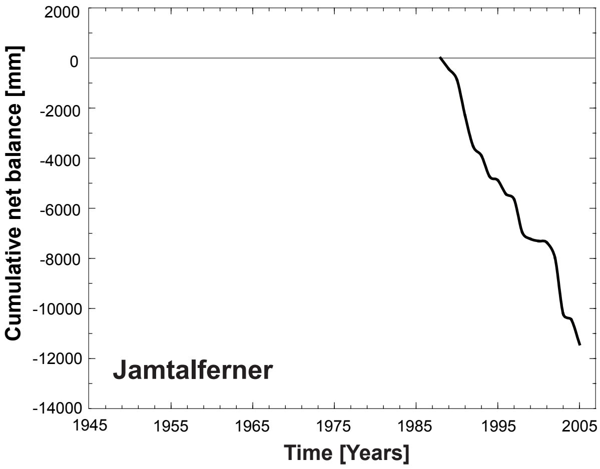


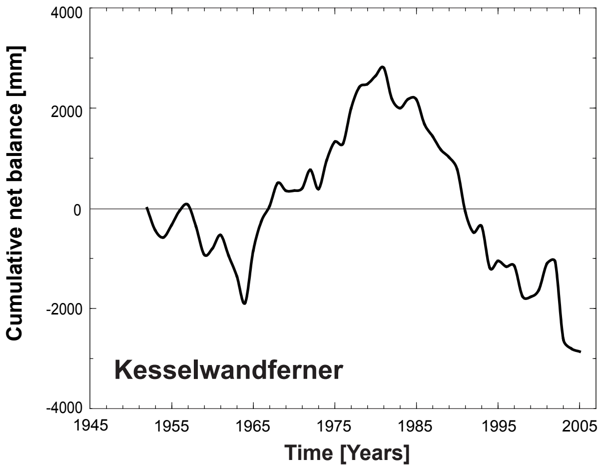
AUSTRIA

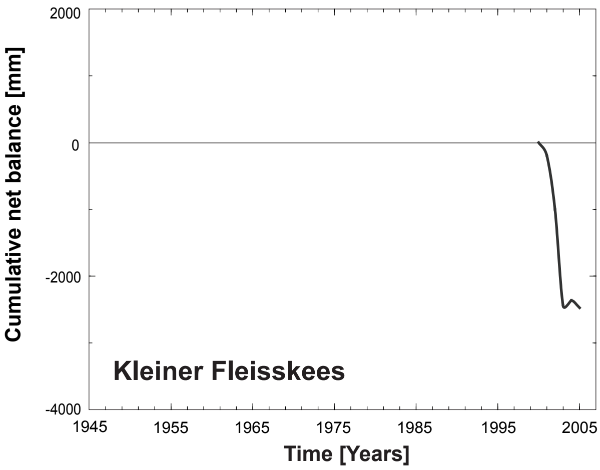


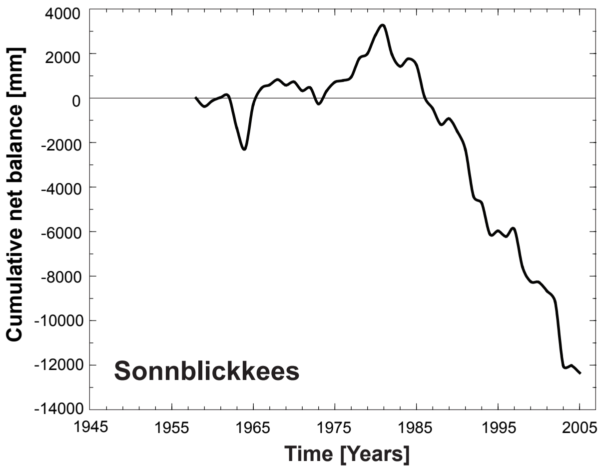


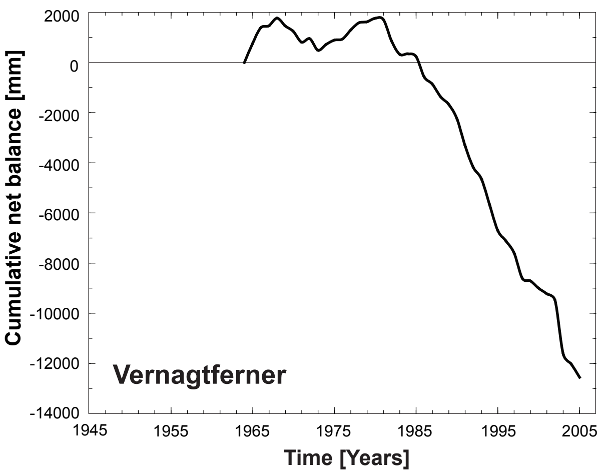
AUSTRIA

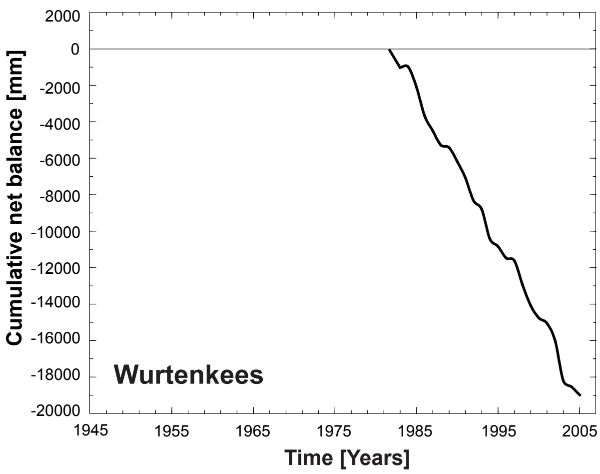

Cumulative net balance [mm]
Time [Years]
Jamtalferner
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945
1955
1965
1975
1985
1995
2005


Cumulative net balance [mm]
Time [Years]
Kesselwandferner
4000
2000
0
-2000
-4000
1945
1955
1965
1975
1985
1995
2005

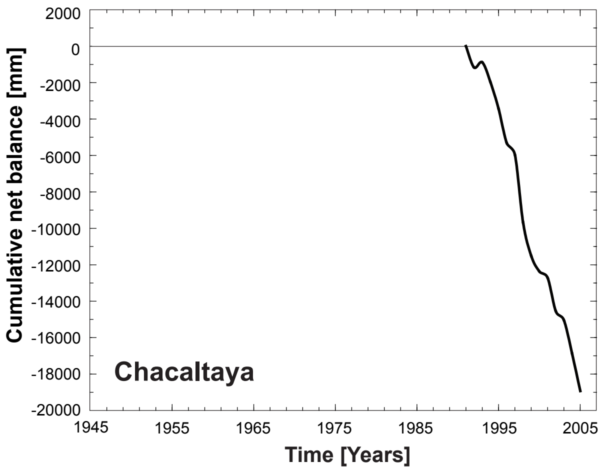

Cumulative net balance [mm]
Time [Years]
Kleiner Fleisskees
2000
0
-2000
-4000
1945
1955
1965
1975
1985
1995
2005

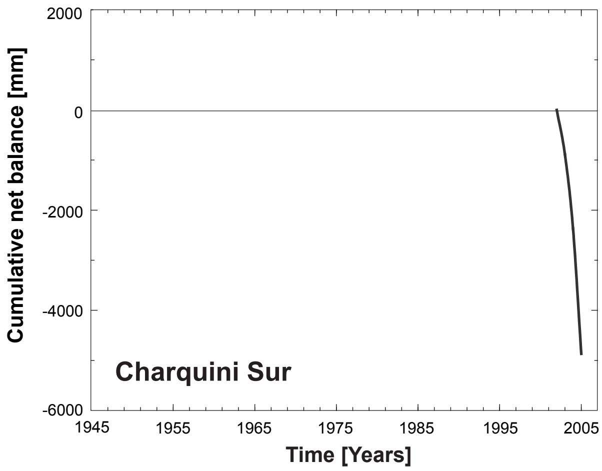

Cumulative net balance [mm]
Time [Years]
Sonnblickkees
4000
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945
1955
1965
1975
1985
1995
2005

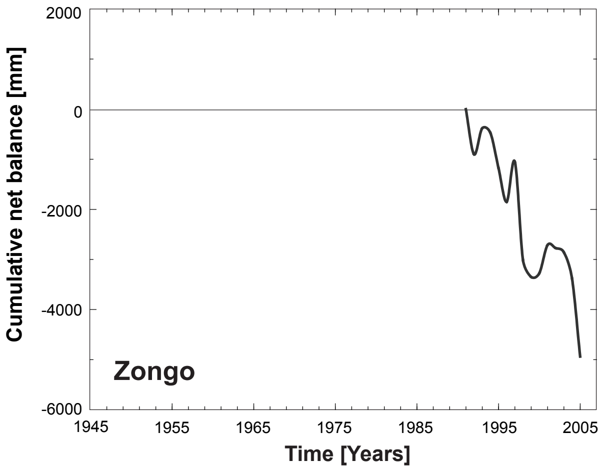

Cumulative net balance [mm]
Time [Years]
Vernagtferner
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945
1955
1965
1975
1985
1995
2005


Cumulative net balance [mm]
Time [Years]
Wurtenkees
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
-18000
-20000
1945
1955
1965
1975
1985
1995
2005

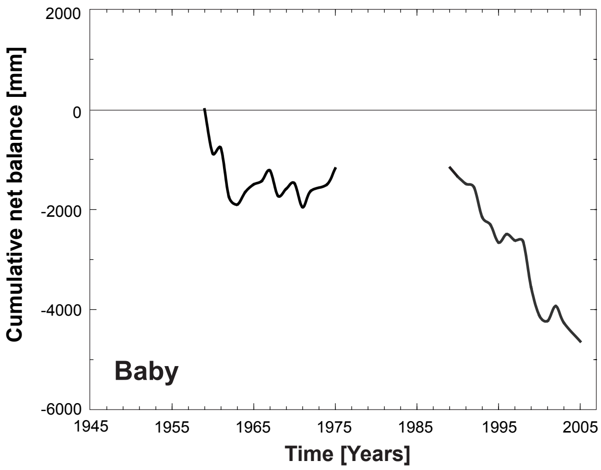
BOLIVIA

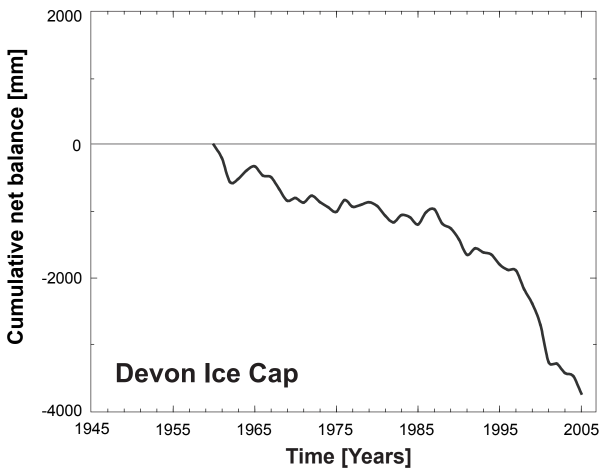




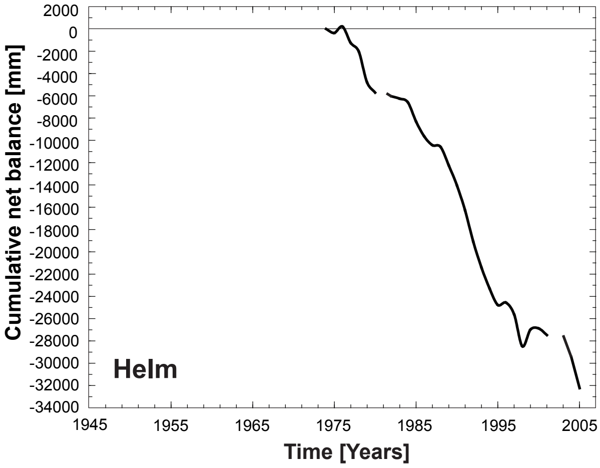


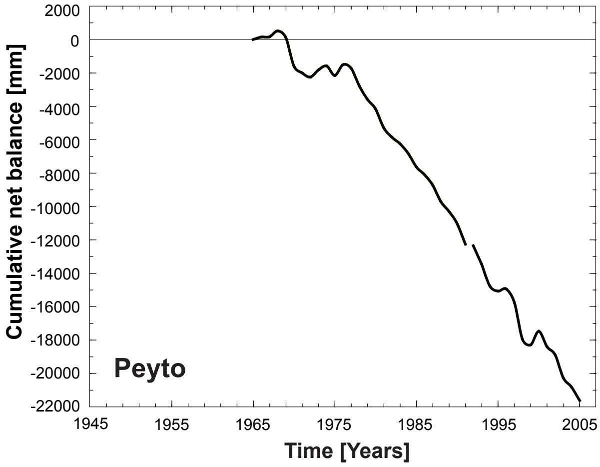
CANADA

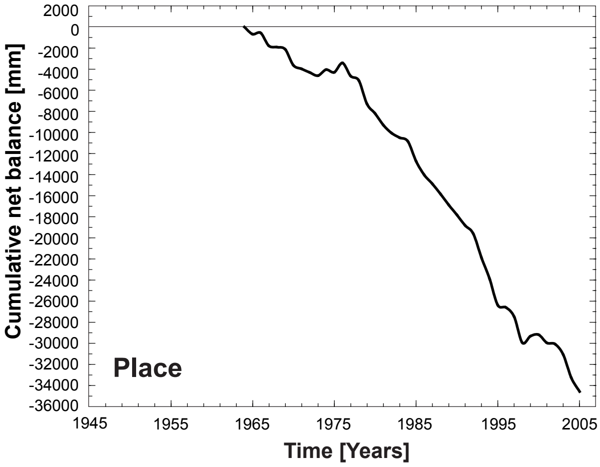


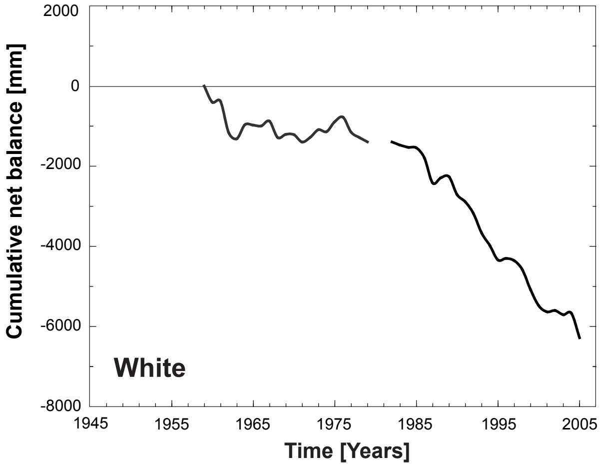


CANADA

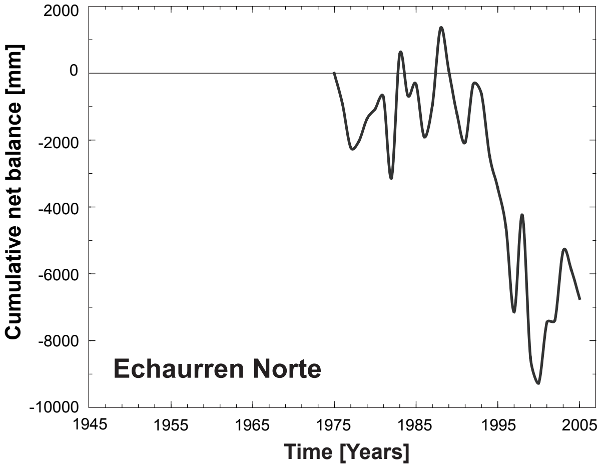




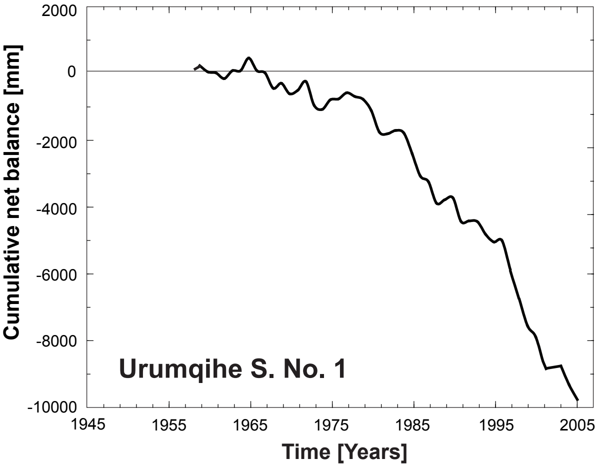




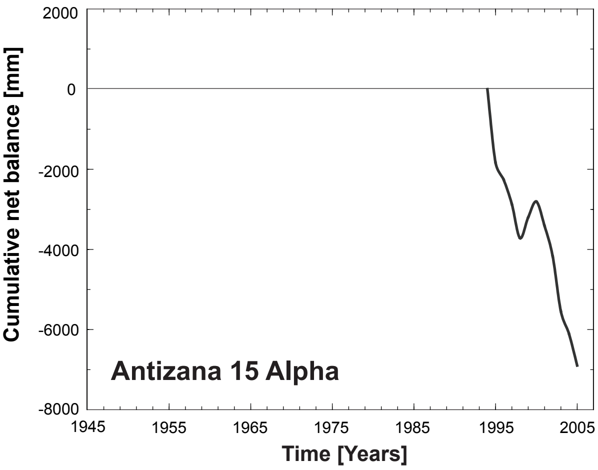
CHILE



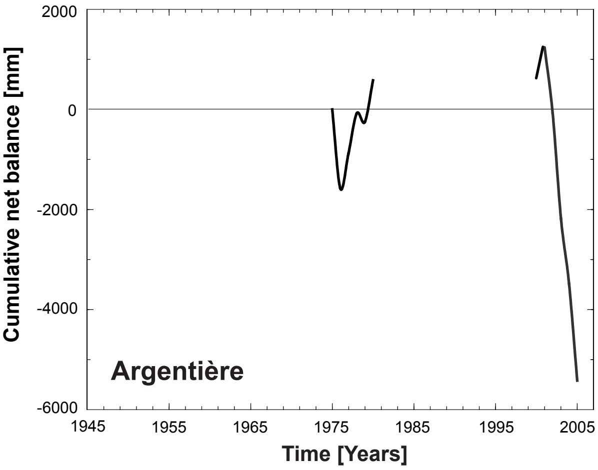
CHINA

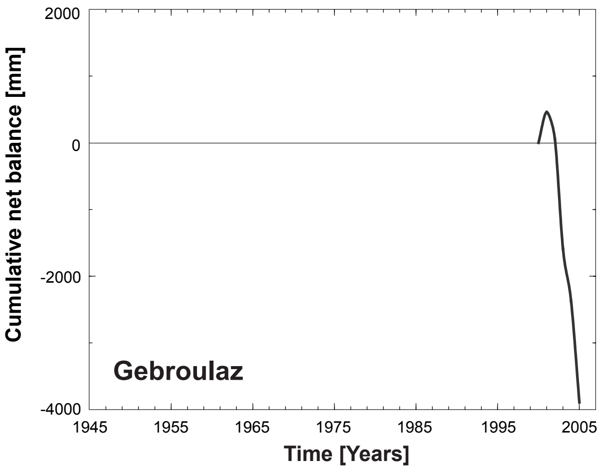


ECUADOR

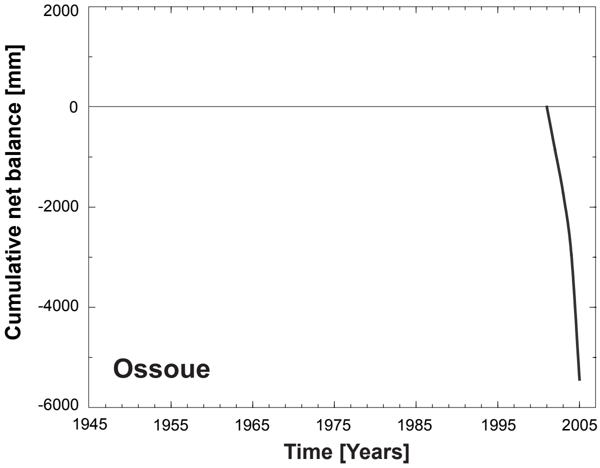


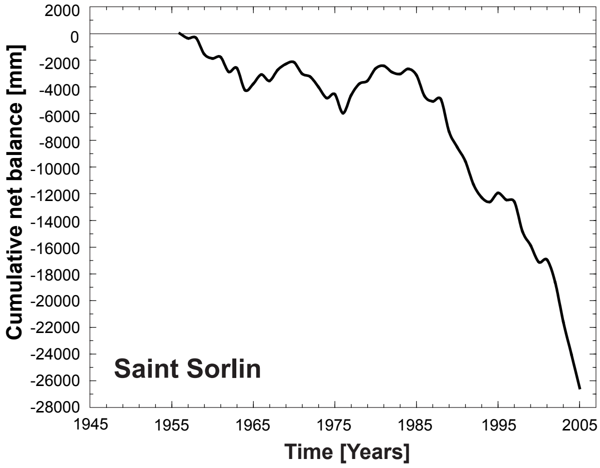
FRANCE

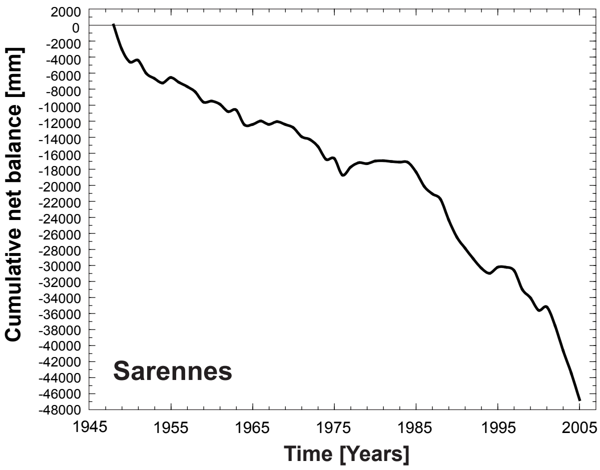




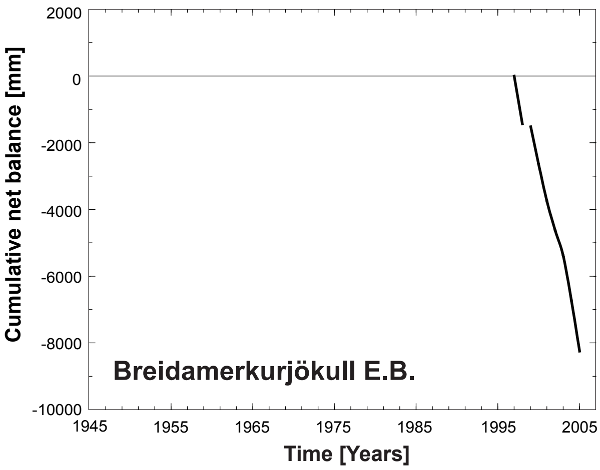
FRANCE

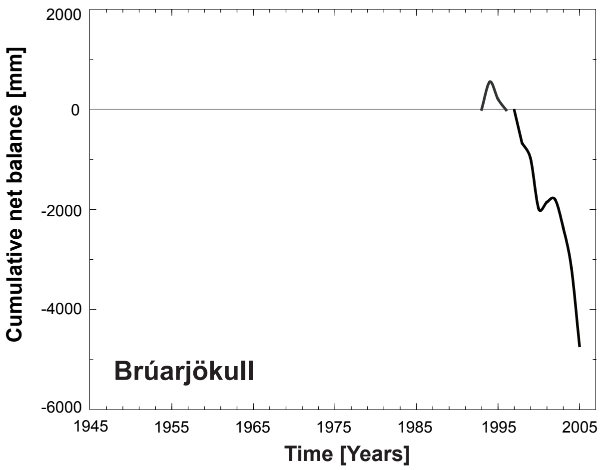






ICELAND





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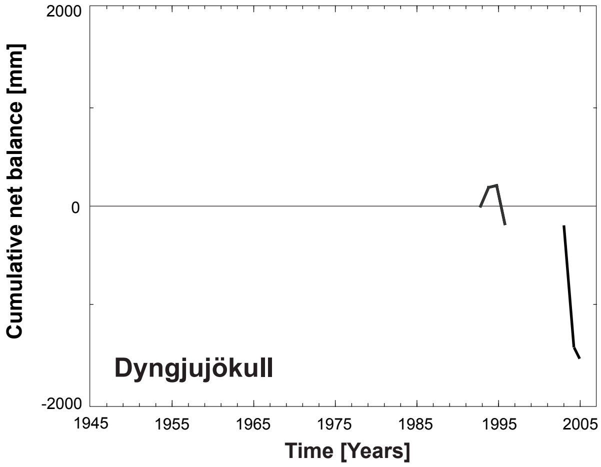
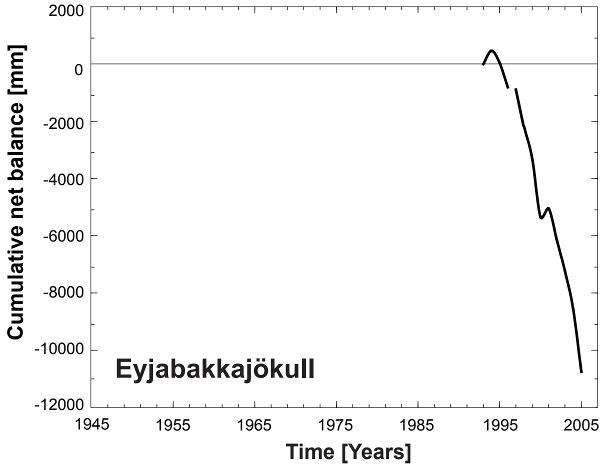
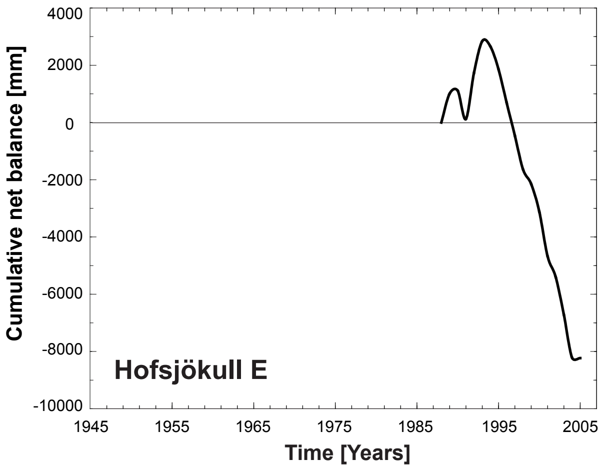
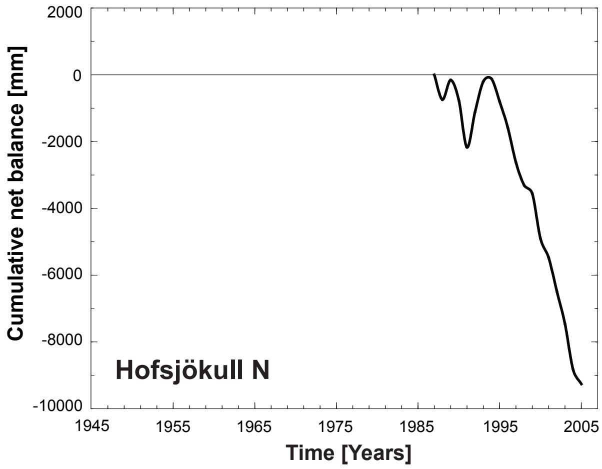
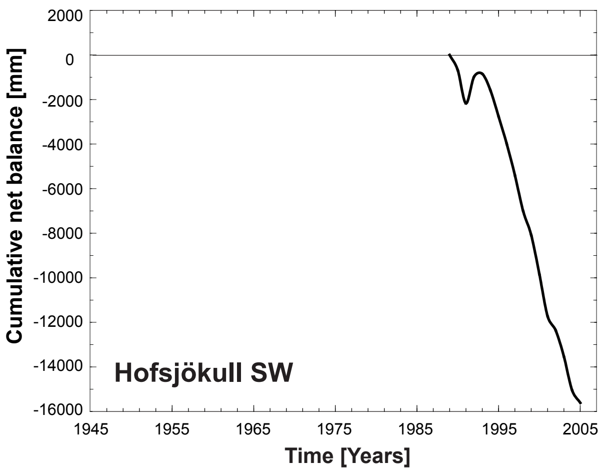
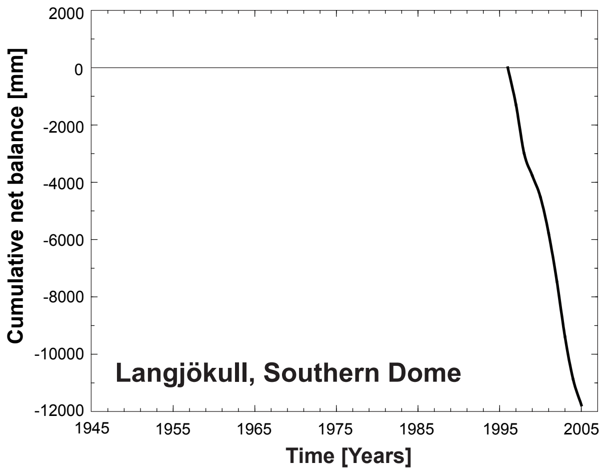

Dyngjujökull
Cumulative net balance [mm]
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005
Time [Years]


Eyjabakkajökull
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
1945
1955
1965
1975
1985
1995
2005
Time [Years]

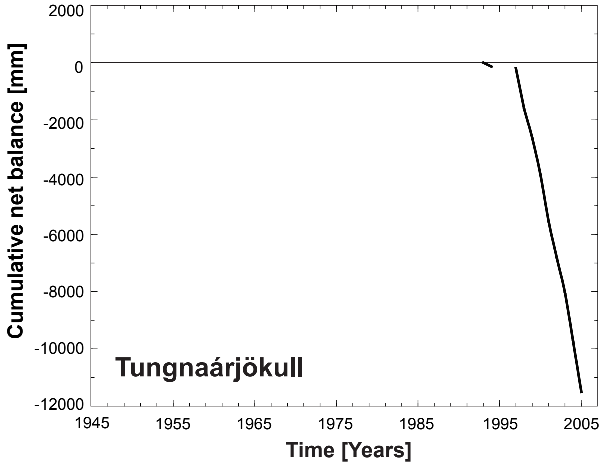

Hofsjökull E
Cumulative net balance [mm]
4000
2000
0
-2000
-4000
-6000
-8000
-10000
1945
1955
1965
1975
1985
1995
2005
Time [Years]


Hofsjökull N
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
1945
1955
1965
1975
1985
1995
2005
Time [Years]

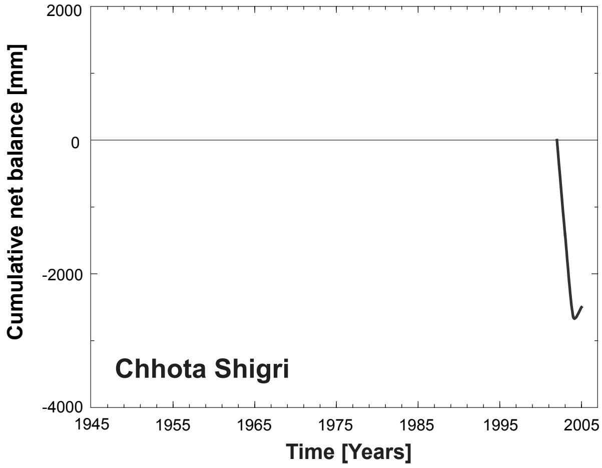

Hofsjökull SW
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
1945
1955
1965
1975
1985
1995
2005
Time [Years]

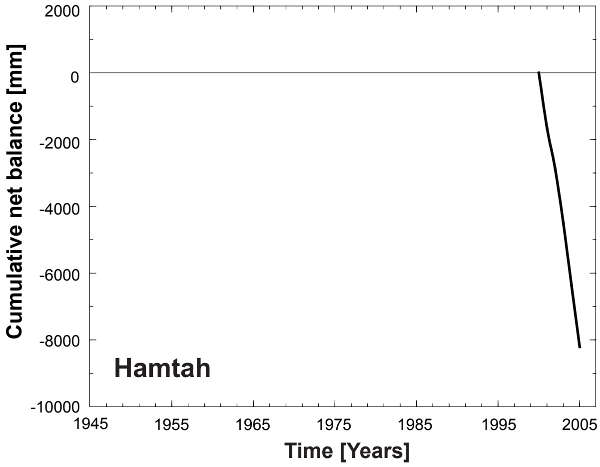

Langjökull, Southern Dome
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
1945
1955
1965
1975
1985
1995
2005
Time [Years]

ICELAND

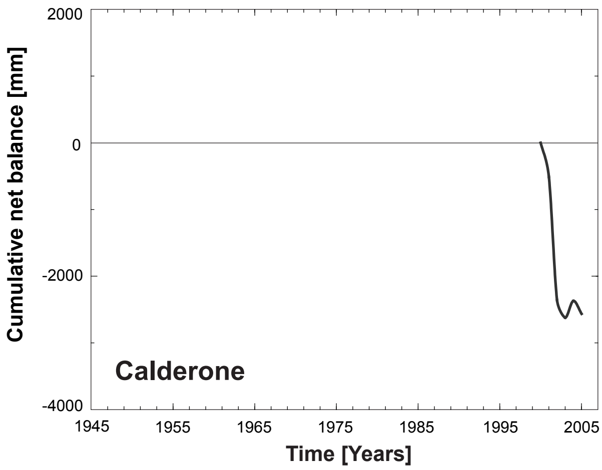


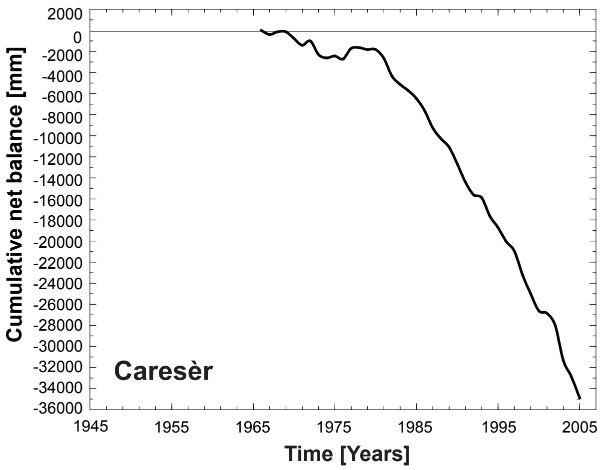
INDIA



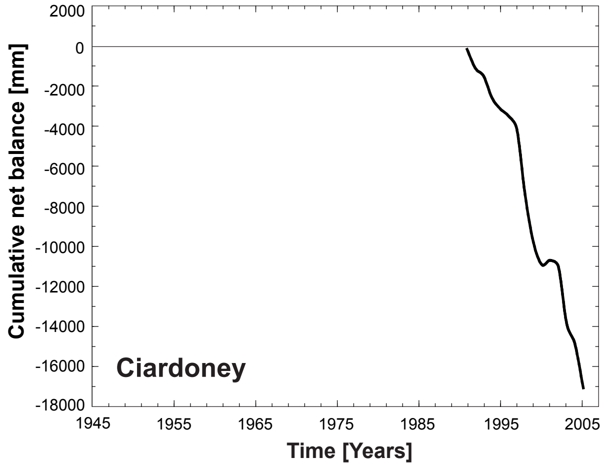


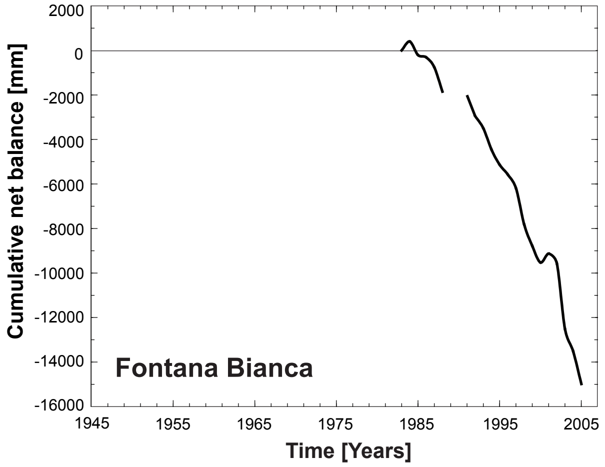
ITALY

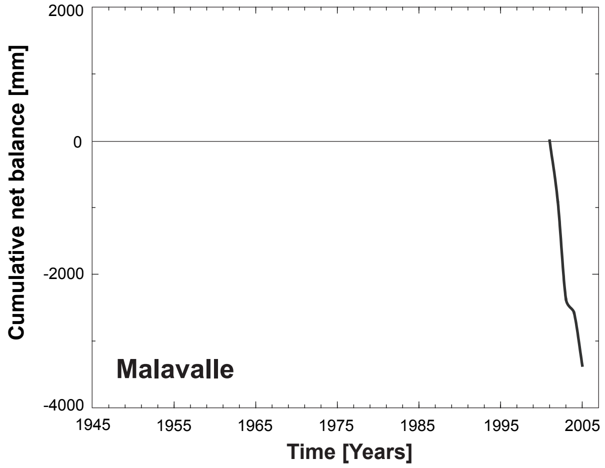


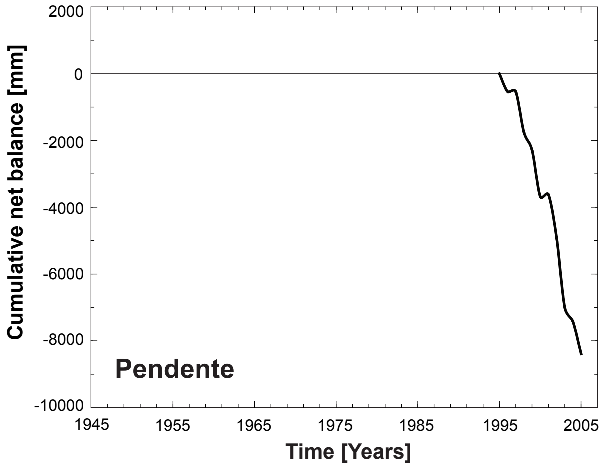


ITALY

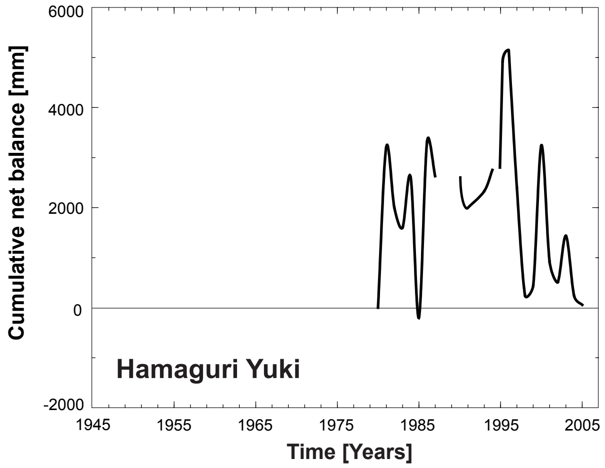

Ciardoney
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
-18000
1945
1955
1965
1975
1985
1995
2005


Fontana Bianca
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
1945
1955
1965
1975
1985
1995
2005

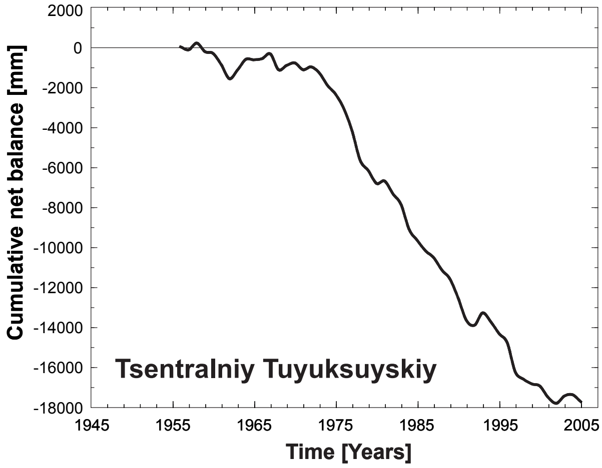

Malavalle
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
1945
1955
1965
1975
1985
1995
2005


Pendente
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
1945
1955
1965
1975
1985
1995
2005

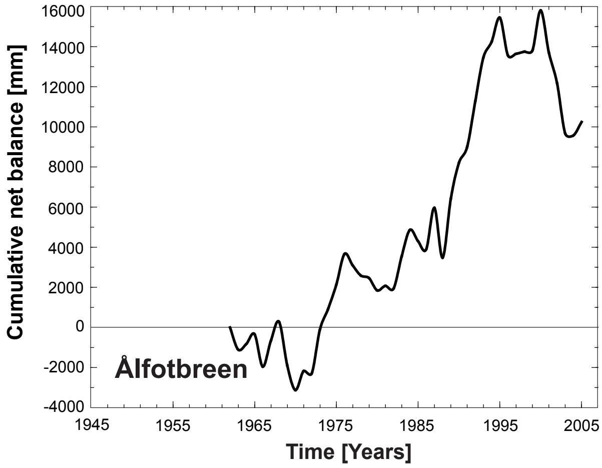
JAPAN

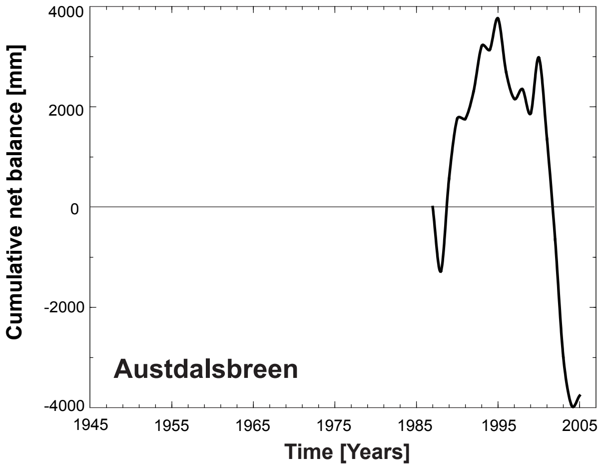

Hamaguri Yuki
Cumulative net balance [mm]
Time [Years]
6000
4000
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005

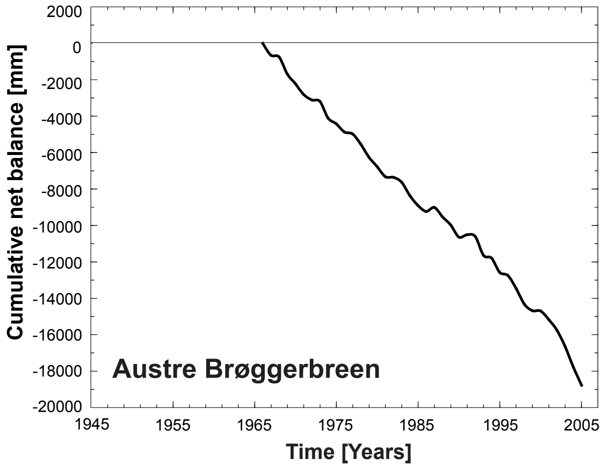
KAZAKHSTAN

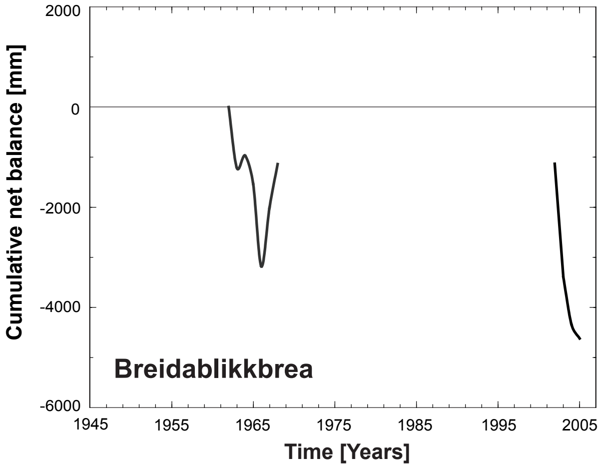


NORWAY

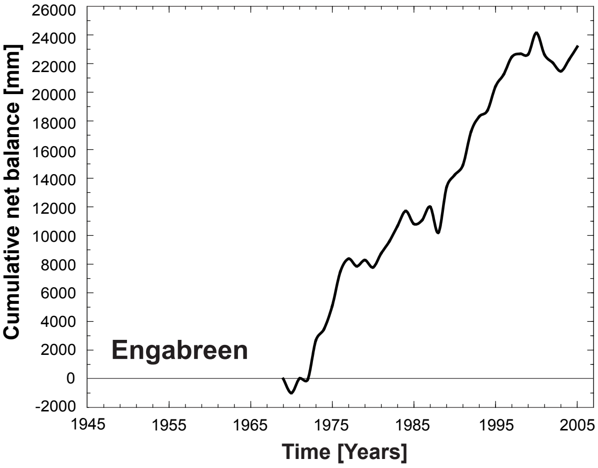


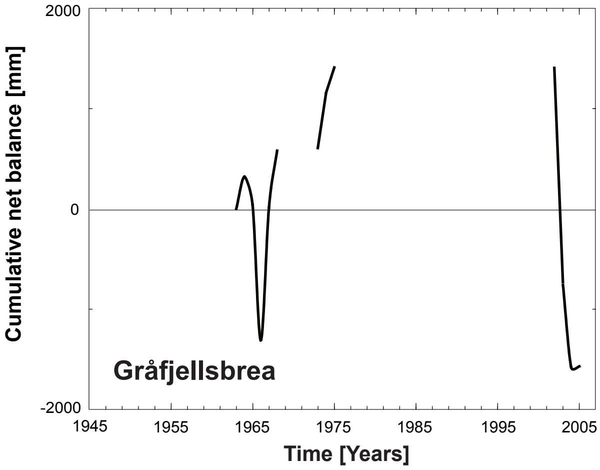


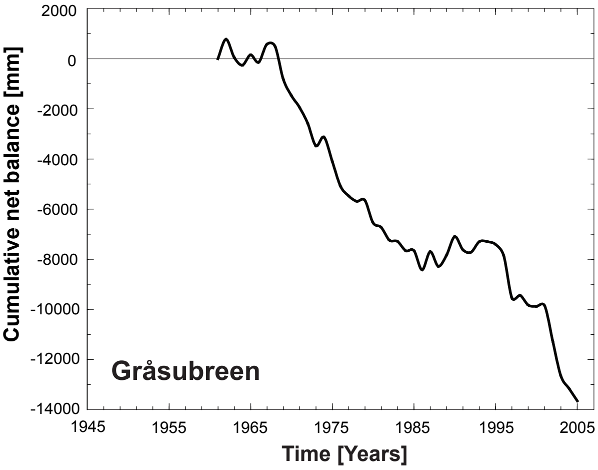


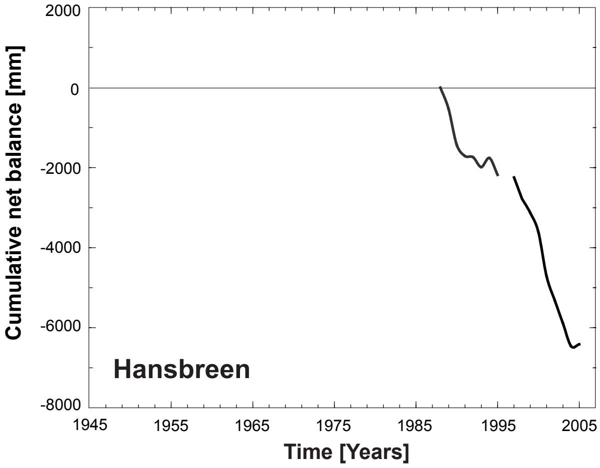


NORWAY


Engabreen
Cumulative net balance [mm]
Time [Years]
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005


Gråfjellsbrea
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005


Gråsubreen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945
1955
1965
1975
1985
1995
2005


Hansbreen
Cumulative net balance [mm]
Time [Years]
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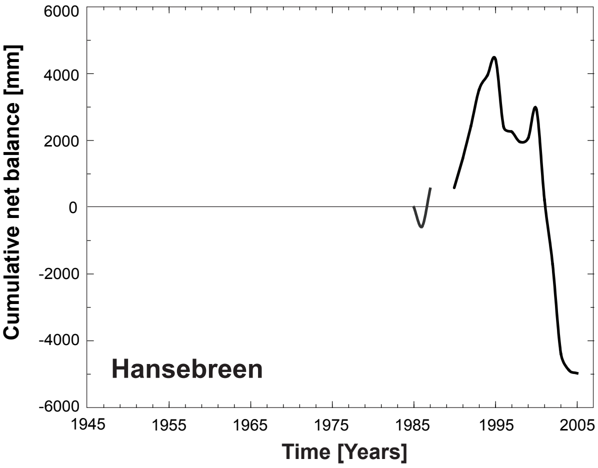
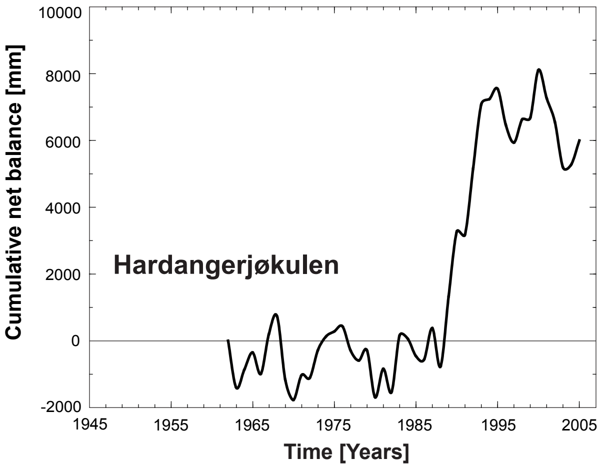
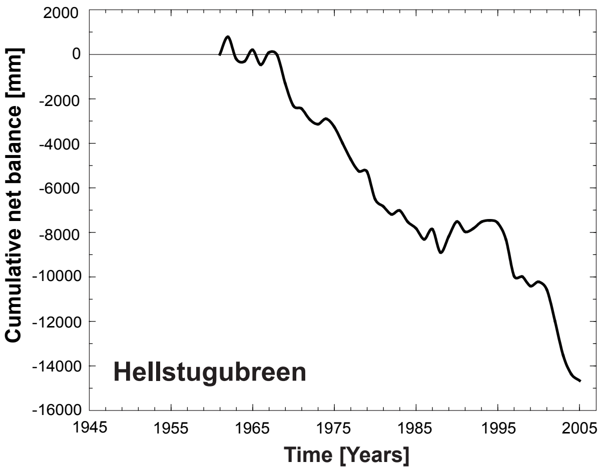
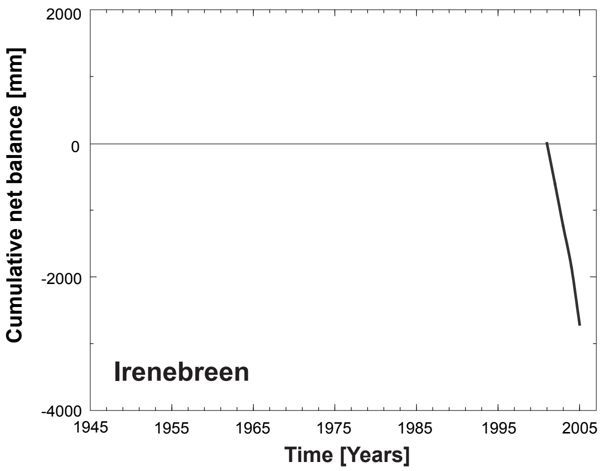
0
-2000
-4000
-6000
-8000
1945
1955
1965
1975
1985
1995
2005

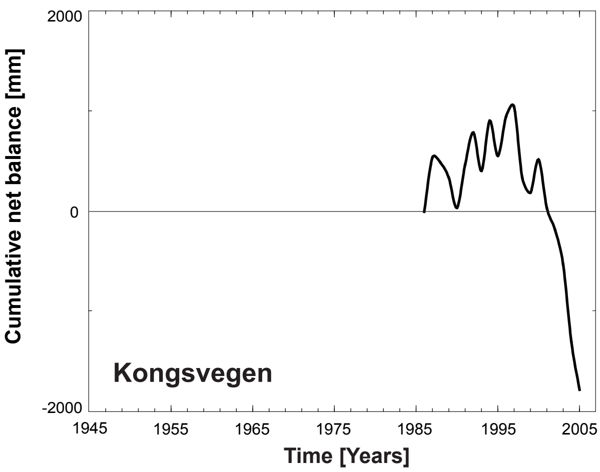

Hansebreen
Cumulative net balance [mm]
Time [Years]
6000
4000
2000
0
-2000
-4000
-6000
1945
1955
1965
1975
1985
1995
2005

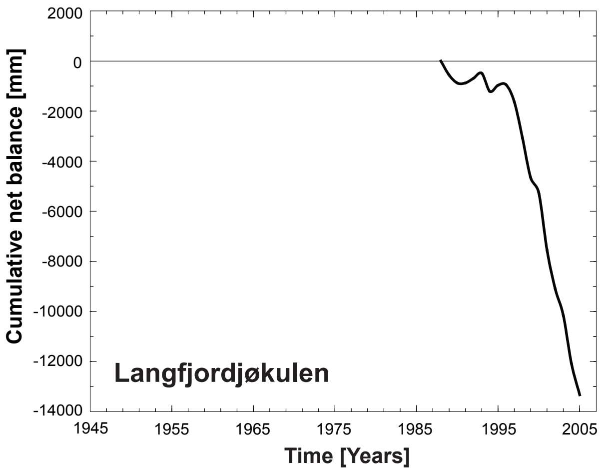

Hardangerjøkulen
Cumulative net balance [mm]
Time [Years]
10000
8000
6000
4000
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005

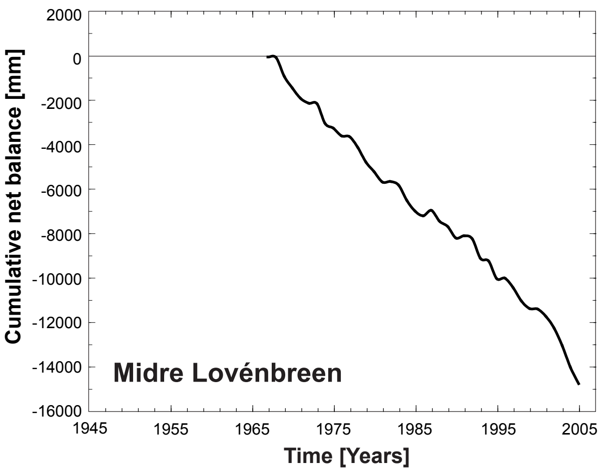
NORWAY


Hellstugubreen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
1945
1955
1965
1975
1985
1995
2005


Irenebreen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
1945
1955
1965
1975
1985
1995
2005


Kongsvegen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005


Langfjordjøkulen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945
1955
1965
1975
1985
1995
2005


Midre Lovénbreen
Cumulative net balance [mm]
Time [Years]
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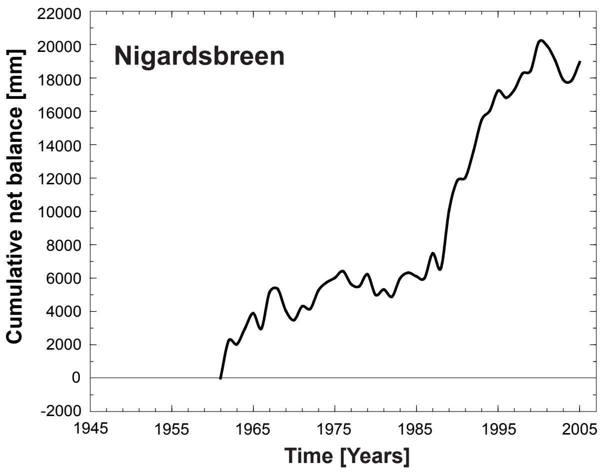
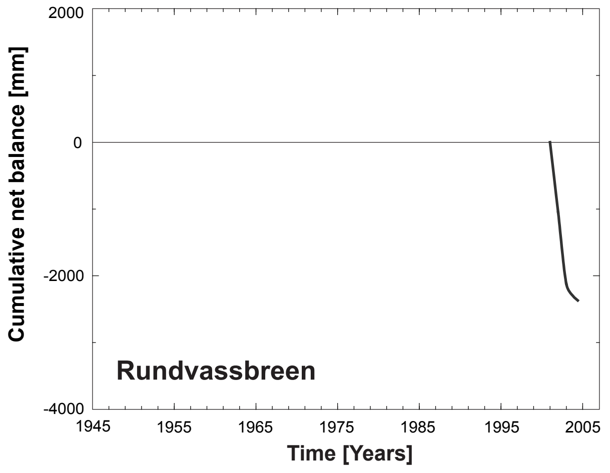
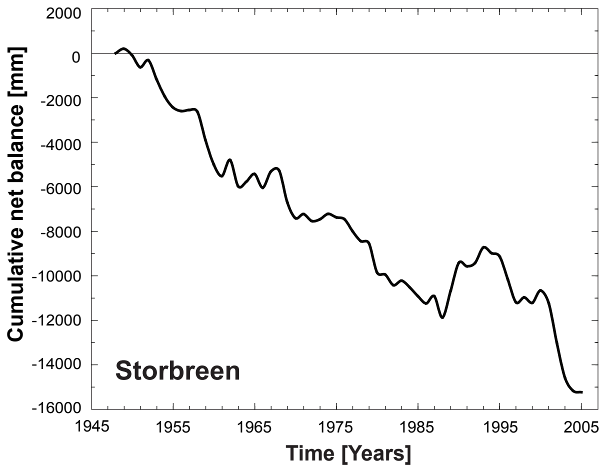
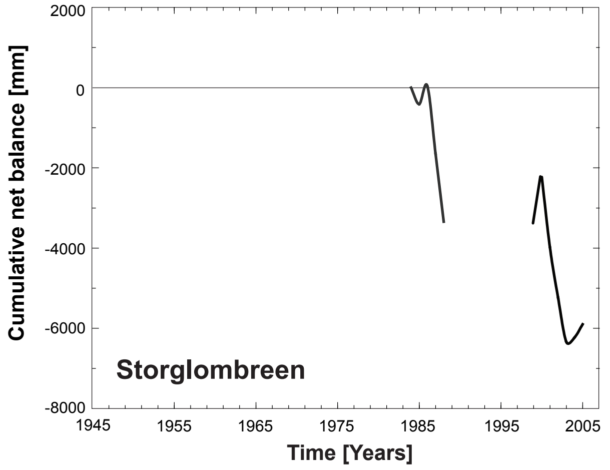
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
1945
1955
1965
1975
1985
1995
2005

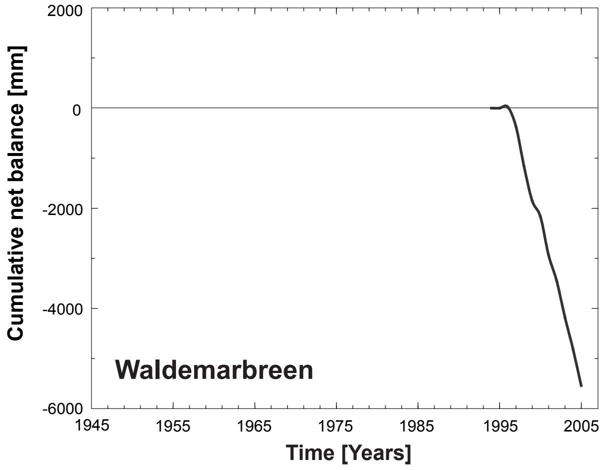

Nigardsbreen
Cumulative net balance [mm]
Time [Years]
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005

NORWAY

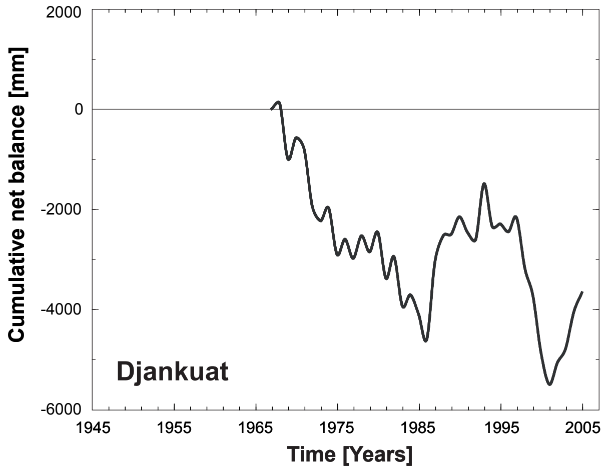


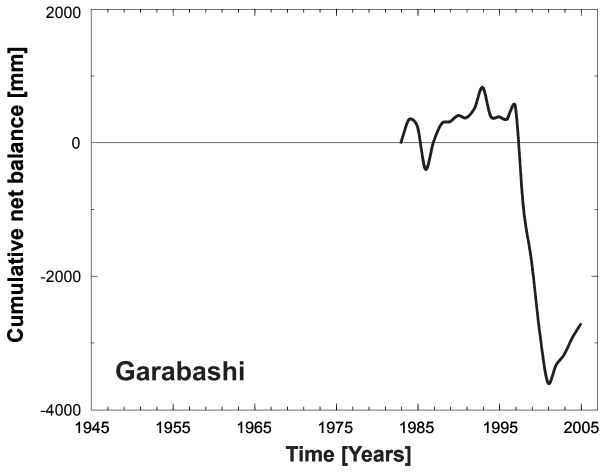




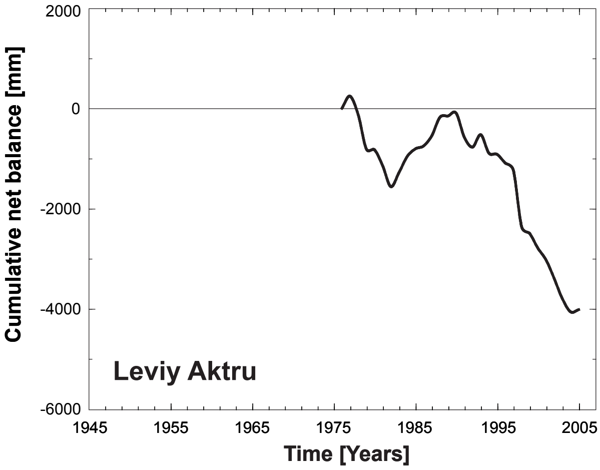


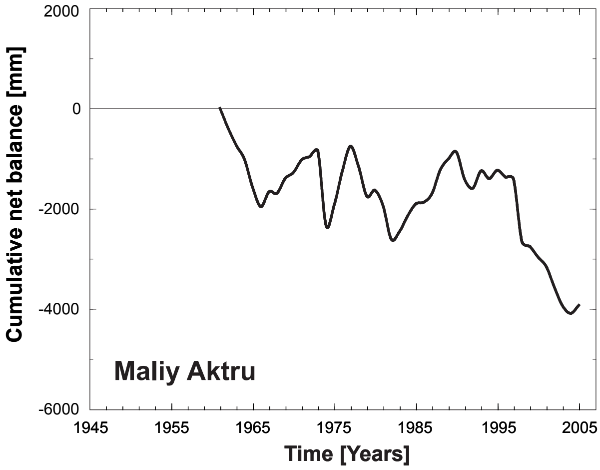
RUSSIA

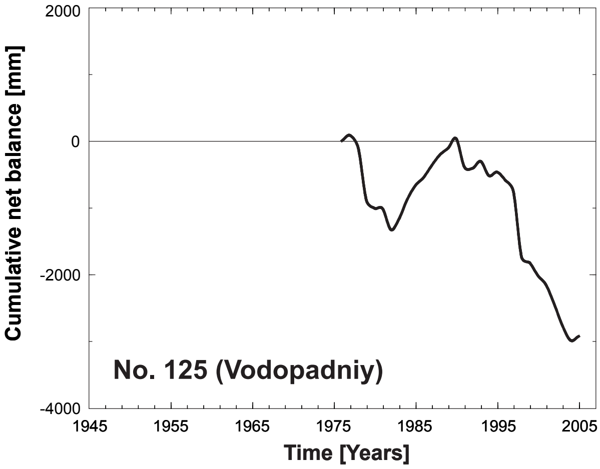




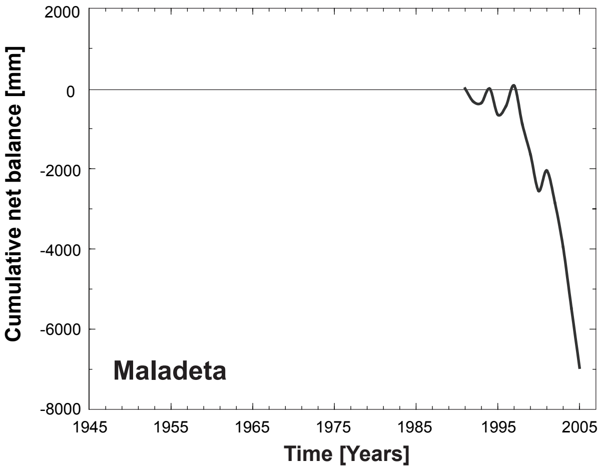
RUSSIA



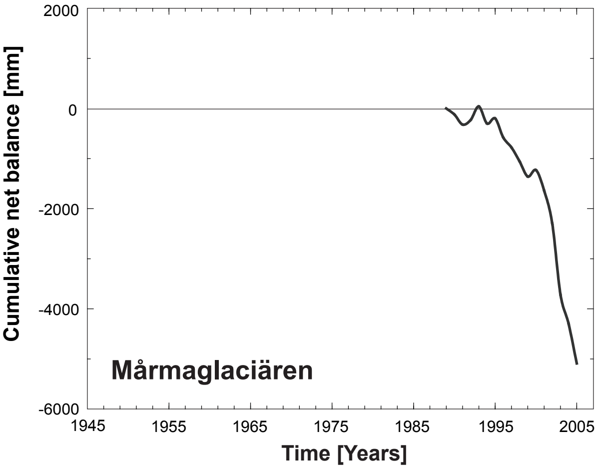


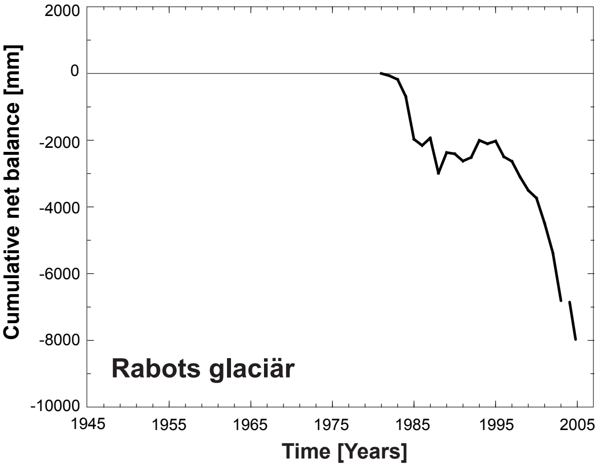


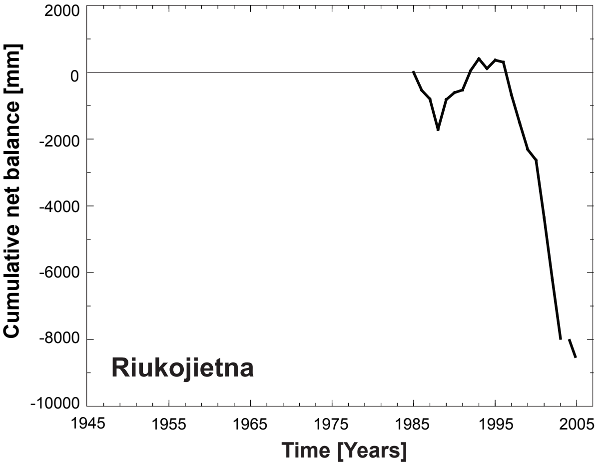
SPAIN

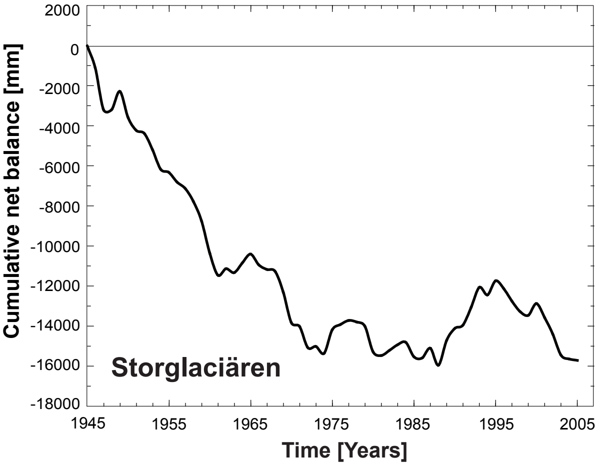


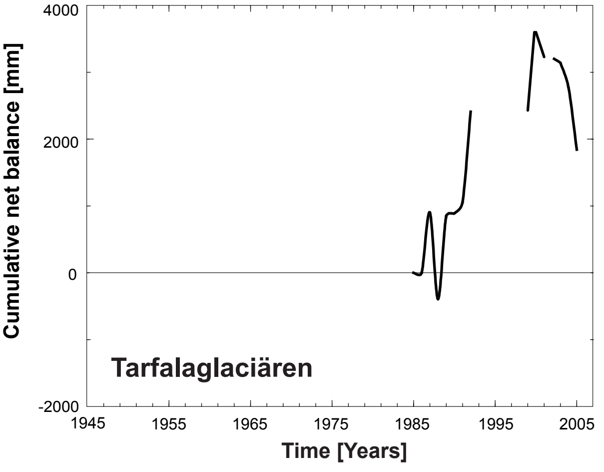
SWEDEN


Cumulative net balance [mm]
Time [Years]
Mårmaglaciären

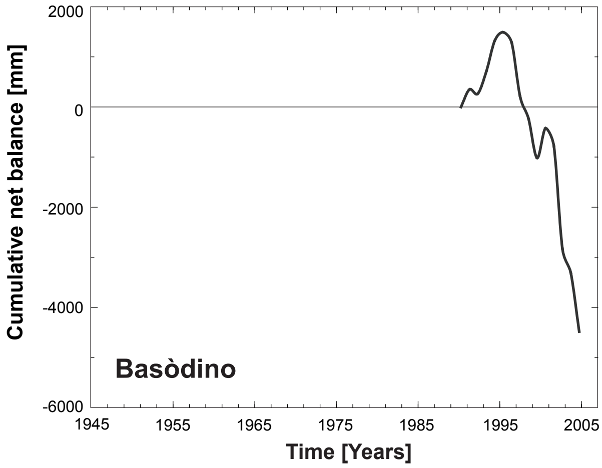

Cumulative net balance [mm]
Time [Years]
Rabots glaciär

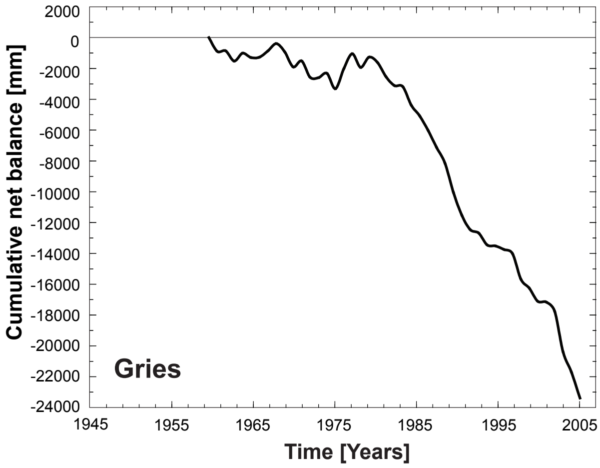

Cumulative net balance [mm]
Time [Years]
Riukojietna

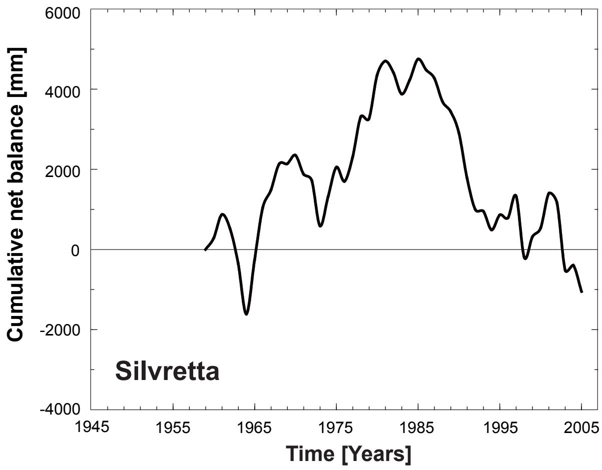

Cumulative net balance [mm]
Time [Years]
Storglaciären


Cumulative net balance [mm]
Time [Years]
Tarfalaglaciären

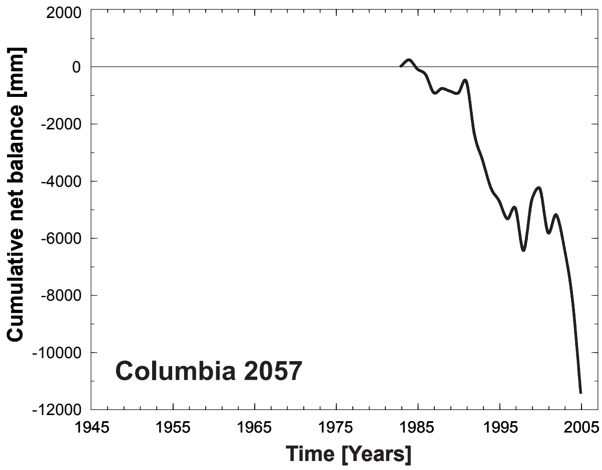
SWITZERLAND

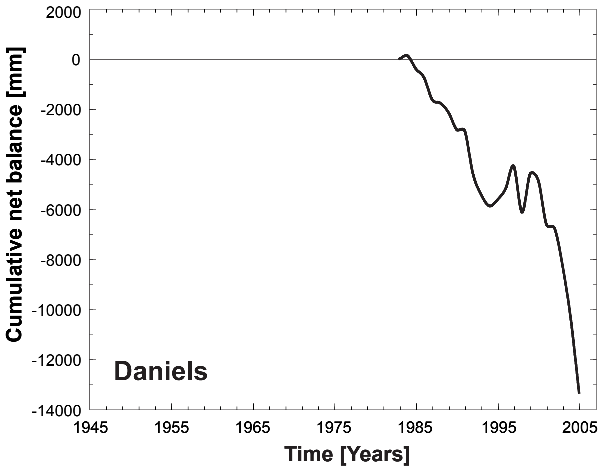




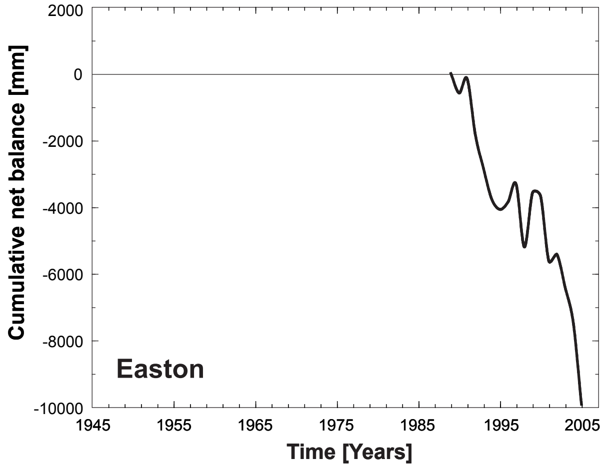


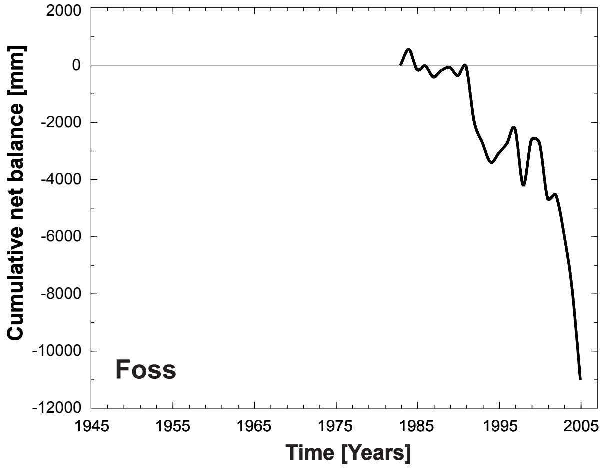
USA

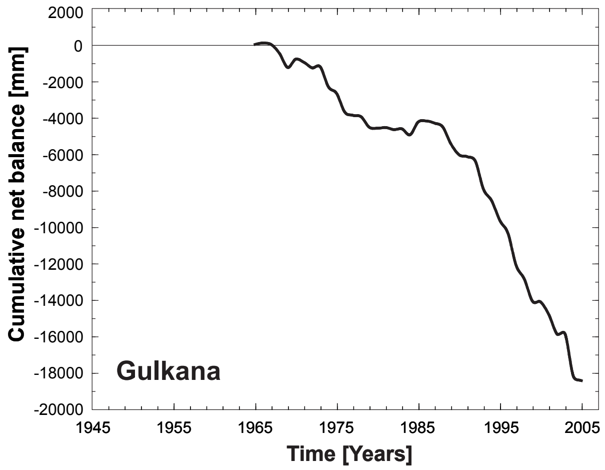


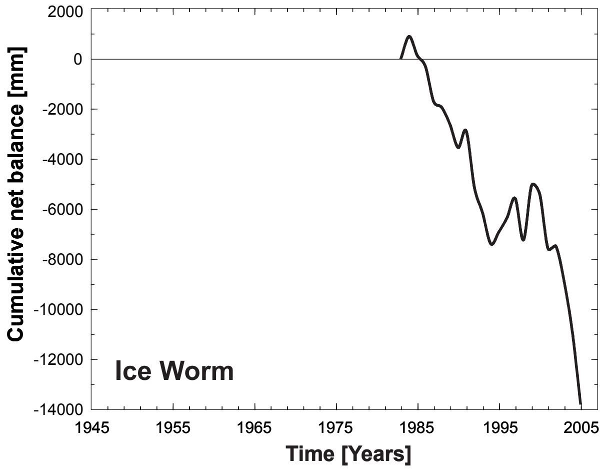


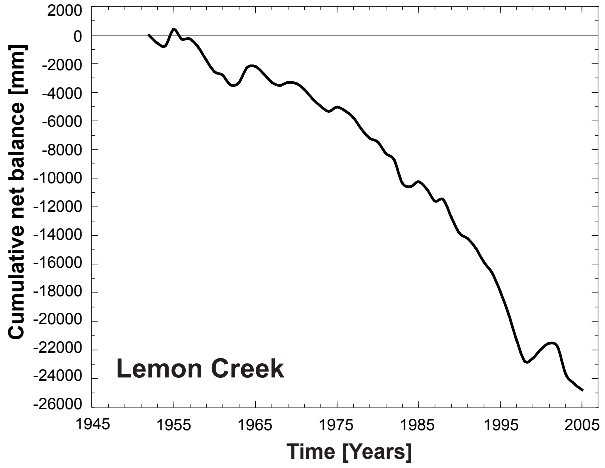
USA

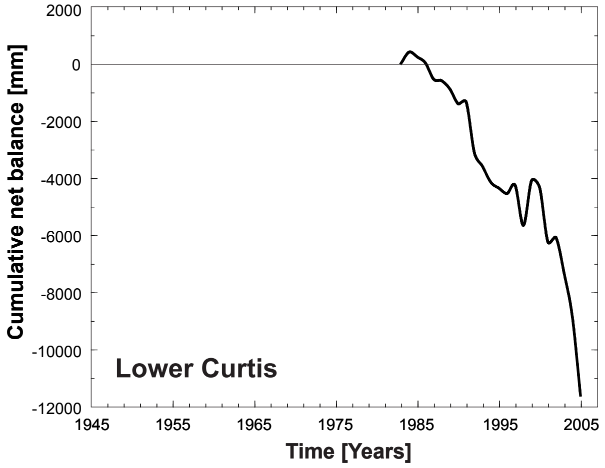

Easton
Cumulative net balance [mm]
Time [Years]


Foss
Cumulative net balance [mm]
Time [Years]

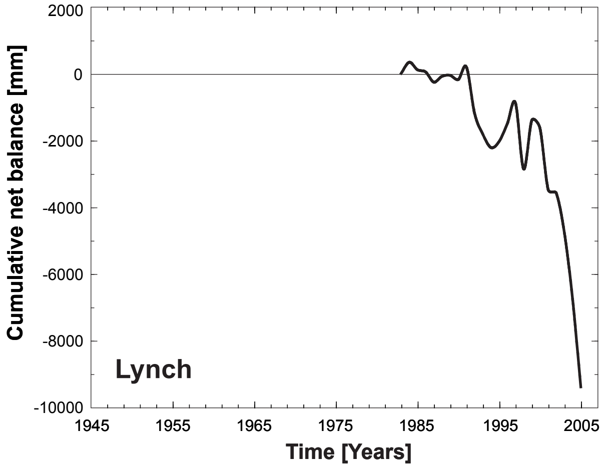

Gulkana
Cumulative net balance [mm]
Time [Years]

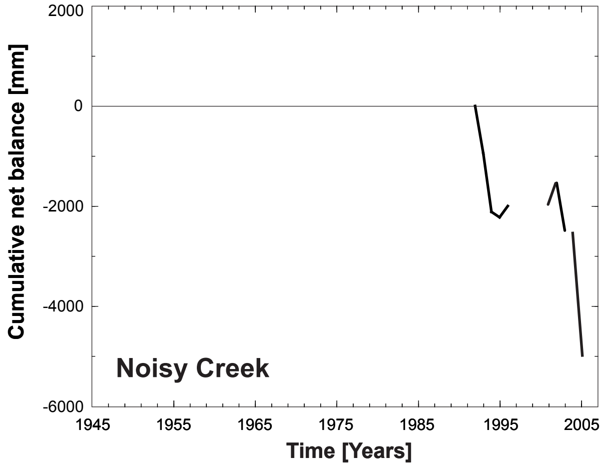

Ice Worm
Cumulative net balance [mm]
Time [Years]

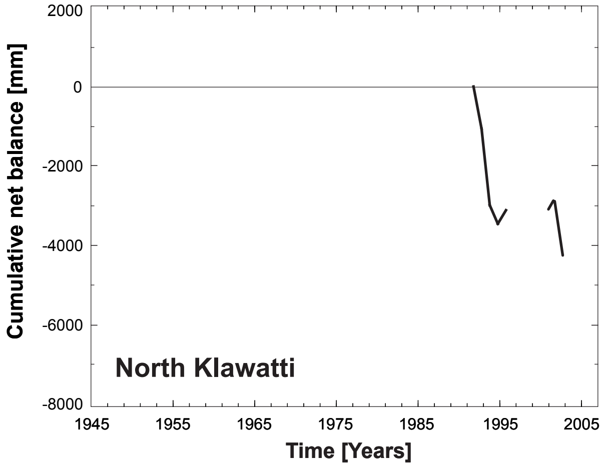

Lemon Creek
Cumulative net balance [mm]
Time [Years]

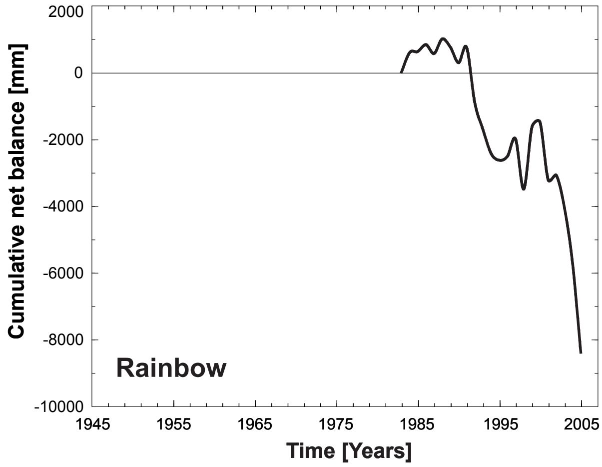

Lower Curtis
Cumulative net balance [mm]
Time [Years]

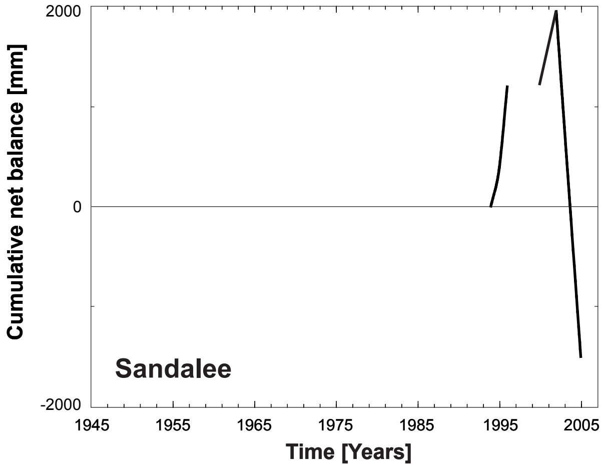
USA

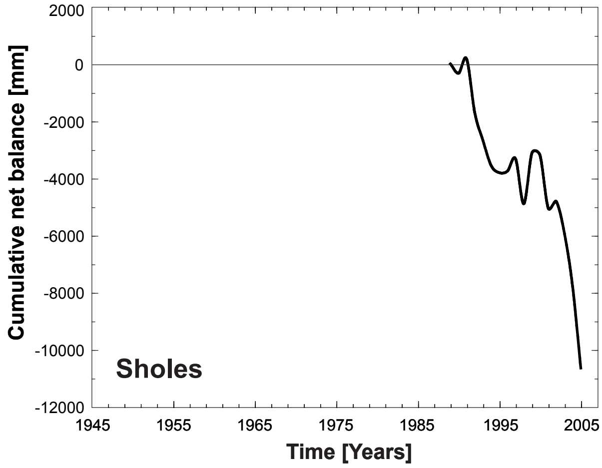

2000
0
-2000
-4000
-6000
-8000
-10000
Cumulative net balance [mm]
Lynch
1945
1955
1965
1975
1985
1995
2005
Time [Years]


2000
0
-2000
-4000
-6000
Cumulative net balance [mm]
Noisy Creek
1945
1955
1965
1975
1985
1995
2005
Time [Years]

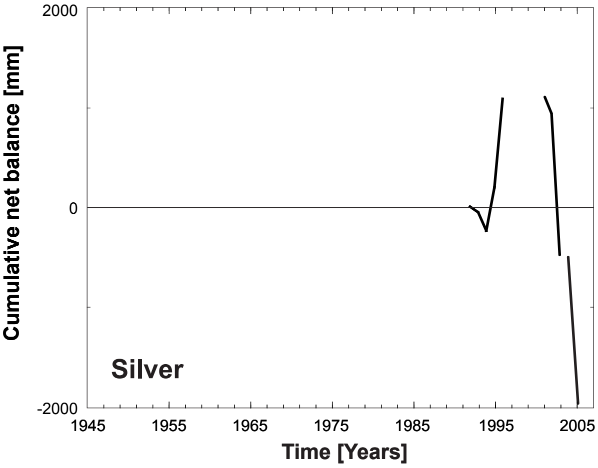

2000
0
-2000
-4000
-6000
-8000
Cumulative net balance [mm]
North Klawatti
1945
1955
1965
1975
1985
1995
2005
Time [Years]

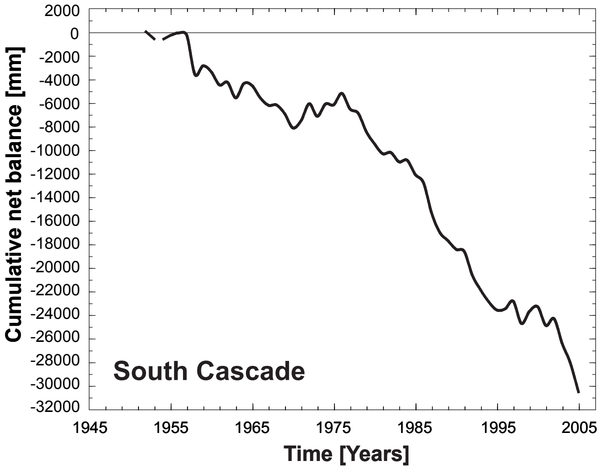

2000
0
-2000
-4000
-6000
-8000
-10000
Cumulative net balance [mm]
Rainbow
1945
1955
1965
1975
1985
1995
2005
Time [Years]

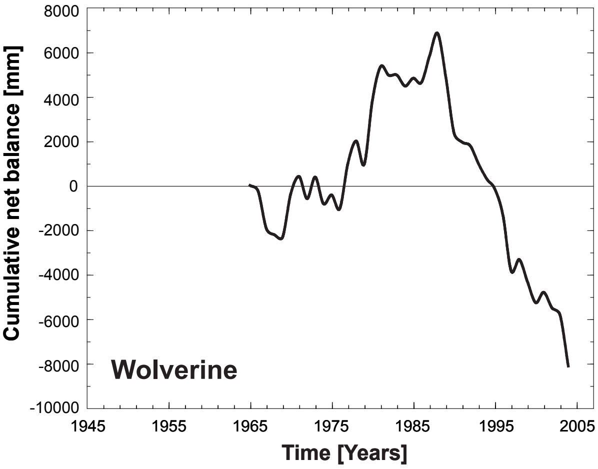

2000
0
-2000
Cumulative net balance [mm]
Sandalee
1945
1955
1965
1975
1985
1995
2005
Time [Years]

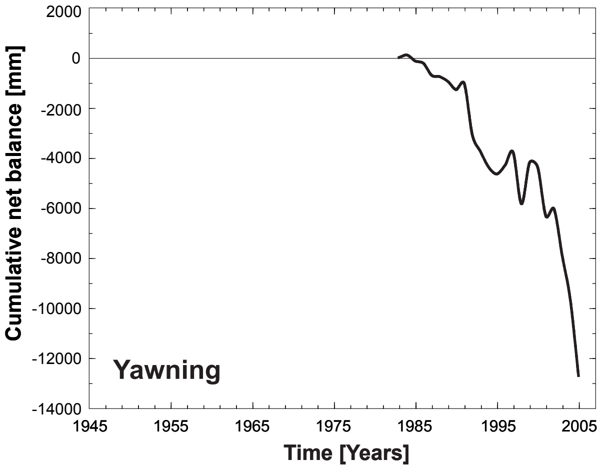

2000
0
-2000
-4000
-6000
-8000
-10000
-12000
Cumulative net balance [mm]
Sholes
1945
1955
1965
1975
1985
1995
2005
Time [Years]

USA


Silver
Cumulative net balance [mm]
2000
0
-2000
1945
1955
1965
1975
1985
1995
2005
Time [Years]


South Cascade
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
-18000
-20000
-22000
-24000
-26000
-28000
-30000
-32000
1945
1955
1965
1975
1985
1995
2005
Time [Years]


Wolverine
Cumulative net balance [mm]
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
1945
1955
1965
1975
1985
1995
2005
Time [Years]


Yawning
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945
1955
1965
1975
1985
1995
2005
Time [Years]

3 DETAILED INFORMATION

More detailed information about selected glaciers in various mountain ranges – with ongoing direct glaciological mass balance measurements – 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 gives general information on the glacier followed by brief comments on 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. An oblique photograph showing the glacier is included.

Three maps are presented for each glacier: the first one, a topographic map, shows the stake and snow pit 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 2004/05. The second and third maps are balance maps from the reported years, illustrating the pattern of ablation and accumulation. The accuracy of such balance maps depends on the density of the observing network, the complexity of the mass balance distribution and the experience of the local investigators.

A graph of net mass balance versus altitude is given for both reported years. 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 last two graphs show the relationship between the specific net balance and the accumulation area ratio (AAR) and the equilibrium line altitude (ELA) for the whole observation period. The regression equation is given at the top of both diagrams. The AAR regression equation is calculated by 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 (2003/04 and 2004/05) are marked in black. Minimum sample size for regression was defined as 6 ELA or AAR values (in order to provide information on glaciers from all regions worldwide, two glaciers with fewer measurement years are included).

3.1 BAHIA DEL DIABLO (ANTARCTICA/A. PENINSULA)

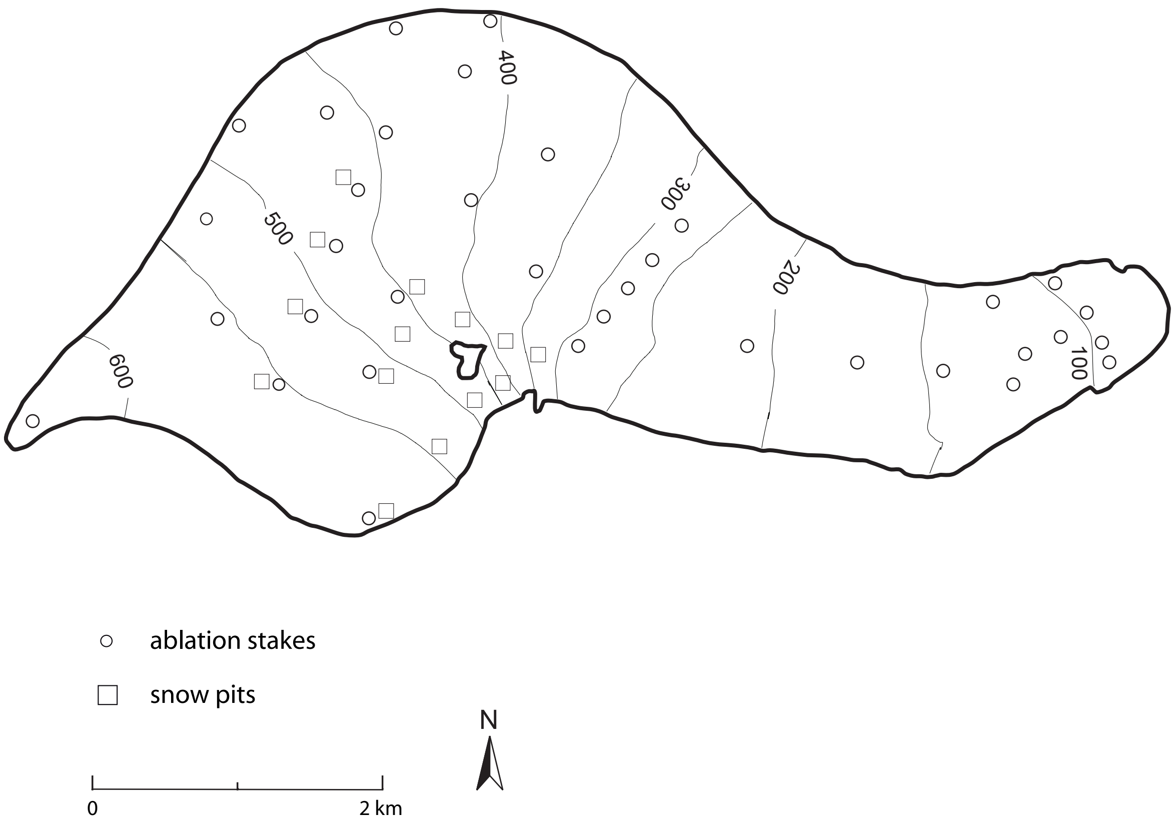
COORDINATES: 63.82 S / 57.43 W

Photo taken by P. Skvarca on 24th of February 2004.

This polythermal outlet-type glacier is located on Vega Island, northeastern side of the Antarctic Peninsula. The glacier is exposed to the Northeast, has an area of 14.3 km^2 and extends from 630 m to 75 m a.s.l. The mean annual air temperature at the equilibrium line (around 400 m a.s.l.) is -7 to -8 °C. The snout of the glacier overrides an ice-cored moraine over a periglacial plain of continuous permafrost. The annual precipitation averaged over the years 2004 and 2005 was measured to be around 600 mm on the highest part of the glacier and 350 mm at sea level. Mass balance mesurements were initiated in austral summer of 1999/00. A combined stratigraphic/fixed date system is applied, because the glacier can only be visited once a year.

The mass balance was negative throughout the period 1999-2005, with a mean of -270 mm w.e. The balance year 2003/04 had a negative mass balance of -110 mm w.e., despite a relatively cold summer with a mean summer temperature of 0 ºC. The summer 2004/05 was warmer yielding in 113 melt days and therefore resulting in a more negative mass balance of -230 mm w.e. The data collected over six years reveal a strong correlation between annual mass balance and mean summer air temperature of the region.

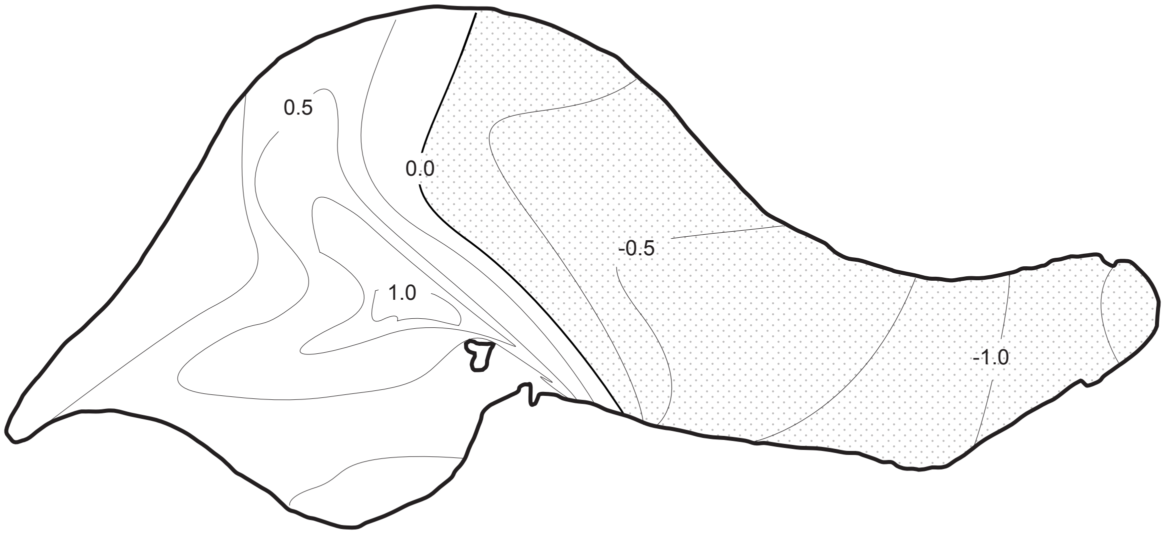
3.1.1 Topography and observation network



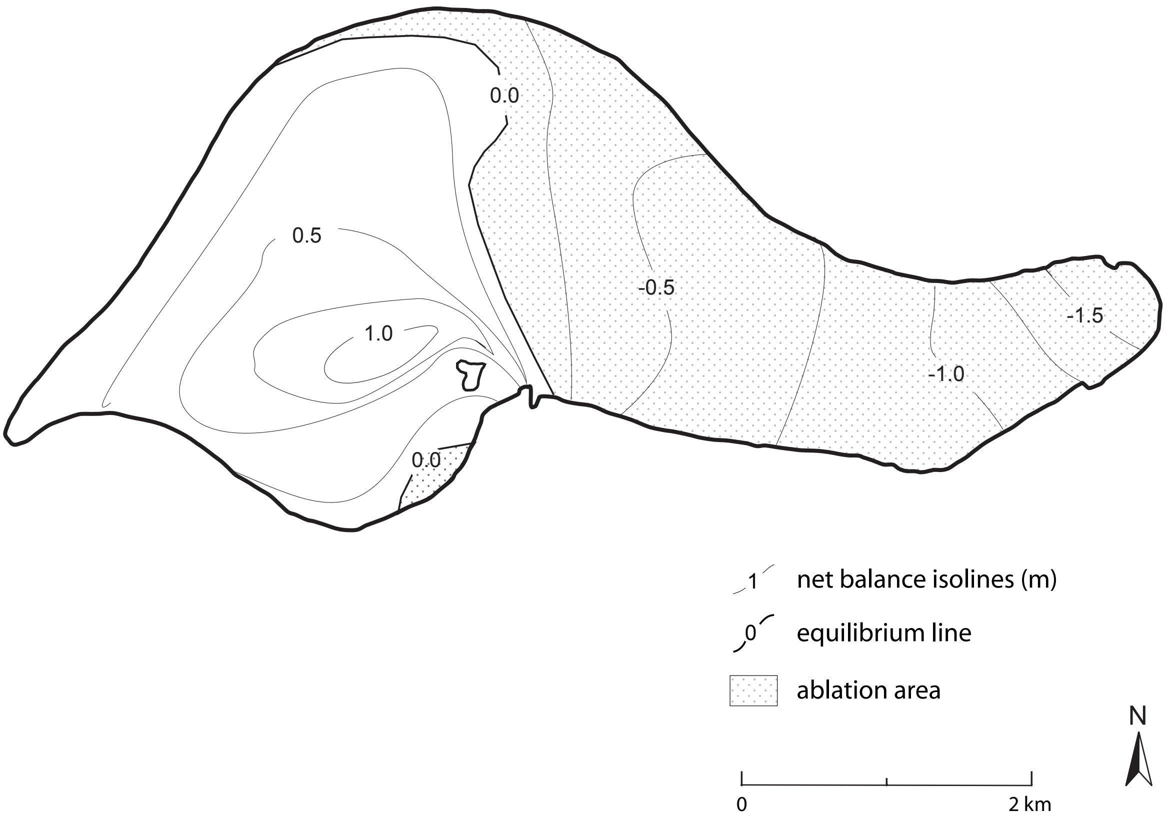
Glaciar Bahía del Diablo (ANTARCTICA)

3.1.2 Net balance maps 2003/2004 and 2004/2005

2003/2004

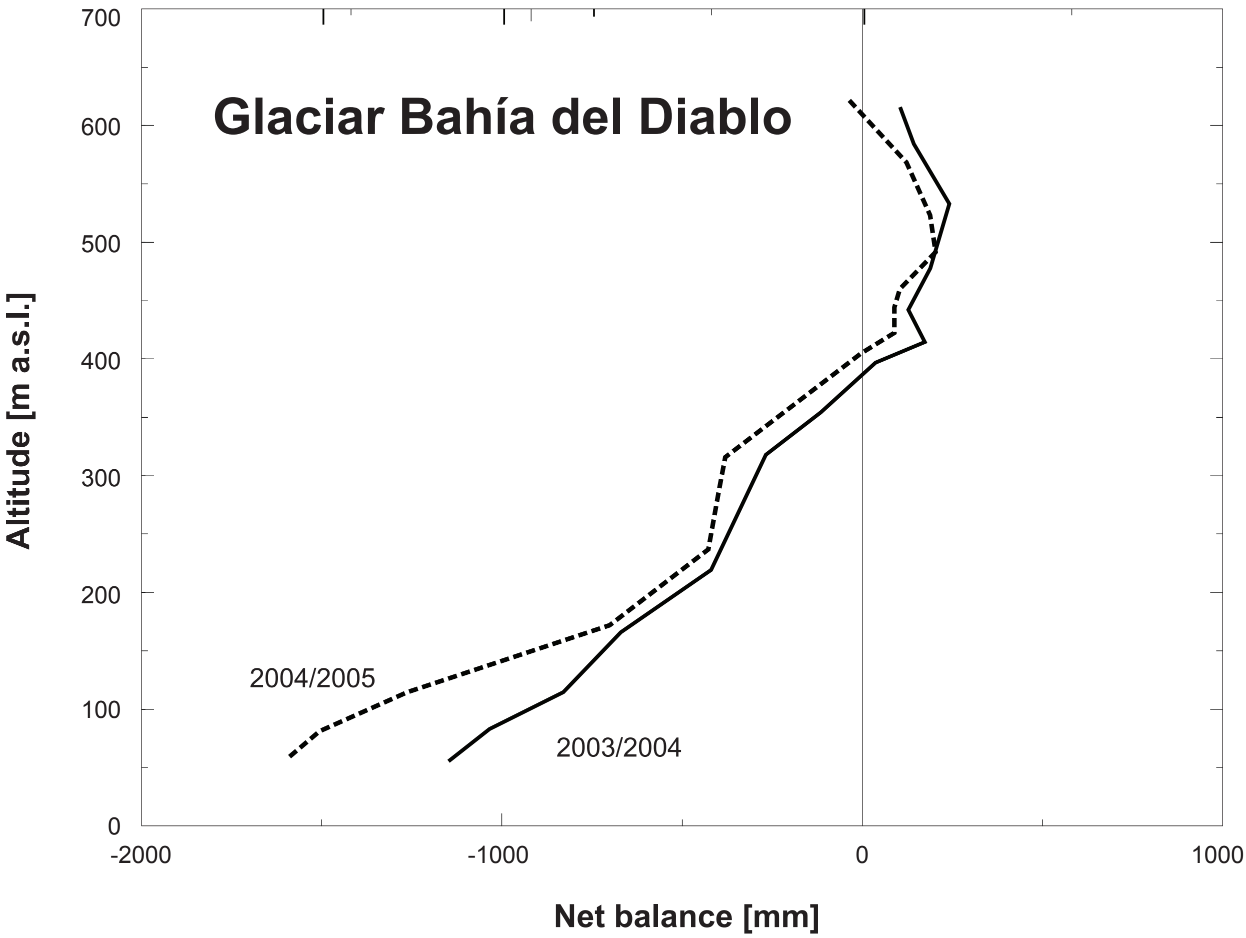


2004/2005

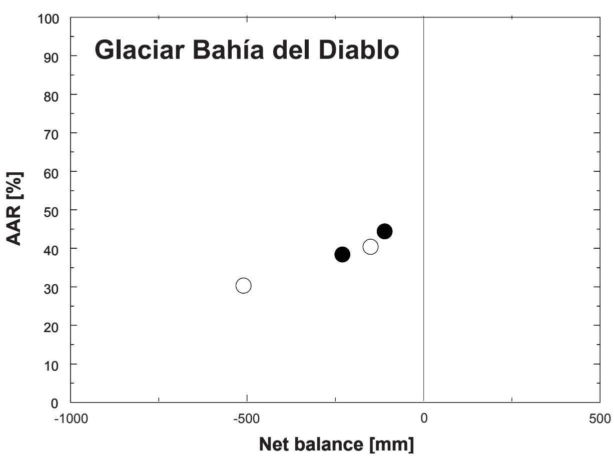


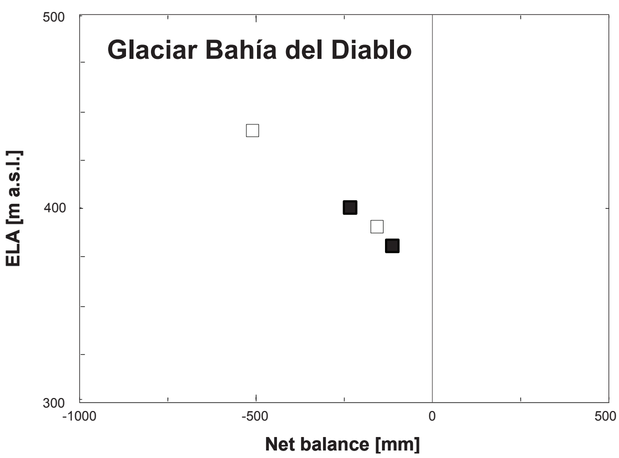
Glaciar Bahía del Diablo (ANTARCTICA)

3.1.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.2 MARTIAL ESTE (ARGENTINA/ANDES FUEGUINOS)

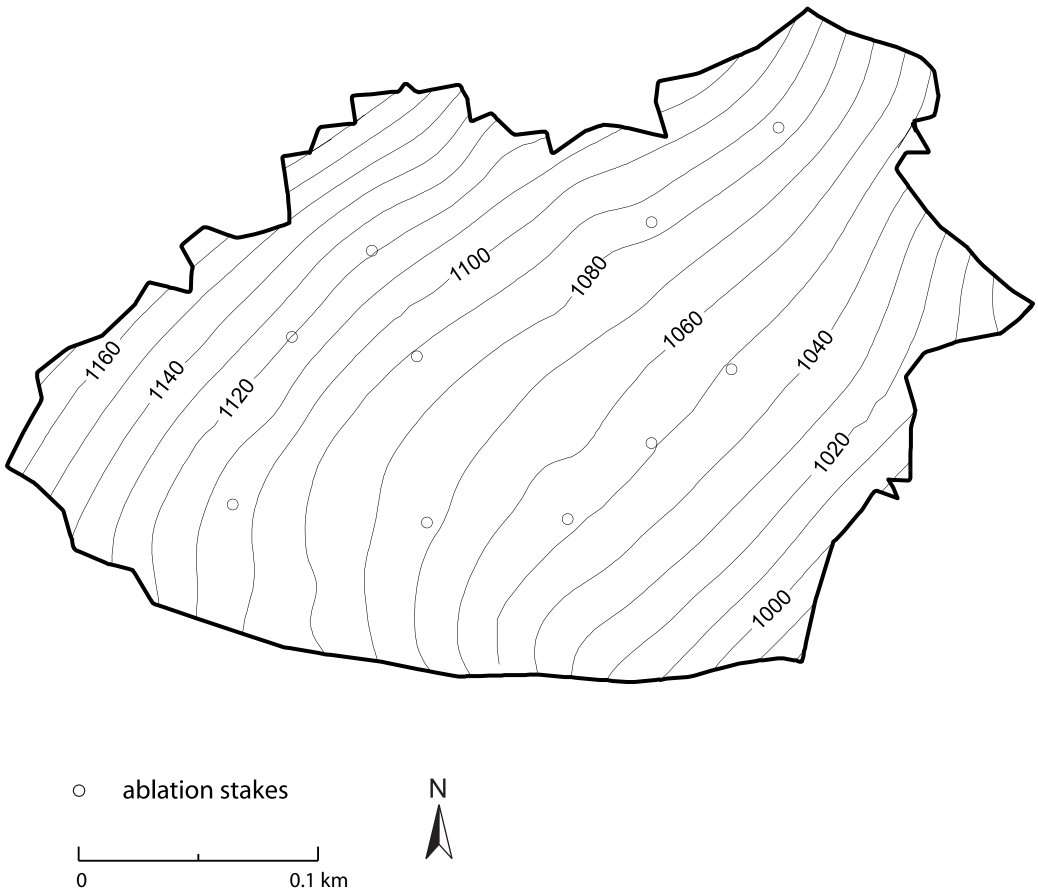
COORDINATES: 54.78 S / 68.40 W

Photo taken by J. Strelin, March 2002.

The Cordón Martial glaciers, located on the Argentinean side of Cordillera Fueguina, comprise a group of three small temperate cirque glaciers and one dead ice body. The east-west extending mountain range containing the glaciers reaches its highest point at Monte Martial (1319 m a.s.l.), which is about 1000 m lower than the nearby and extensively glacierized Cordillera Darwin in Chile with Mount Darwin, 2440 m a.s.l. The more eastward located cirque glacier, called Martial Este Glacier, extends from 1180 to 1000 m a.s.l. Its surface of 0.1 km^2 and average slope of 29 °, is exposed to the southeast and, of the four ice bodies, receives the smallest amount of direct solar radiation. The glacier is wide rather than long, has a maximum ice thickness of 40 m and an estimated total volume of ca. 3×10^6 m^3. Mean annual air temperature at the equilibrium line is -1.5 °C and average precipitation amounts to 1300 mm. Since the Little Ice Age the glaciers have lost 75 % of their total area. From 1984 to 1998 vertical thinning at the Martial Este Glacier was 7.0 m (450 mm w.e./year)

During the hydrological years 2003/04 and 2004/05, the mass balance of Martial Este was markedly negative, reaching -1318 and -991 mm w.e. respectively. This deficit is caused entirely by increased air temperature. Precipitation was close to the historical average during these years but temperature reached the secular highest positive anomaly, as in 1998. The mass balance of the last two years is around double the 450 mm w.e. of the long-term value in the 1984-1998 period.

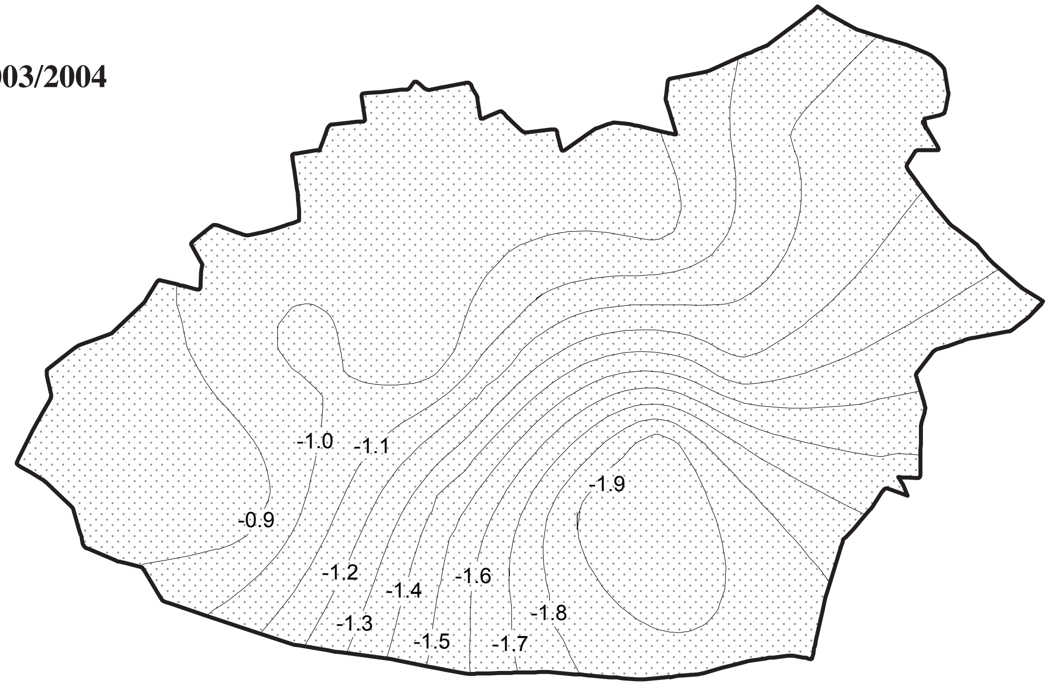
3.2.1 Topography and observation network



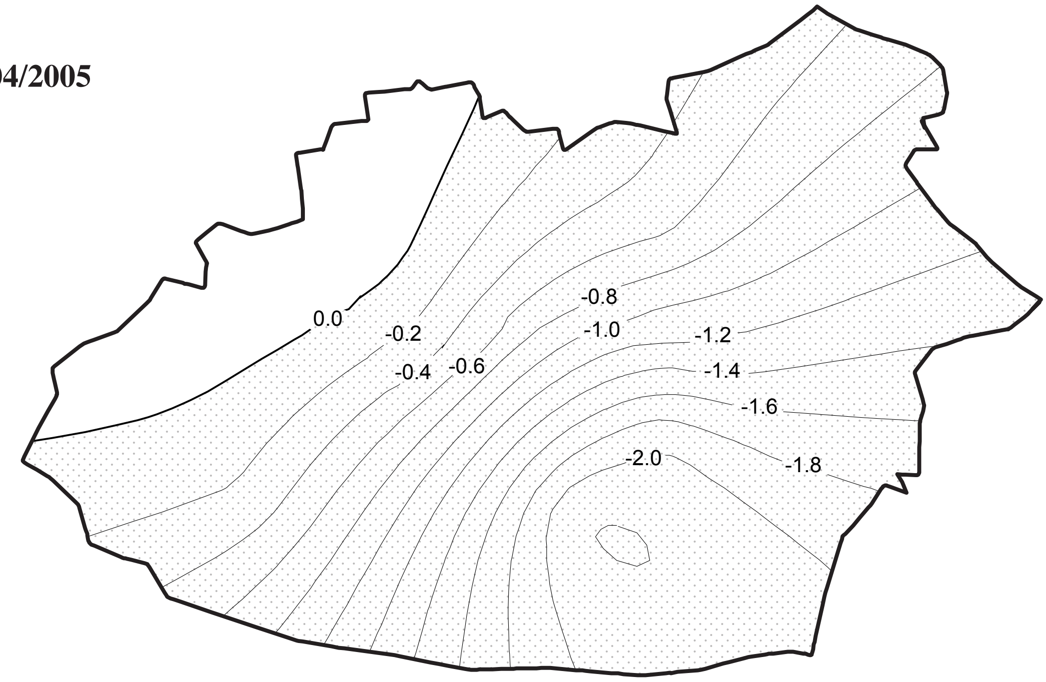
Martial Este (ARGENTINA)

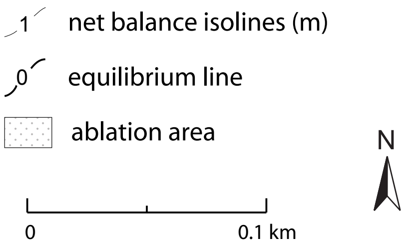
3.2.2 Net balance maps 2003/2004 and 2004/2005

2003/2004



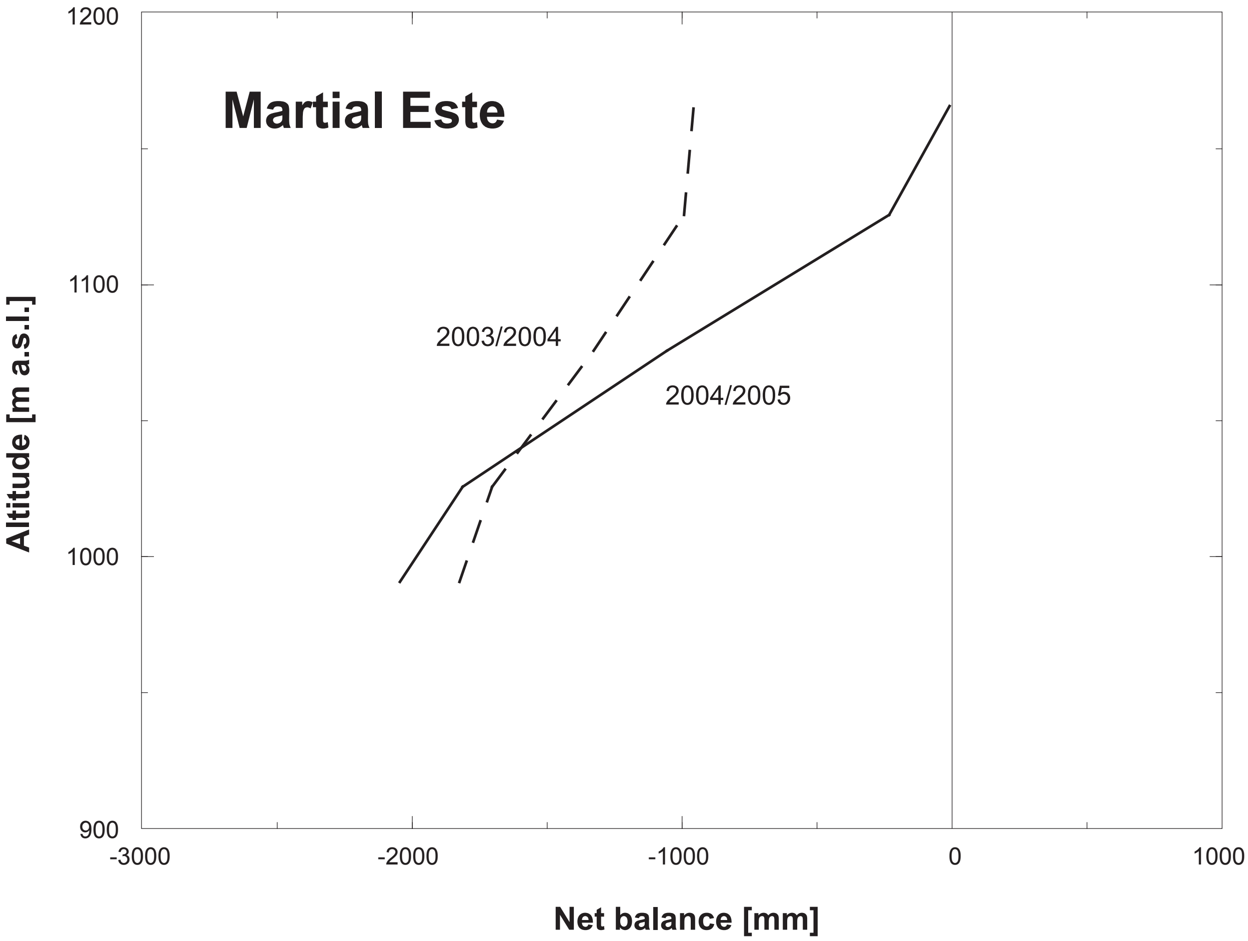
2004/2005



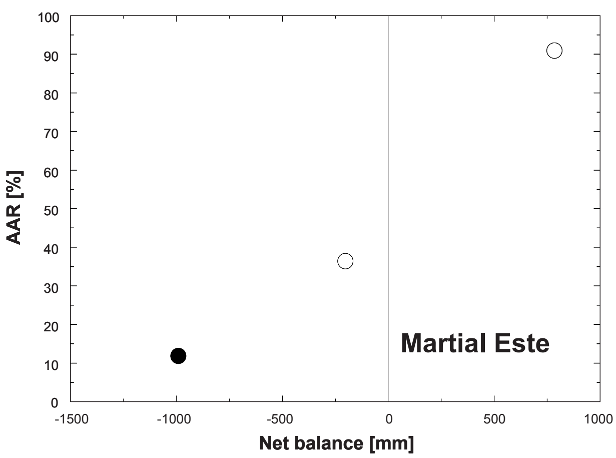


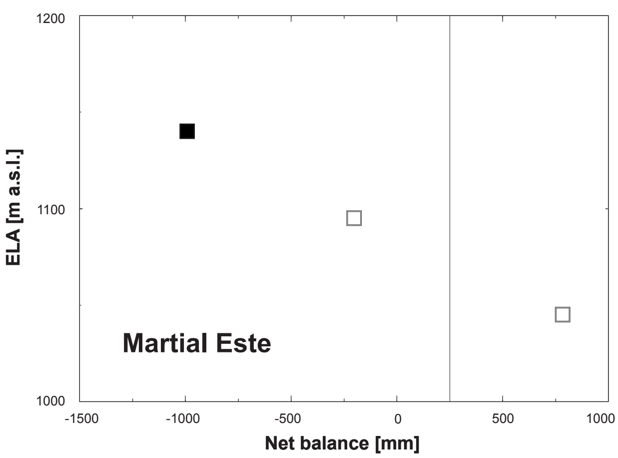
Martial Este (ARGENTINA)

3.2.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.3 VERNAGTFERNER (AUSTRIA/EASTERN ALPS)

COORDINATES: 46.88 N / 10.82 W

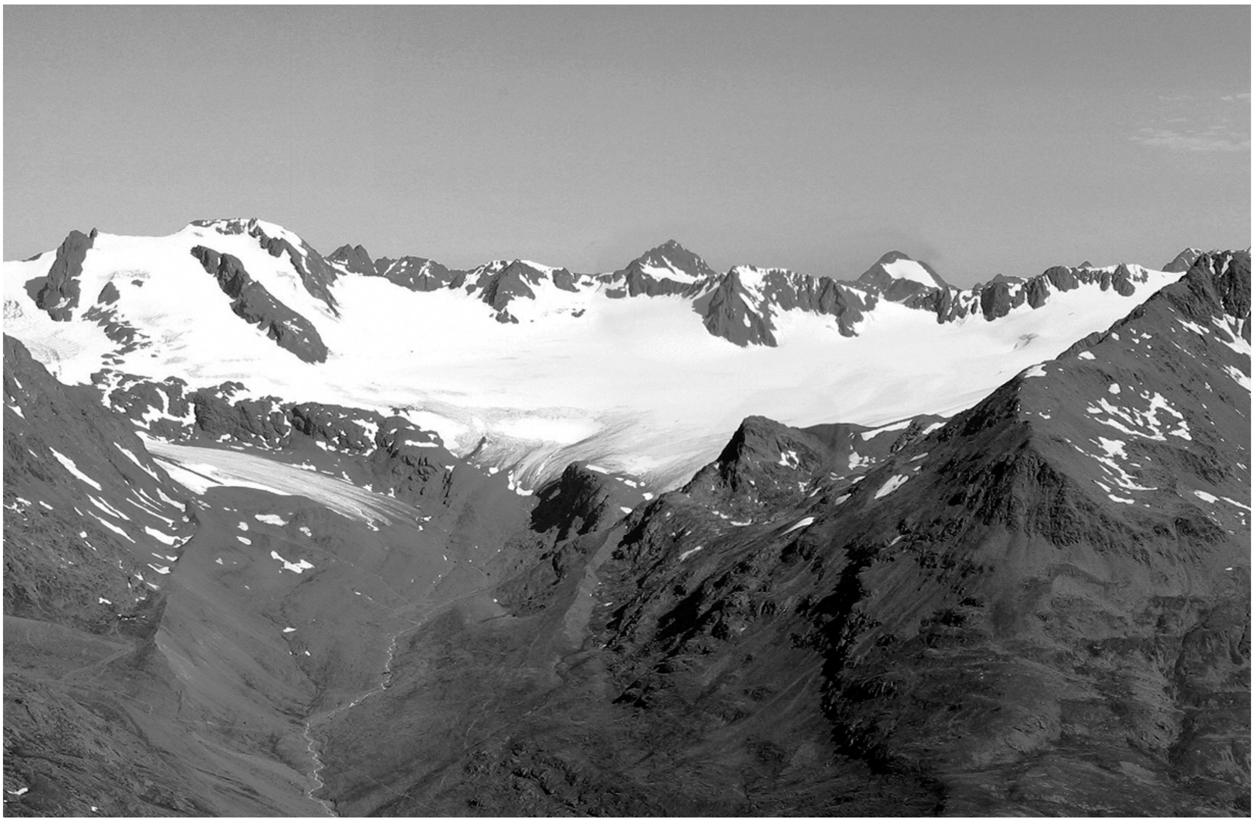
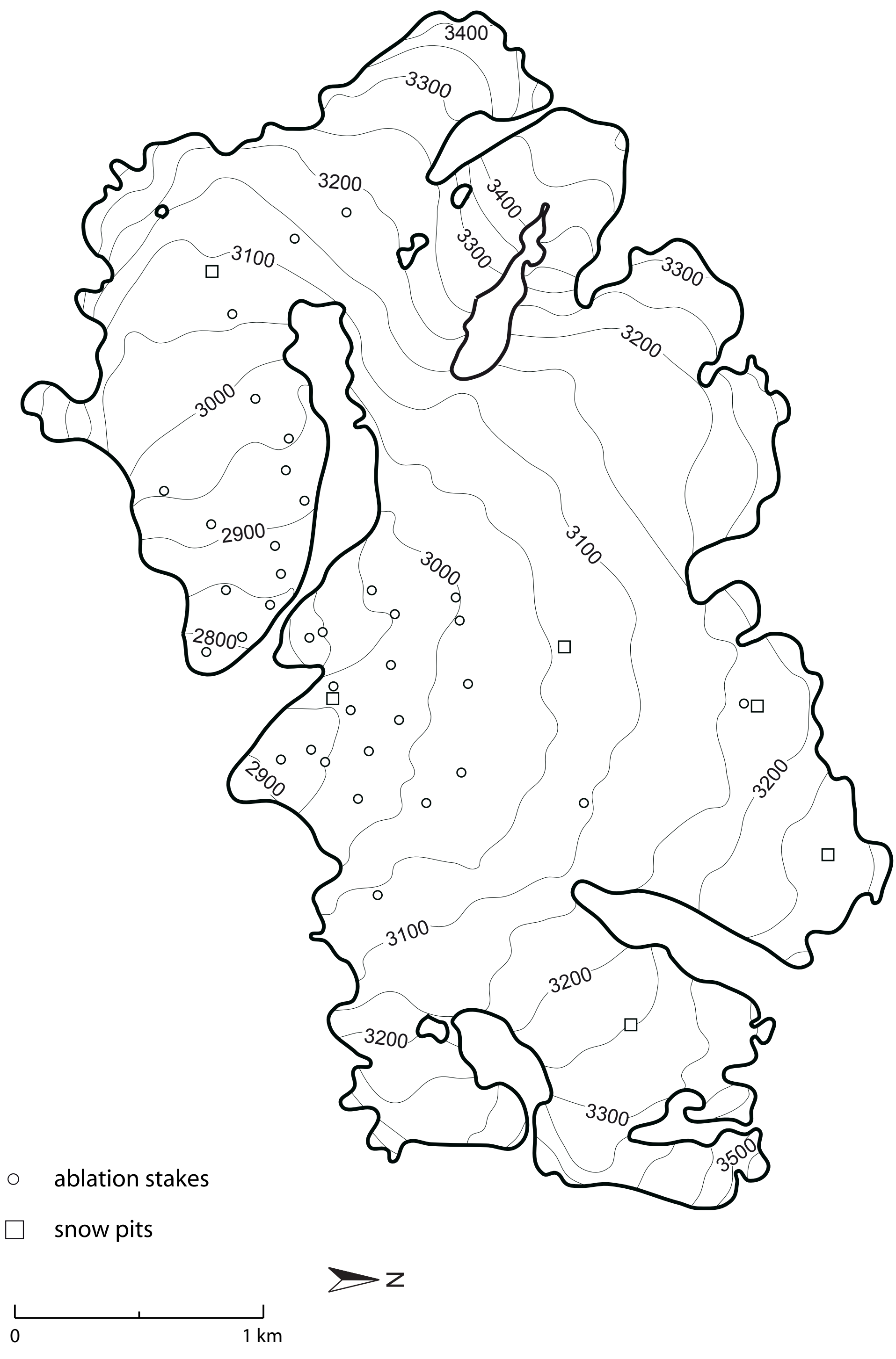


Photo from Commission for Glaciology archive, Bavarian Academy of Sciences, Munich, July 2005.

The rather flat temperate plateau glacier is located in the southern part of the Oetztal Alps 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), and there are topographic maps at the 1:10000 scale based on photogrammetric surveys for 1889, 1969, 1979, 1982, 1990 and 1999.

The year 2003/04 brought a rather moderate mass loss (-407 mm, AAR = 0.34) due to a rather short ablation season, and also the year 2004/05 showed a small mass loss (-523 mm, AAR = 40). The winter balance 2004/05 was only about 2/3 of the long-term mean, and as a result, ice ablation started rather early, but ended abruptly in mid-September.

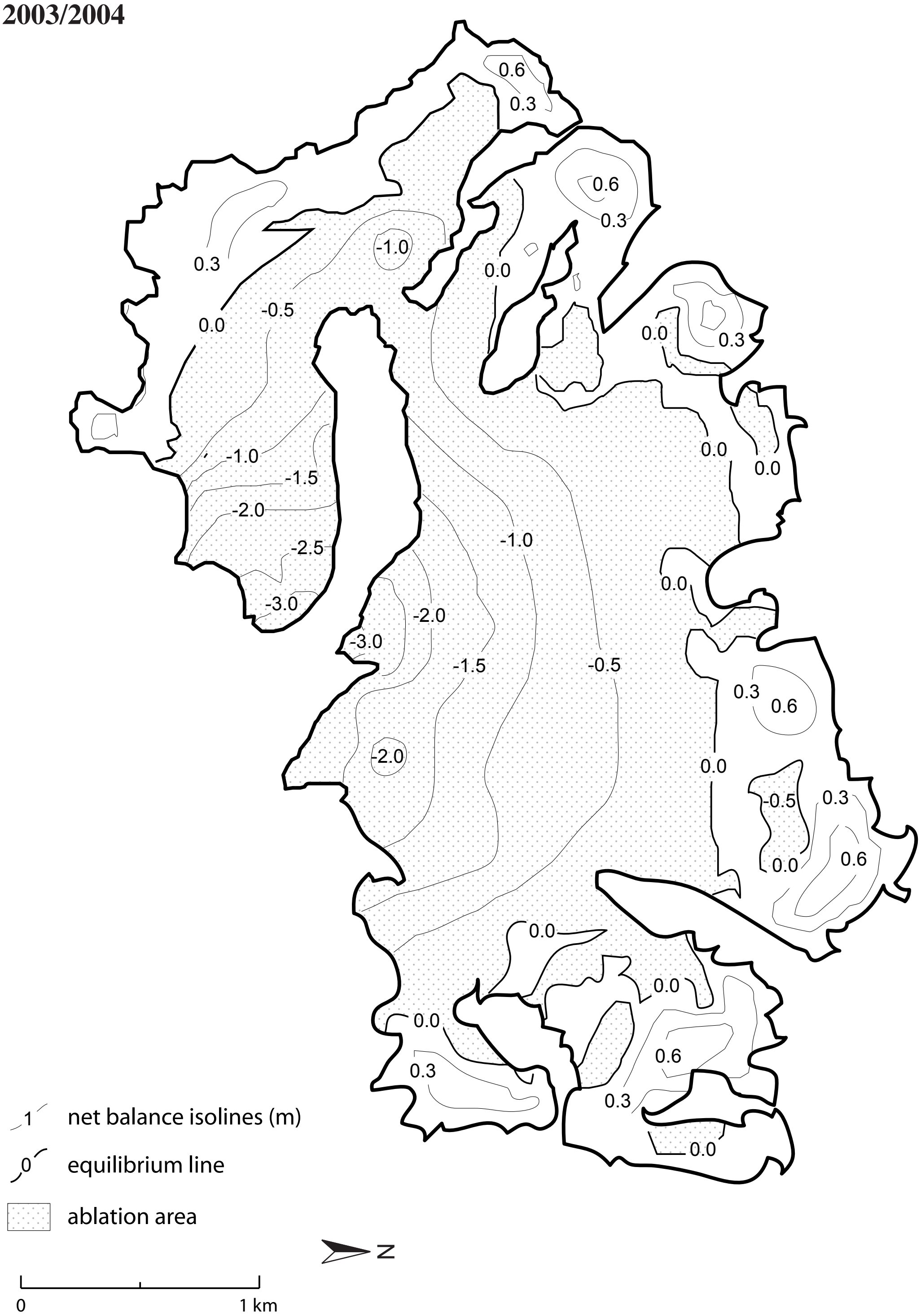
3.3.1 Topography and observation network



Vernagtferner (AUSTRIA)

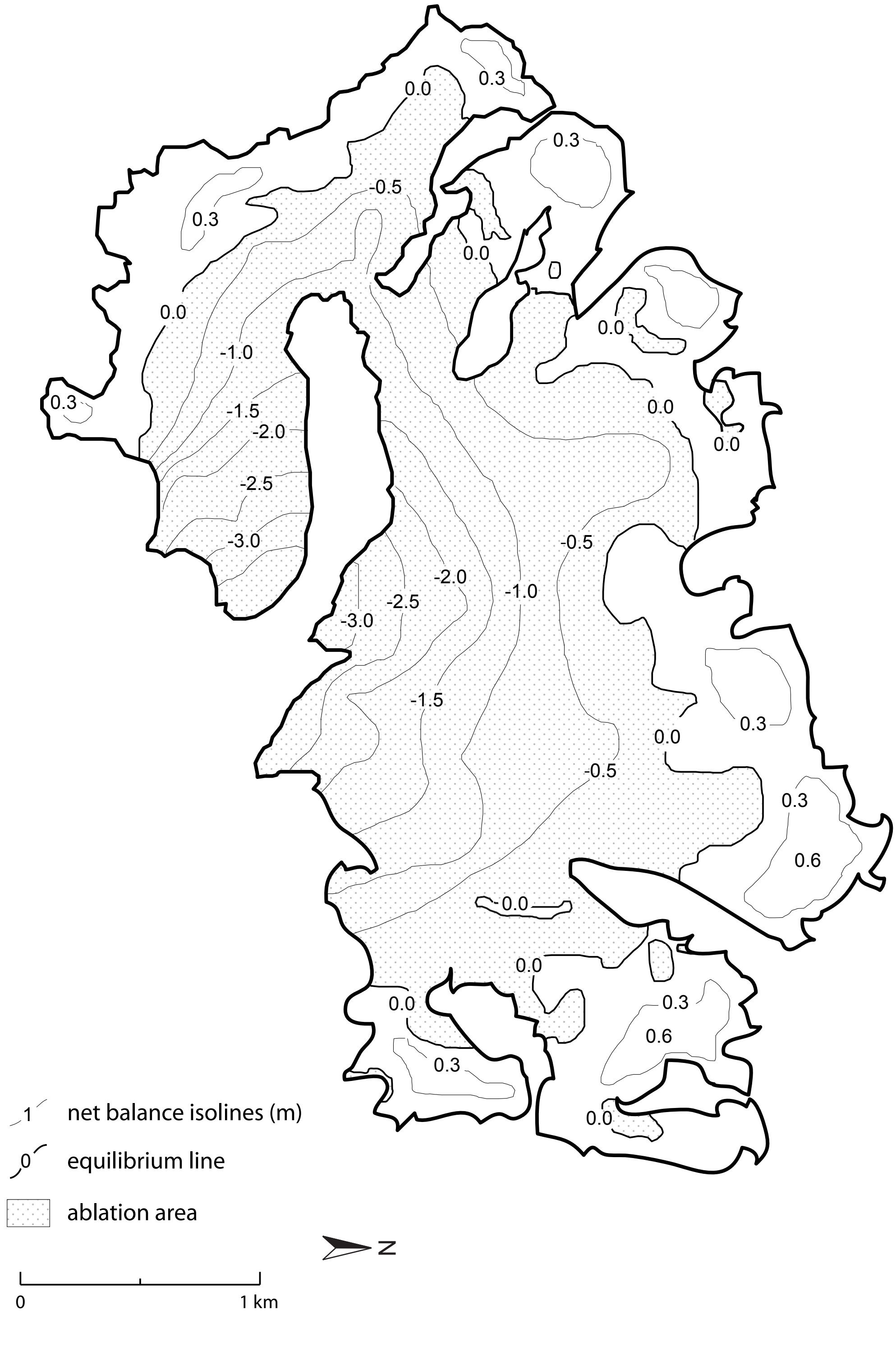
3.3.2 Net balance maps 2003/2004 and 2004/2005

2003/2004



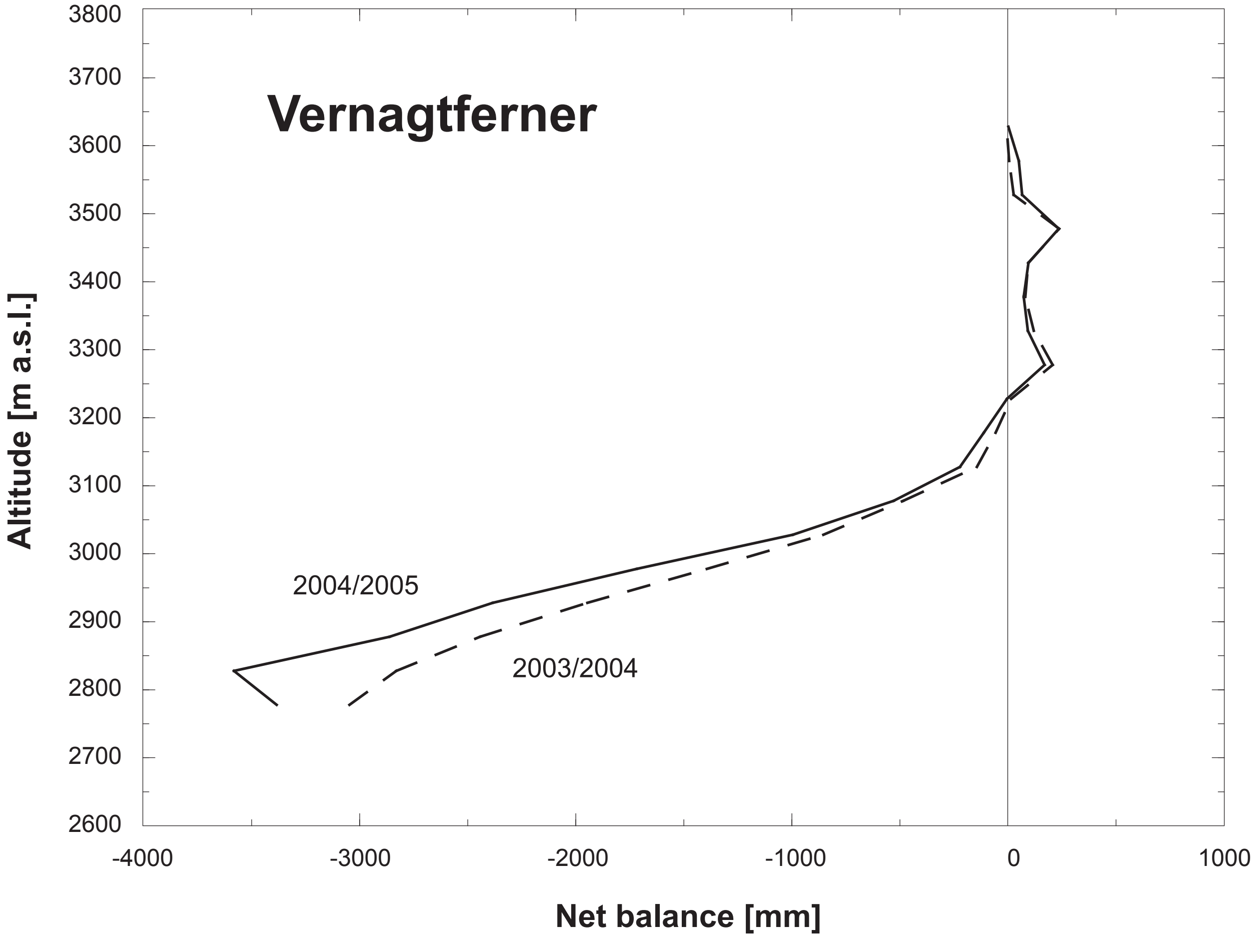
Vernagtferner (AUSTRIA)

2004/2005

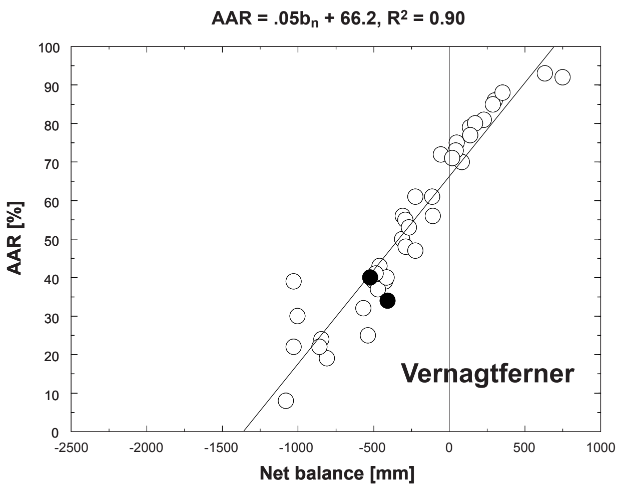


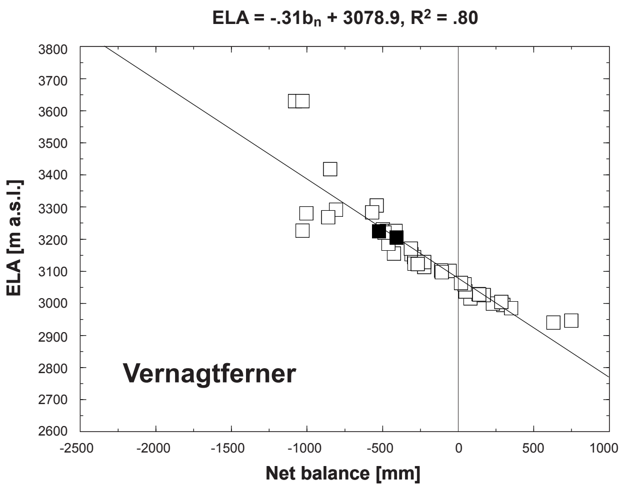
Vernagtferner (AUSTRIA)

3.3.3 Net balance versus altitude 2003/2004 and 2004/2005



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





3.4 ZONGO (BOLIVIA/TROPICAL ANDES)

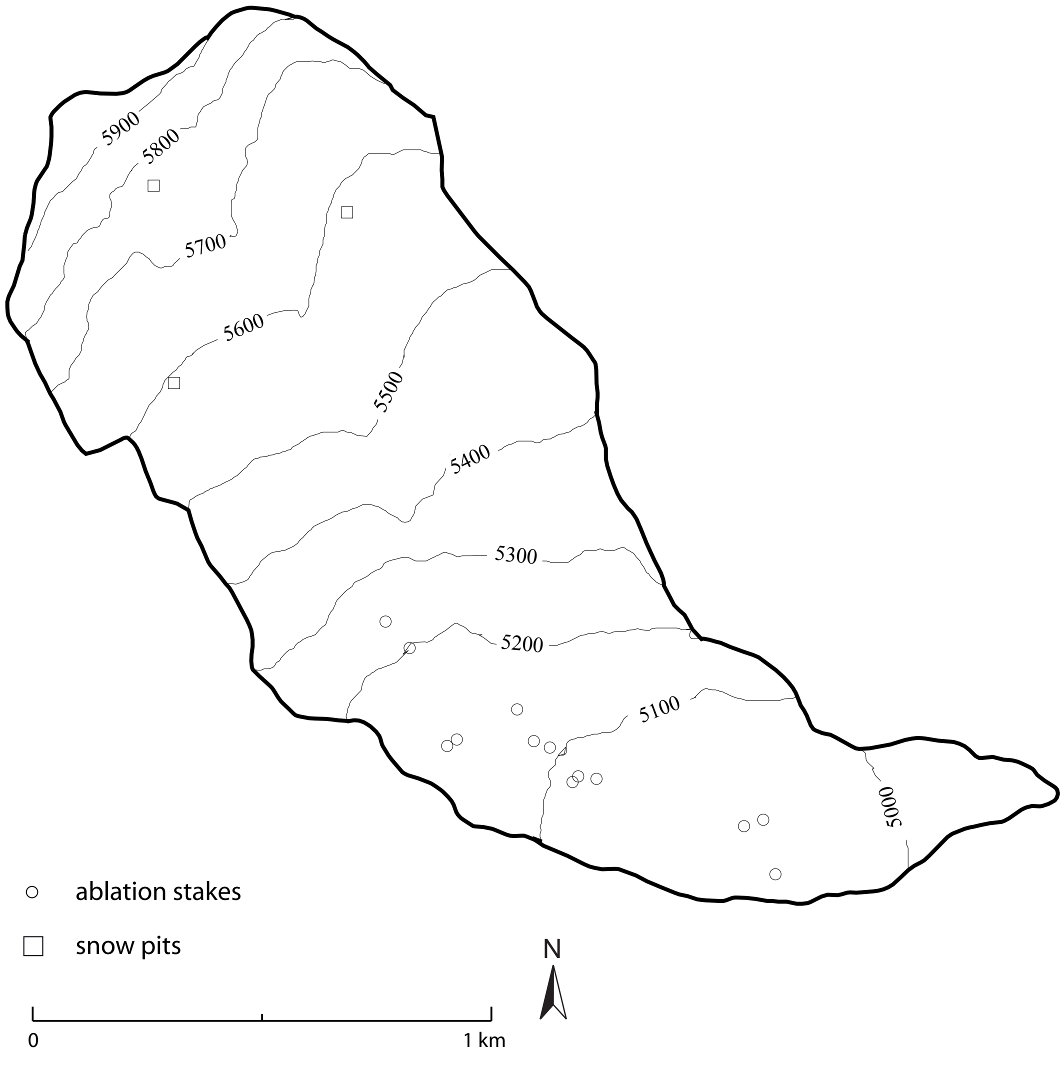
COORDINATES: 16.25 S / 68.17 W

Photo taken by B. Francou, July of 2006.

Zongo is a small valley-type glacier located to the north-east of La Paz city, at the head of an important hydraulic power station which supplies the city. It is a 2.9 km long glacier, between 6000 and 4900m a.s.l. and its surface area reaches 1.9 km^2. Exposure is to the south in the upper part and to the east at the lower tongue. Mean annual air temperature at the ELA (ca. 5250 m a.s.l. for balanced years) is -1.5 °C. The glacier is assumed to be temperate, except probably near the summit. Mean precipitation at the “Plataforma” (4770 m a.s.l.) was about 900 mm/year (±150 mm) during the last 20 years. Ablation is concentrated during the wet summer season (October-April) and presents a clear peak in October-December, before the precipitation maximum of January-March.

After several years of negative mass balances with a dramatic peak during the El Niño of 1997-98 (-1962 mm w.e.), the last year of the 1990s and the first years of the following decade (2000-2002) were marked by a near-equilibrium/slightly positive situation. This change relates to a cold ENSO event (La Niña) in the Pacific. In the second half of 1998, this pattern had started to replace the long-lasting warm event that had been in place since the early 90‘s (with a short break in 1996/97). Colder temperatures and wetter conditions thereby caused high albedo values to persist throughout the whole accumulation season. The year 2003/04 had a moderate negative mass balance (-521 mm w.e.), influenced by a moderate anomaly of positive sea surface temperature (SST) developing in the equatorial part of the Pacific in early 2003. The last year 2004/05 presents a strong negative specific net balance (-1559 mm w.e.).

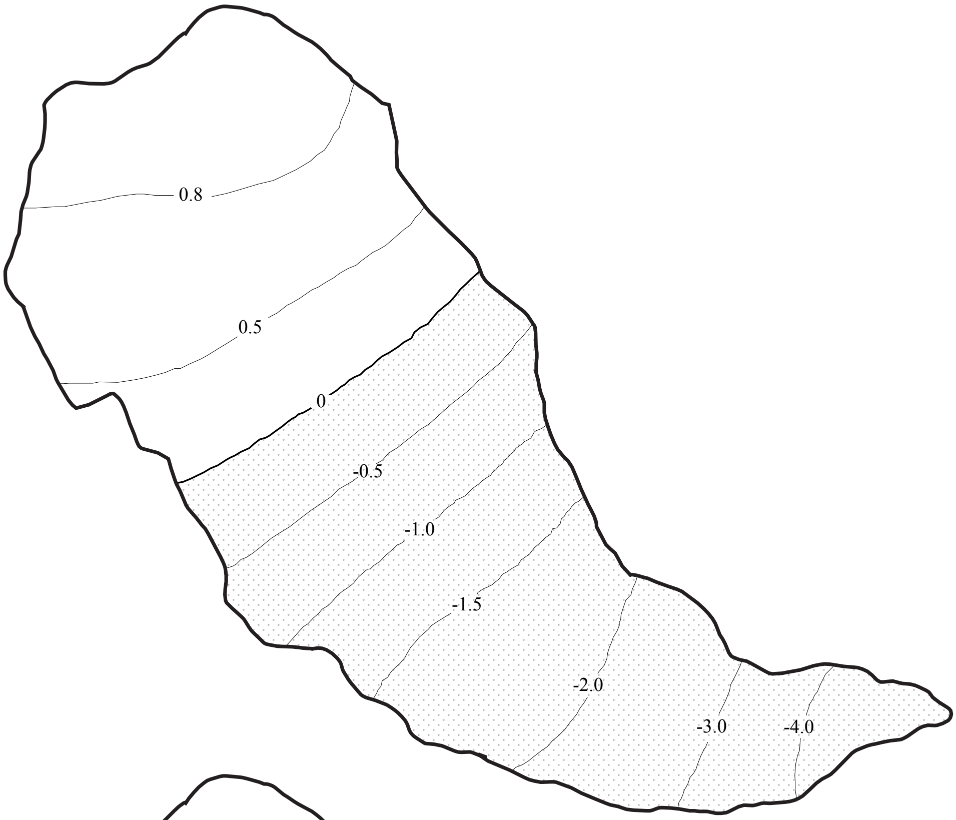
3.4.1 Topography and observation network



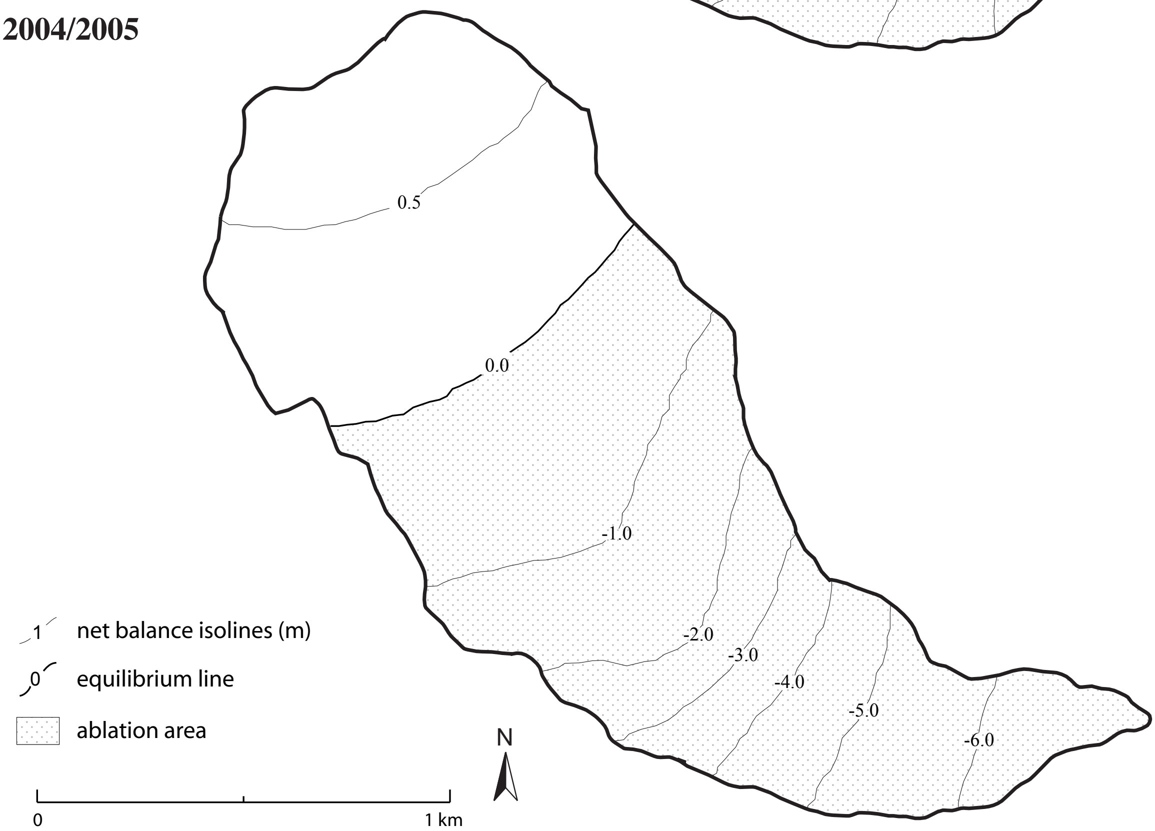
Zongo (BOLIVIA)

3.4.2 Net balance maps 2003/2004 and 2004/2005

2003/2004

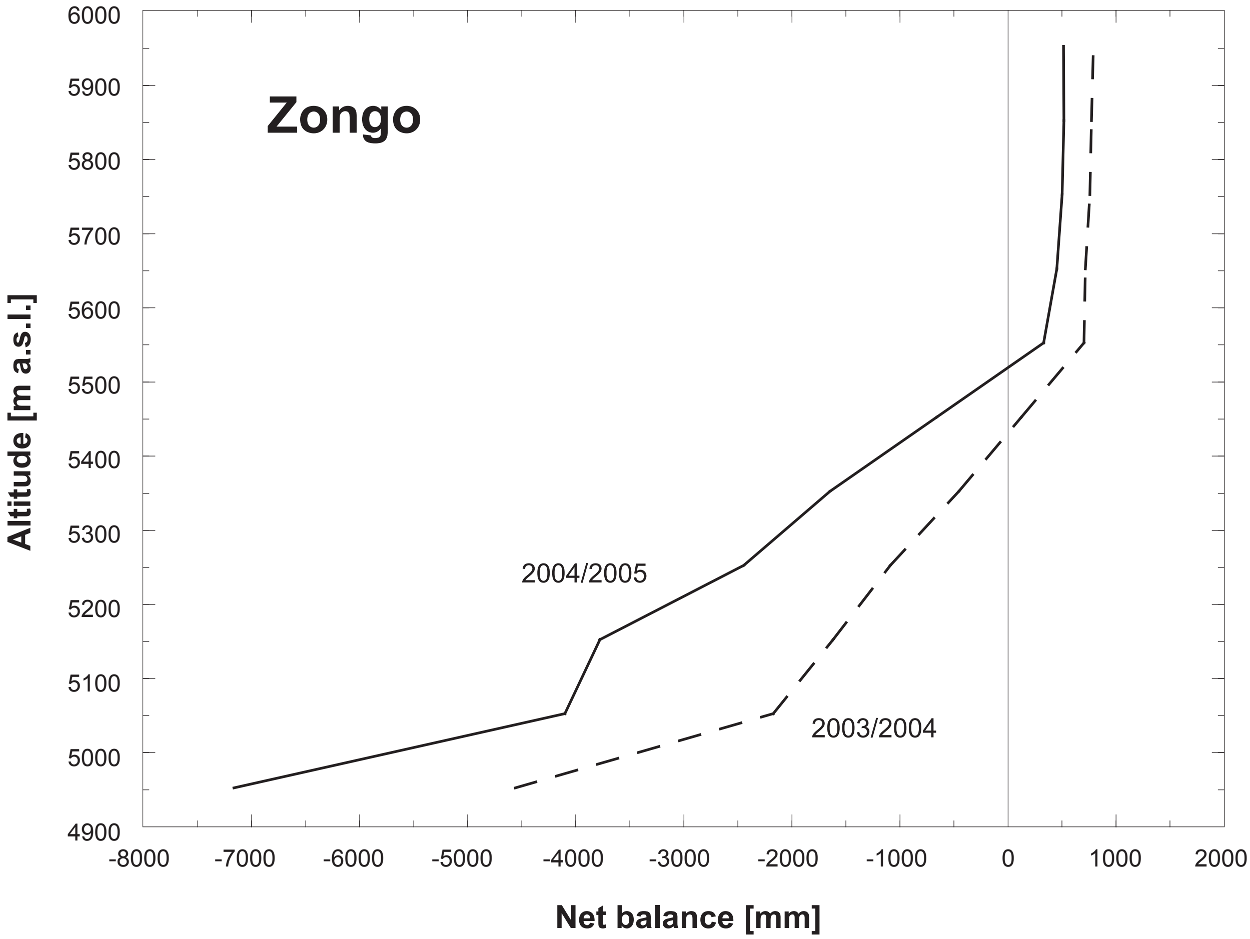


2004/2005

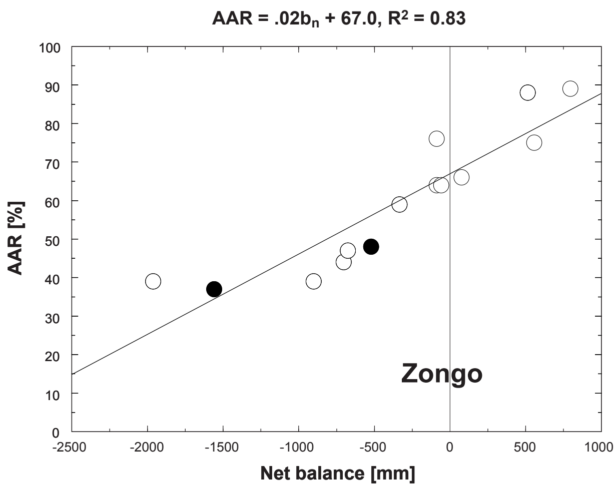


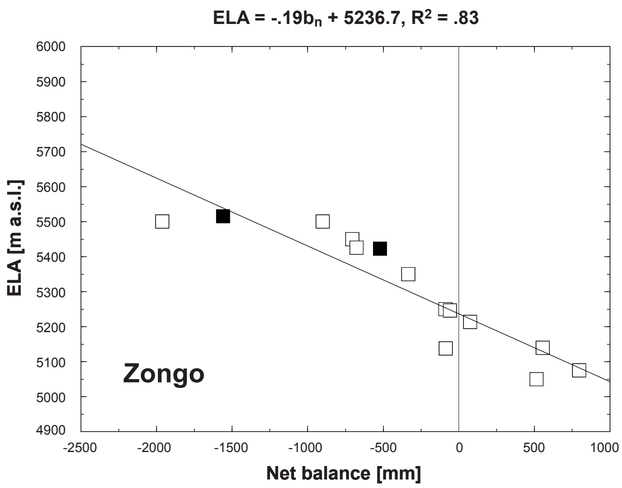
Zongo (BOLIVIA)

3.4.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.5 WHITE (CANADA/HIGH ARCTIC)

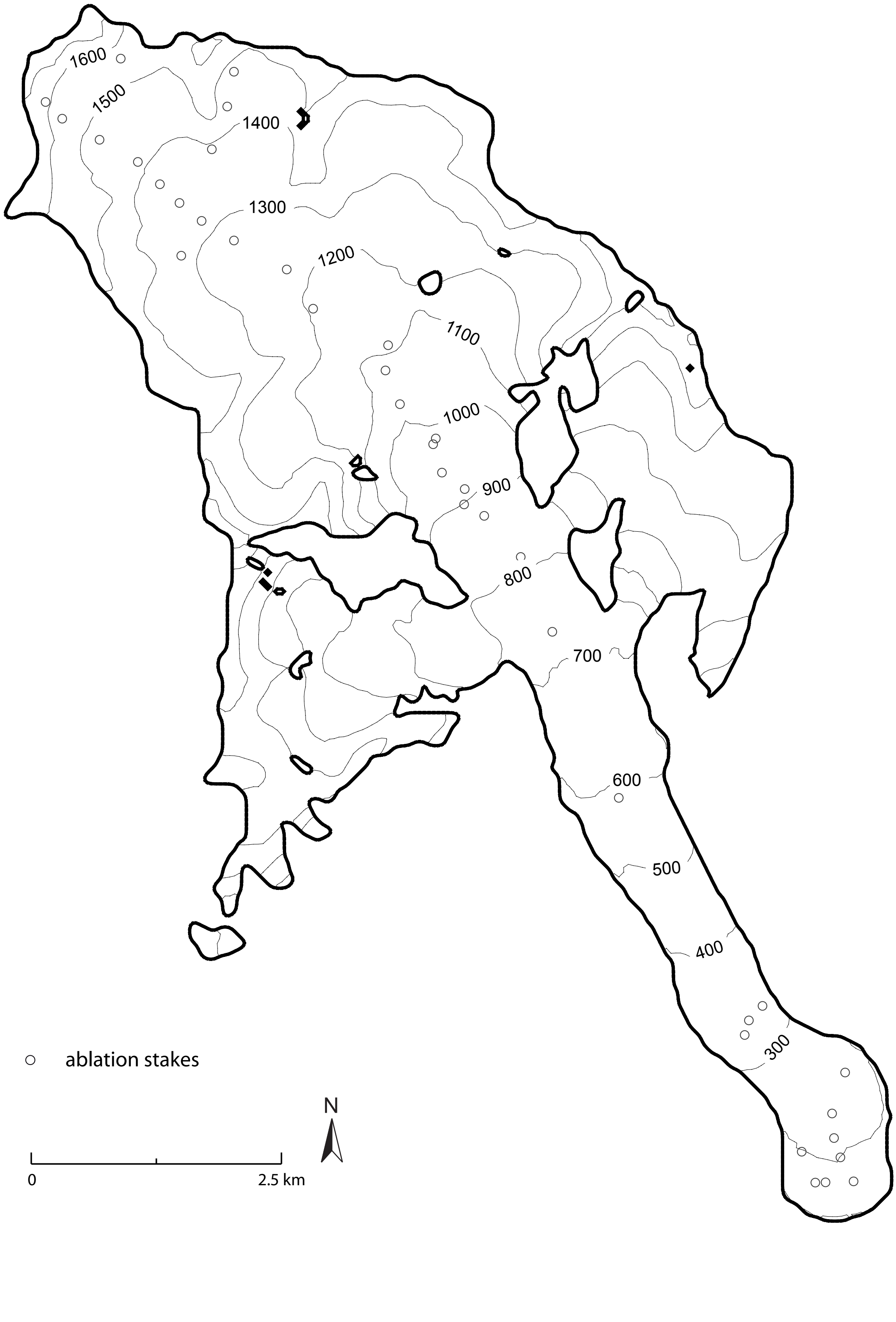
COORDINATES: 79.45 N / 90.67 W

Photo taken by C.S.L. Ommanney (NHRI Canadian Glacier Information Centre, date unknown).

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. The latter area is greater than an earlier estimate (38.7 km^2) as a result of a cartographic revision which, however, has had minimal effect on the hypsometric curve of the glacier. A recent geodetic resurvey of the lower tongue has had a slightly greater impact, discussed below, on estimates of mass balance. Sea-level air 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 reaches or exceeds 400 m. Annual precipitation at sea level is very low, about 100 mm, although annual accumulation at higher altitudes is greater. Annual ablation at the terminus of White Glacier is typically 2000-4000 mm/year. However, the advance of Thompson Glacier continues. The terminuses of the two glaciers have been in contact since at least the time of the earliest photographs in 1948, but, although the two terminuses remain distinguishable, White Glacier has become a tributary of Thompson Glacier.

The balance year 2003/04 on White Glacier, with a balance of 37 mm w.e., was above normal and yielded the second positive mass balance of the period 2001-2005. However, the balance year 2004/05 was well below normal, and indeed its balance was the second most negative in the period of record. The estimated balance, -612 mm w.e., is subject to revision because many of the measurement stakes on the tongue of the glacier melted out during summer 2005. These stakes, which provide minimum estimates of ablation, have not been factored into the calculation. The average balance for 2001-2005 is estimated as -160 mm w.e./year. The cartographic revision mentioned above allows for an improved estimate of the evolution of mass balance over the 45 years since measurements began. The new and more accurate balance normal is -95 mm w.e. for 1960-1991, slightly but not significantly less negative than the previous estimate (-100 mm w.e.). The cumulative balance since 1959/60, with due allowance for three missing years, is -6370 mm w.e.

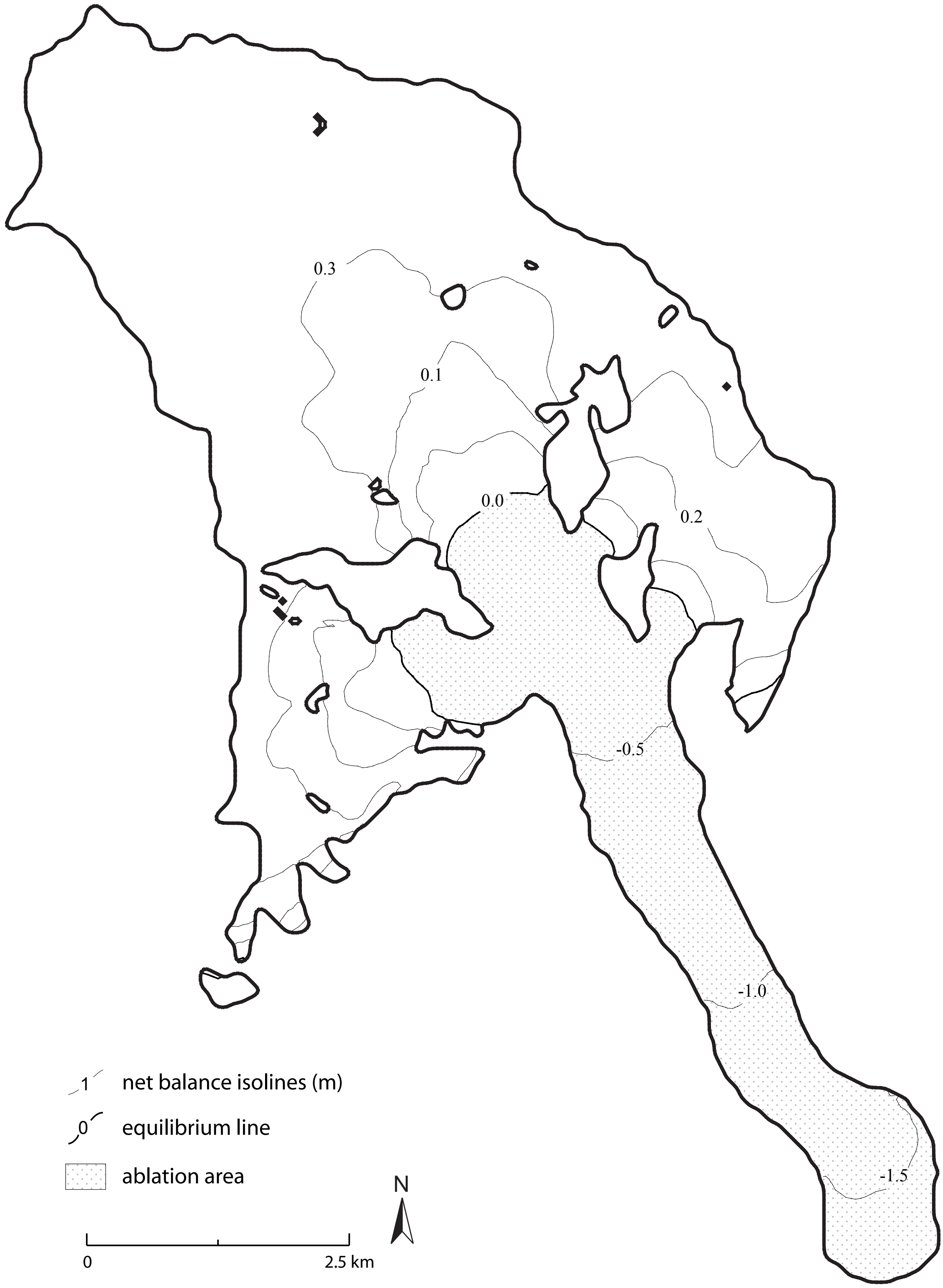
3.5.1 Topography and observation network



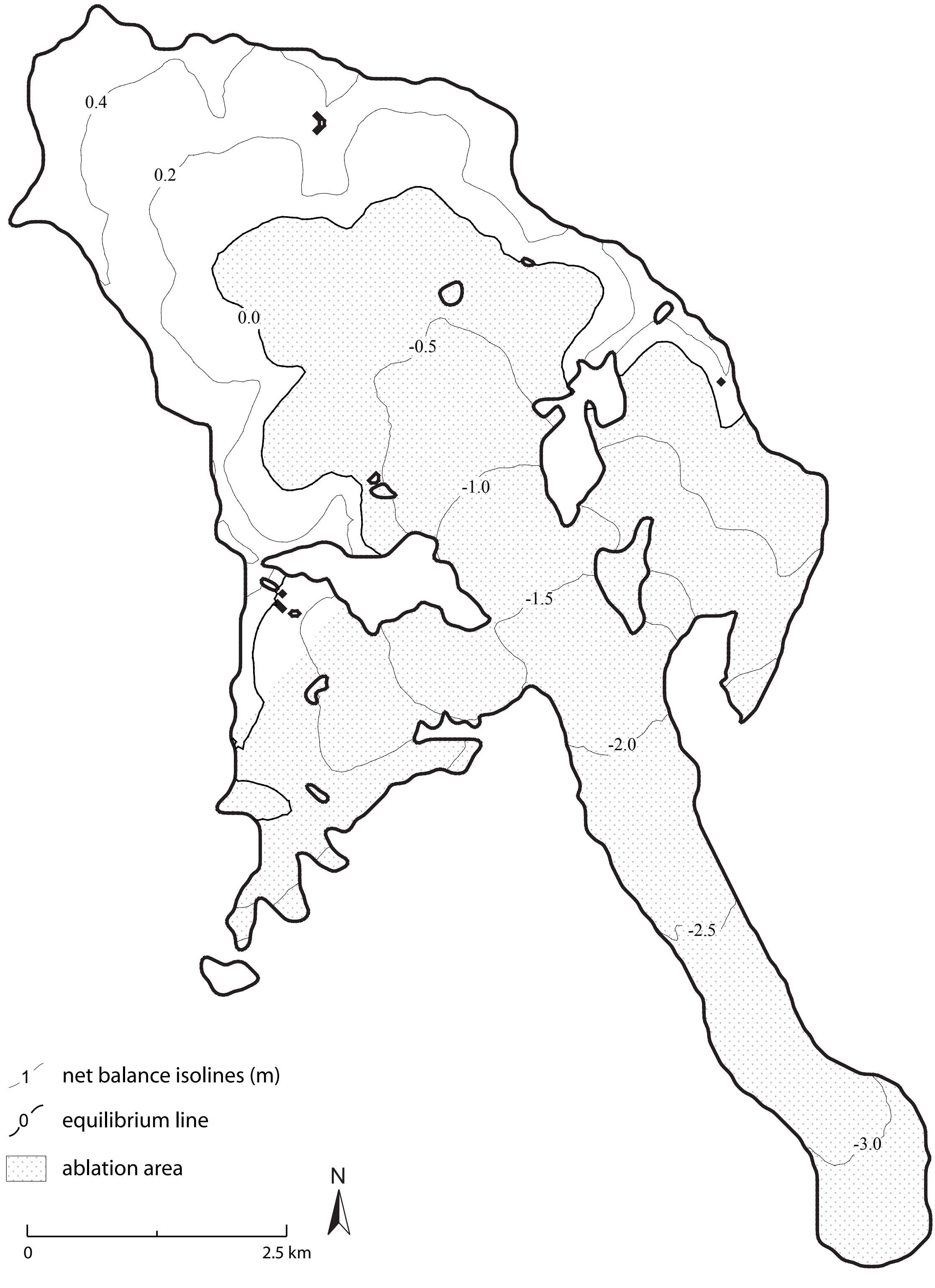
White (CANADA)

3.5.2 Net balance maps 2003/2004 and 2004/2005

2003/2004

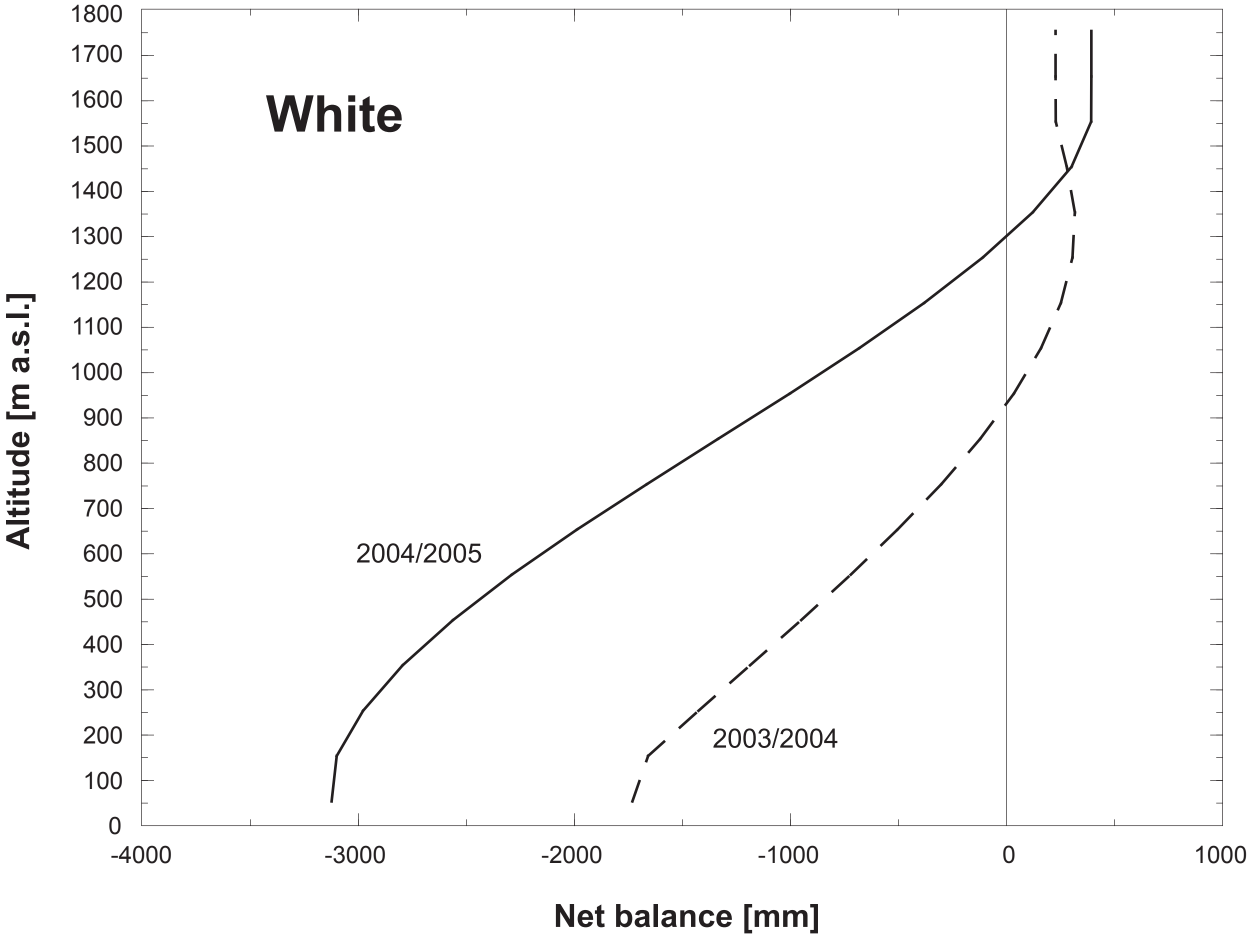


2004/2005

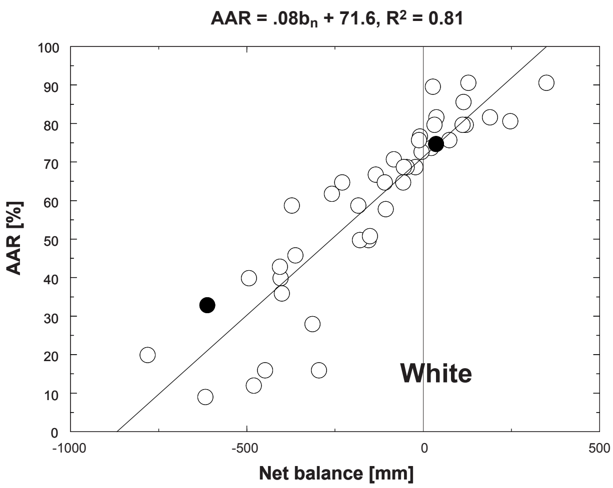


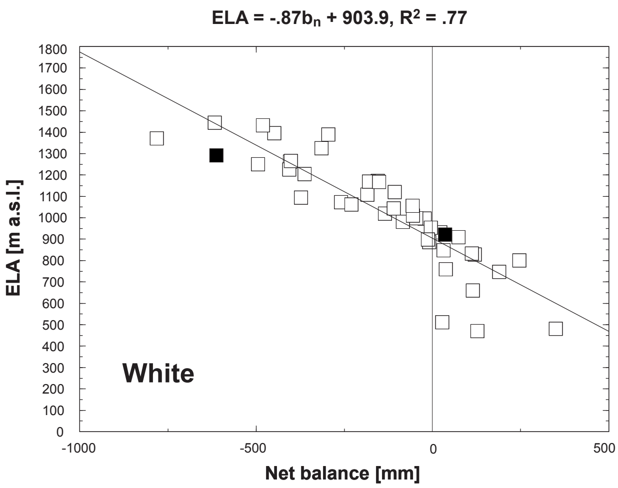
White (CANADA)

3.5.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.6 URUMQIHE S. NO 1 (CHINA/TIEN SHAN)

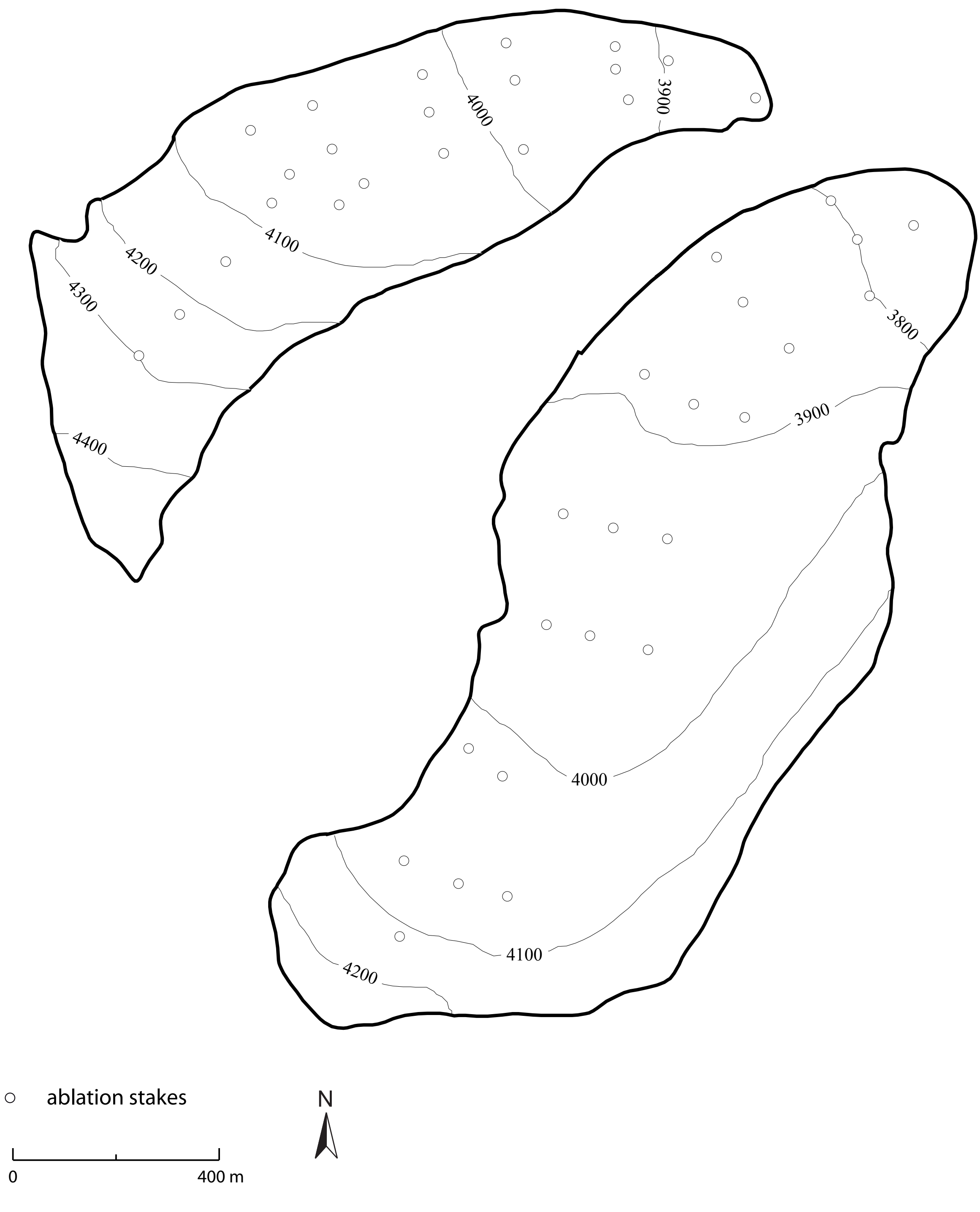
COORDINATES: 43.08 N / 86.82 E

Photo taken by T. Bolch, 2006.

Due to continued glacier shrinkage, the two branches of the former glacier have become two separated small glaciers but are still called East and West branch of Glacier No. 1, respectively. The East branch has a total area of 1.1 km^2, the highest and lowest points are at 4267 m and 3742 m a.s.l.; the West branch has a total area of 0.7 km^2, the highest and lowest points are at 4486 m and 3825 m a.s.l. Average annual precipitation measured at the nearby meteorological station at 3539 m a.s.l. is 400 to 500 mm and 600 to 700 mm at the glacier. Mean annual air temperature at the equilibrium line (4096 m a.s.l. for balance years) is estimated at -8.0 to -9.0 °C. The predominantly cold glacier is surrounded by continuous permafrost but reaches melting temperatures over wide areas of the bed. Accumulation and ablation both take place primarily during the warm season and the formation of superimposed ice on this continental-type glacier is important. A 1:5000 topographic map of the glacier and its forefield in August 2001 is available for further analysis.

In 2003/2004, the mass balance was -706 mm w.e. for the East branch and -844 mm w.e. for the West branch. In 2004/2005 , the corresponding values are -480 mm w.e. for the East branch and -503 mm w.e. for the West branch. The calculated mass balance for the entire glacier was -755 mm w.e. in 2003/2004 and –488 mm w.e. in 2004/2005. The latter value is the second most negative balance observed since the beginning of the record.

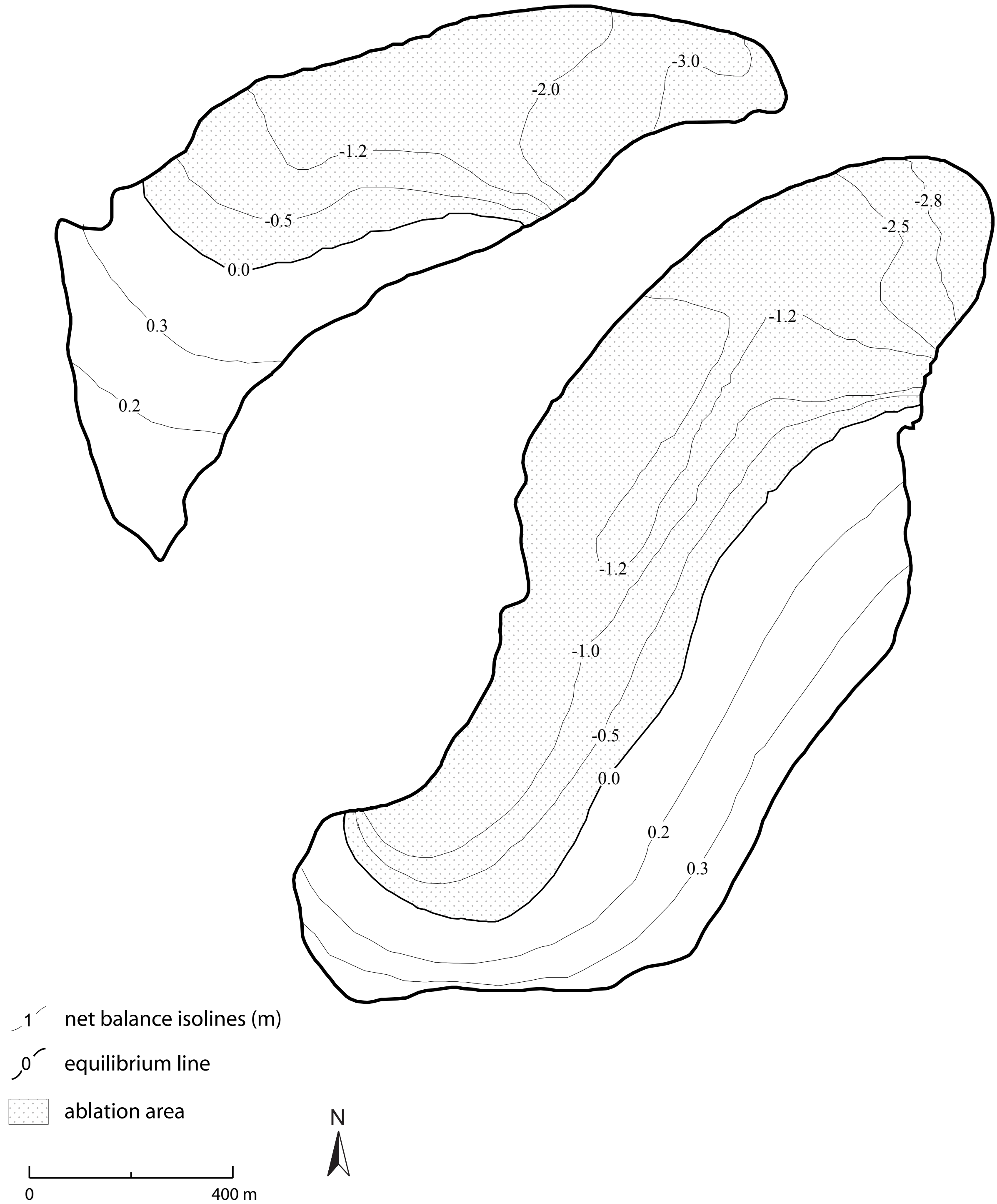
3.6.1 Topography and observation network



Urumqihe S. No. 1 (CHINA)

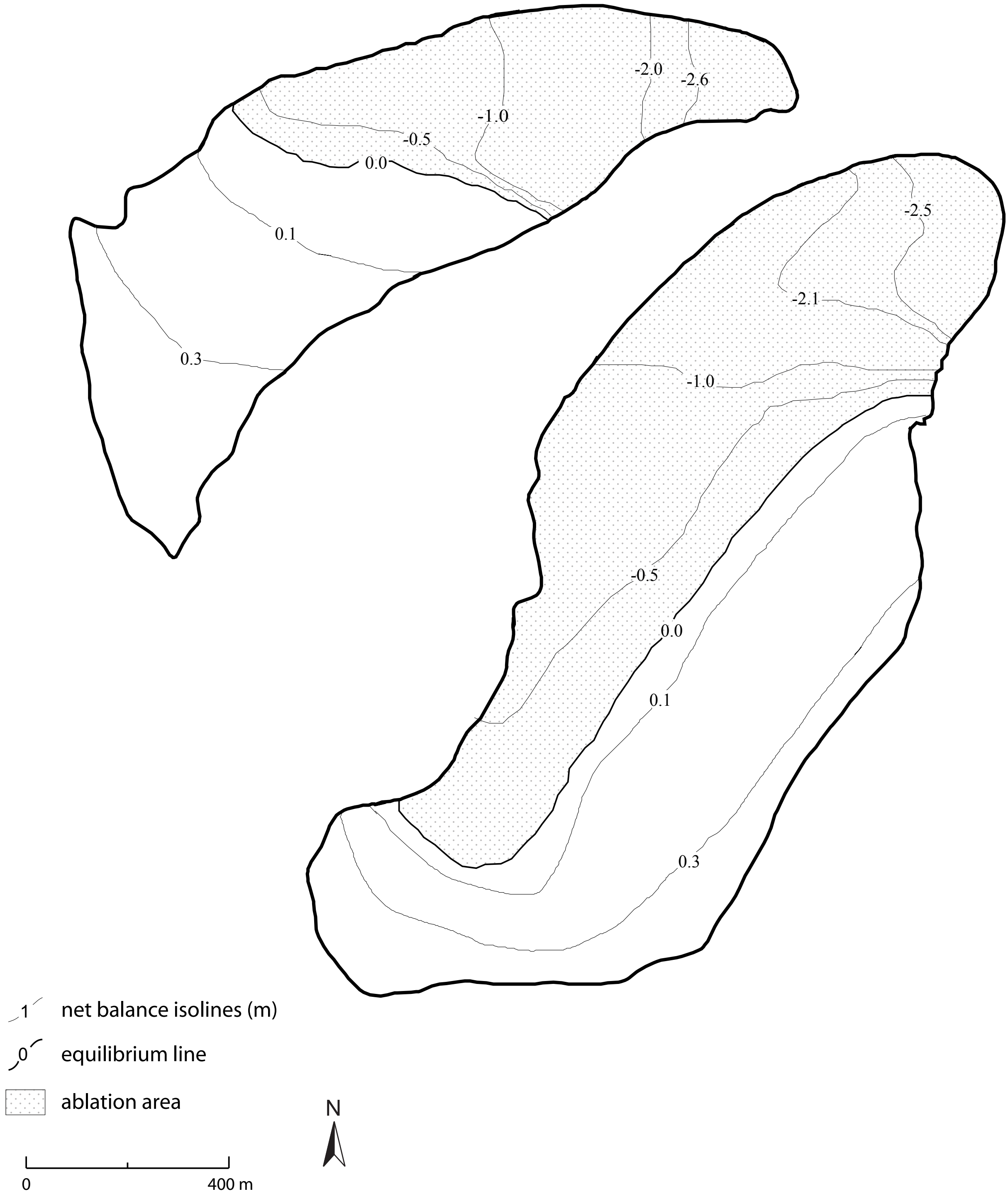
3.6.2 Net balance maps 2003/2004 and 2004/2005

2003/2004



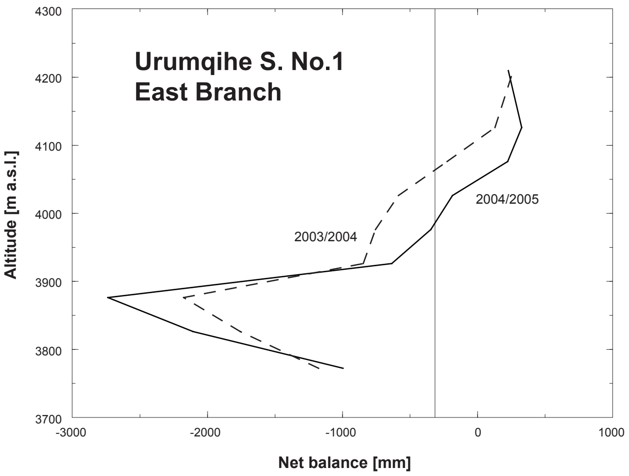
Urumqihe S. No. 1 (CHINA)

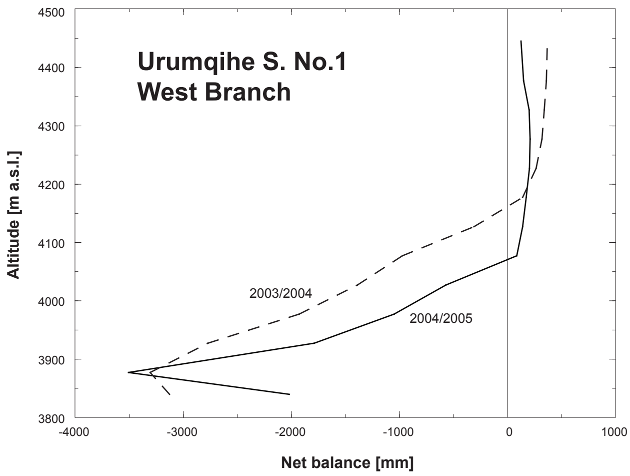
2004/2005



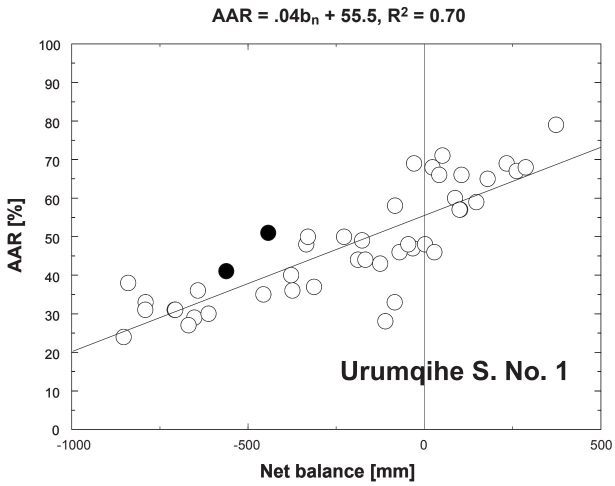
Urumqihe S. No. 1 (CHINA)

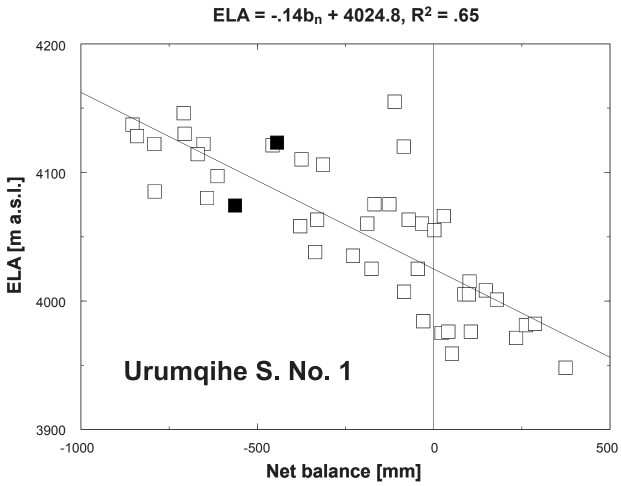
3.6.3 Net balance versus altitude (2003/2004 and 2004/2005)





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





3.7 ANTIZANA 15 ALPHA (ECUADOR/ EASTERN CORDILLERA)

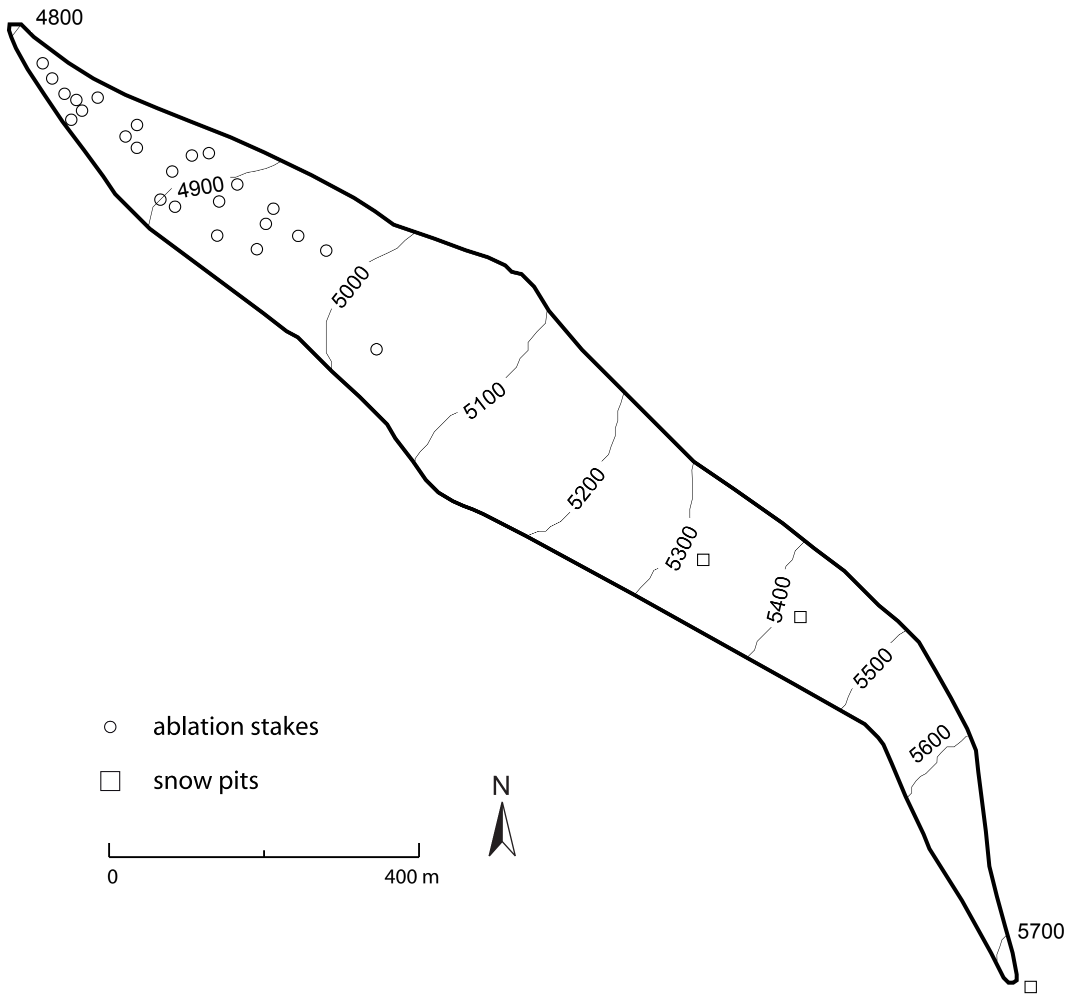
COORDINATES: 0.47 S / 78.15 W

Photo taken by B. Cáceres, 2004.

The glacier 15 Alpha of Antizana (5760-4830 m a.s.l., 0.32 km^2) is the only one situated near the equatorial line in South America providing regular mass balance information to the scientific community. The surface elevations of the glacier have been determined using aerial-photogrammetry from the year 1956 and 1997. First stakes were placed in 1994 to undertake direct measurements in the terminal zone of the glacier. The main exposition of the glacier is to the west and its length is 1.9 km. During the last eleven years a mean annual average precipitation of 936 mm/year was measured. In the year 2004/05 a mean annual air temperature of 1.3 °C at the nearby meteorological station was recorded.

The glacier 15 Alpha had an average annual mass balance of -627 mm w.e./year since 1995. The inter-annual variation is highly variable. Negative balances were observed during most of the years. Negative records were in the years 1995 and 2003. The negative mass balance series was interrupted by two positive balance years in 1999 and 2000. The years 2004 and 2005 had a negative balance with values of -572 mm w.e. and -789 mm w.e., respectively. The variability of the ENSO (El Niño Southern Oscillation) has been an important factor controlling the climatic conditions and their resulting influence on the mass balance evolution of the Ecuadorian glaciers. Years with favorable conditions for the Ecuadorian glaciers seem to be related to La Niña (cold) events and for unfavorable conditions to El Niño (warm) events.

3.7.1 Topography and observation network

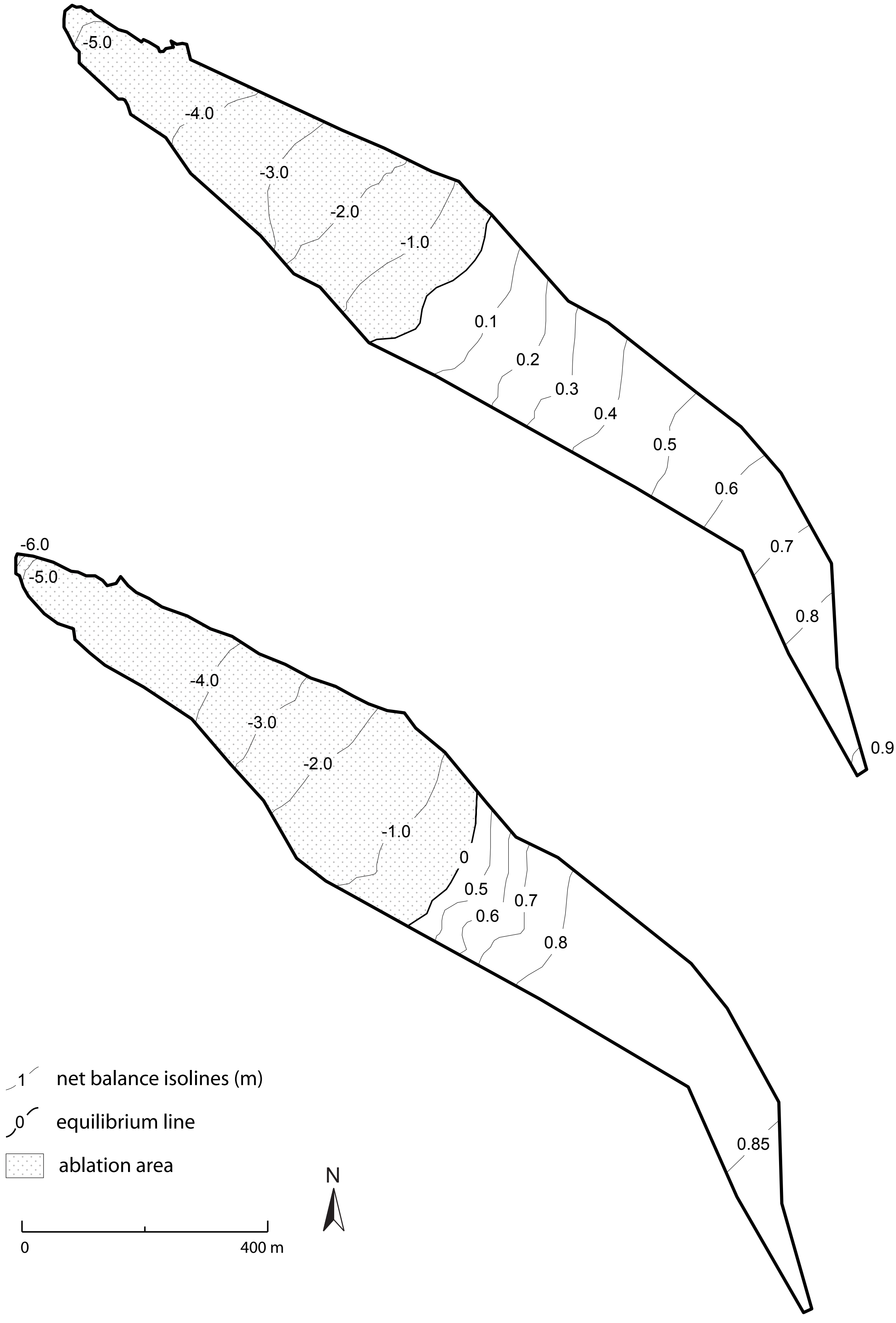


Antizana 15 Alpha (ECUADOR)

3.7.2 Net balance maps 2003/2004 and 2004/2005

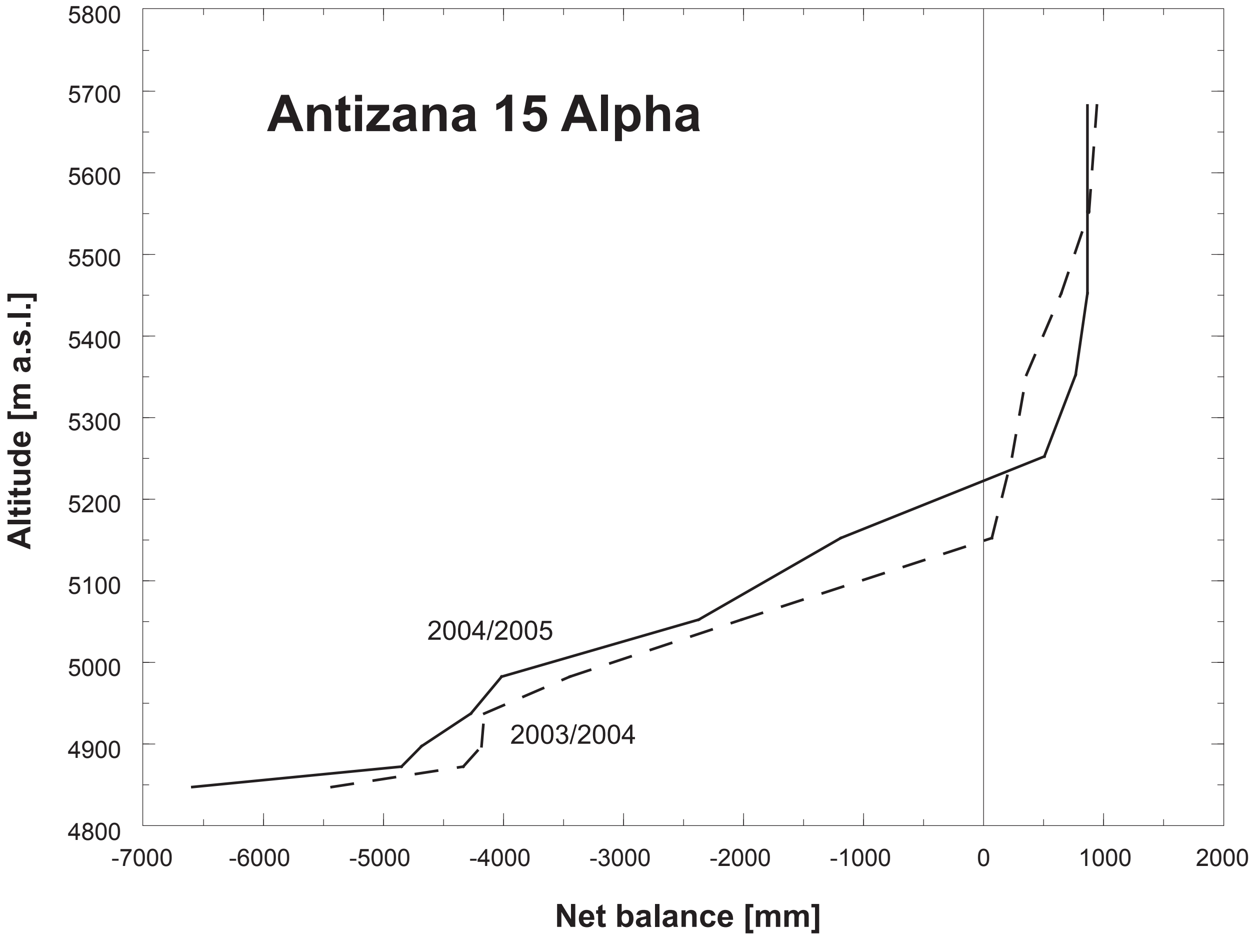
2003/2004

2004/2005

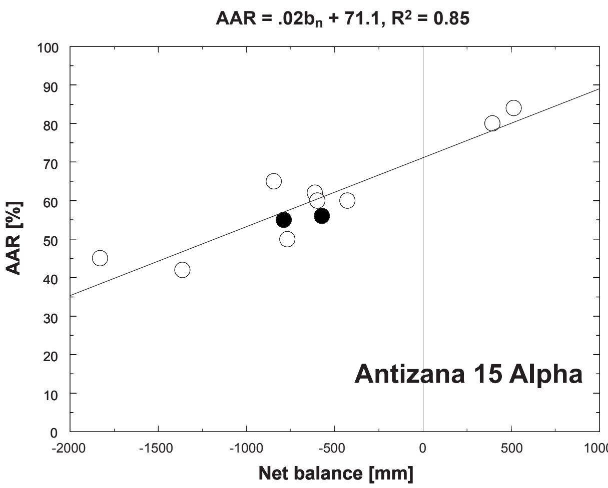


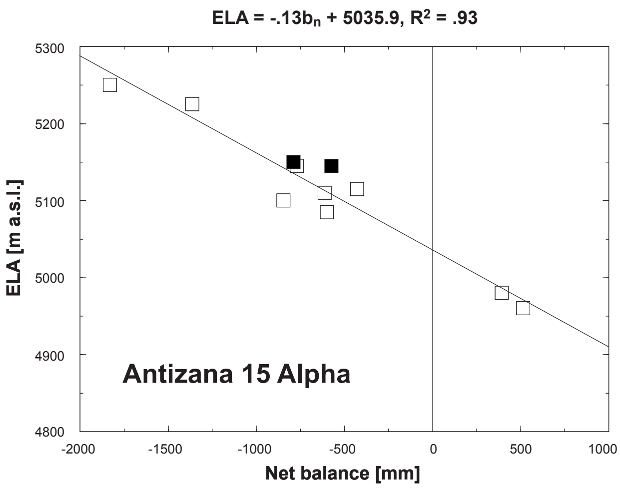
Antizana 15 Alpha (ECUADOR)

3.7.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.8 FONTANA BIANCA (ITALY/CENTRAL ALPS)

COORDINATES: 46.48 N / 10.77 E

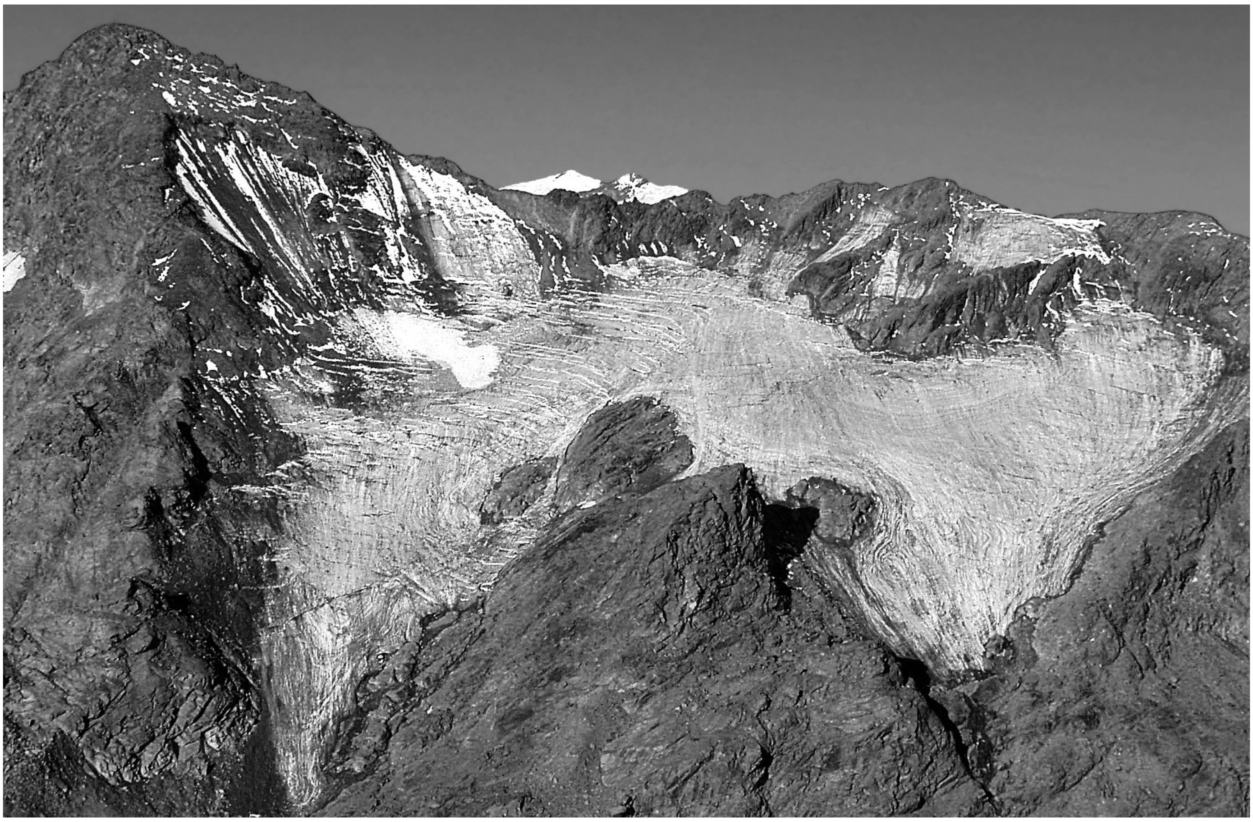
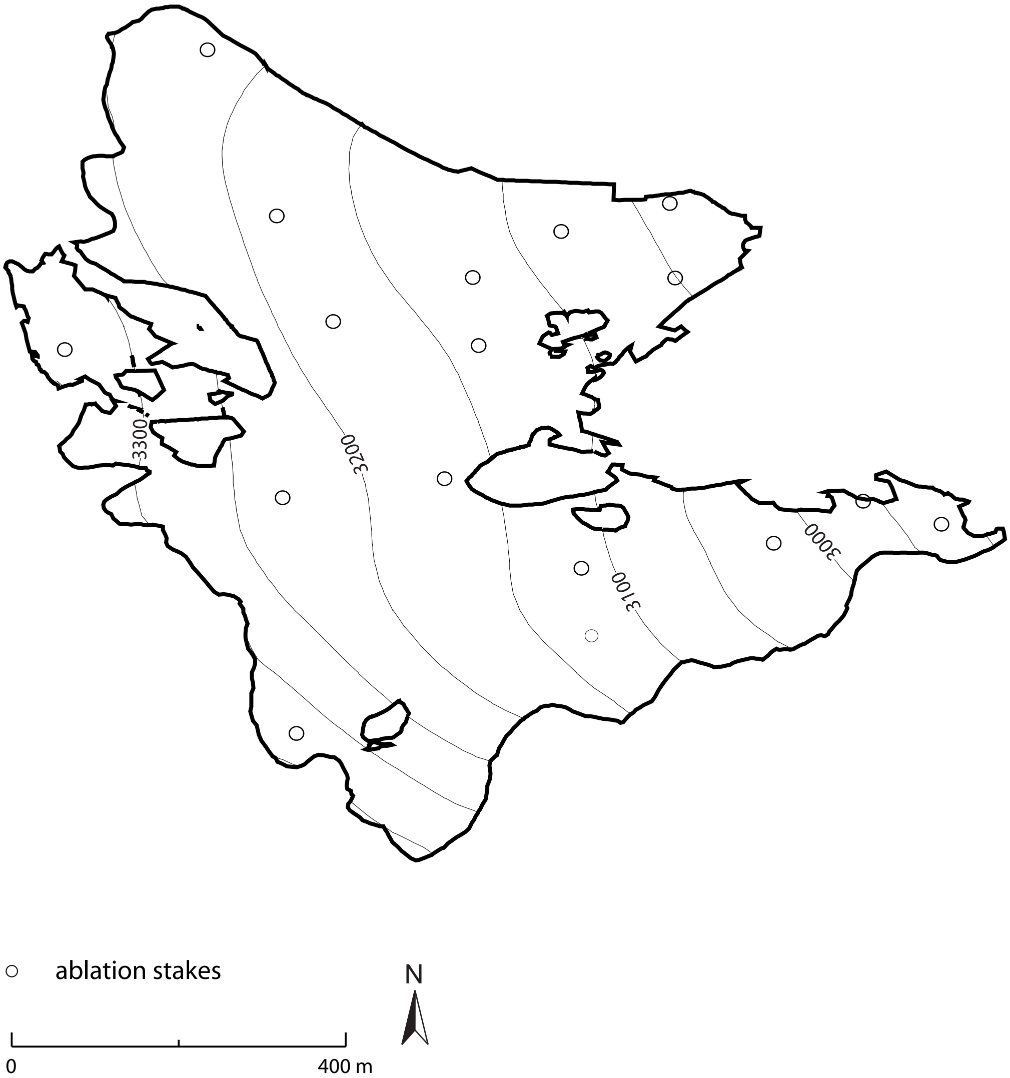


Photo taken by C. Oberschmied, 8th of September 2005.

Weißbrunnferner (Fontana Bianca) is a small east-exposed glacier in the southern part of the Eastern Alps (Ortles/Cevedale Group, Italy). It covers an area of 0.54 km^2, extends from 3340 m to 2890 m a.s.l. and has two short tongues on which blown-in winter snow tends to last far into the summer months. At the nearby Weißbrunn meteorological station (1900 m a.s.l.) mean annual air temperature is 3.2 °C and precipitation amounts to 1025 mm per year on average. Because of the lasting negative mass loss and equilibrium line altitudes usually reaching above the highest point of the glacier, ice movement has diminished to near-zero. As a consequence, the remaining ice body has begun to show first signs of disintegration with several fast-growing rock islands.

The balance years 2003/04 and 2004/05 in particular brought both a strong mass loss of -994 mm w.e. and -1471 mm w.e. respectively. The cumulative mass balance since 1991 reached -13189 mm w.e., which means about -950 mm w.e. per year. The progressive retreat of the glacier affects its extension and volume and is emphasized by the enlargement of the rock outcrops in the central part and in the steep south-western upper limit of the ice body. For this reason during summer 2005 a new topographic survey was conducted to update the glacier borders. The mass balance studies carried out by the direct glaciological method are integrated by the hydrological data collected at two gauging stations positioned immediately downstream the glacier tongues on the orographic left and right of the glacier. Discharge measurements allowed maximum icemelt rates of 5-6 cm ice per day to be calculated for the entire glacier.

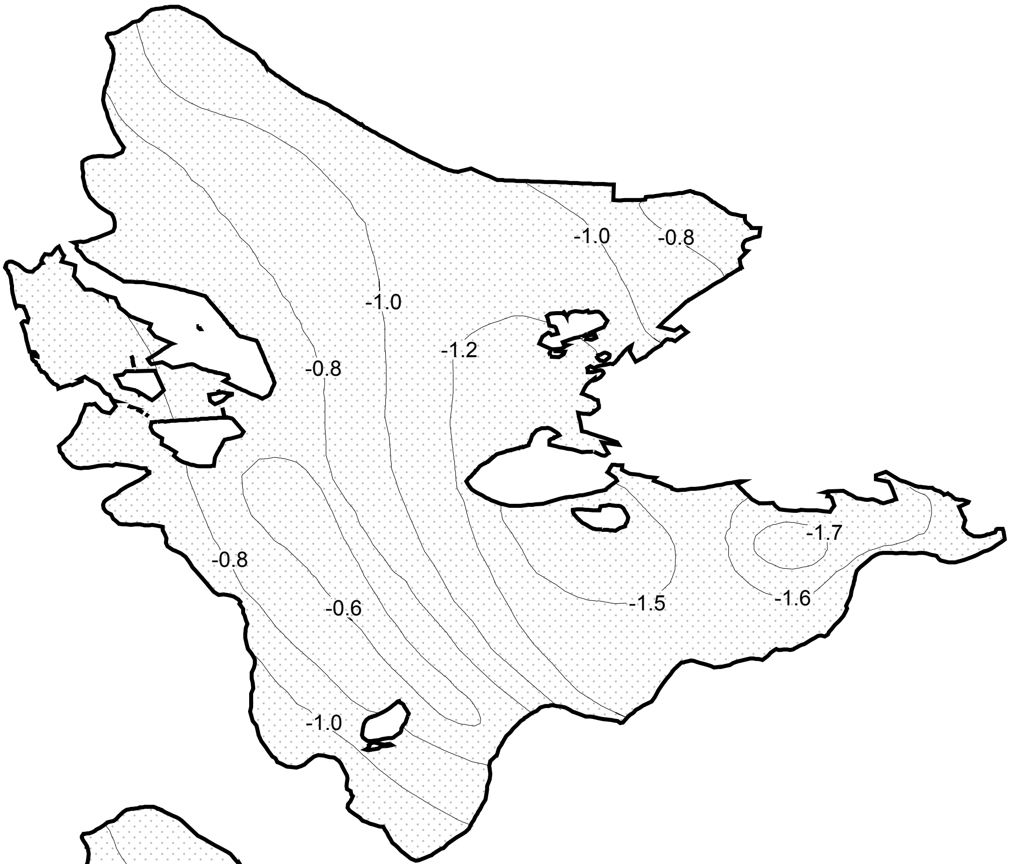
3.8.1 Topography and observation network



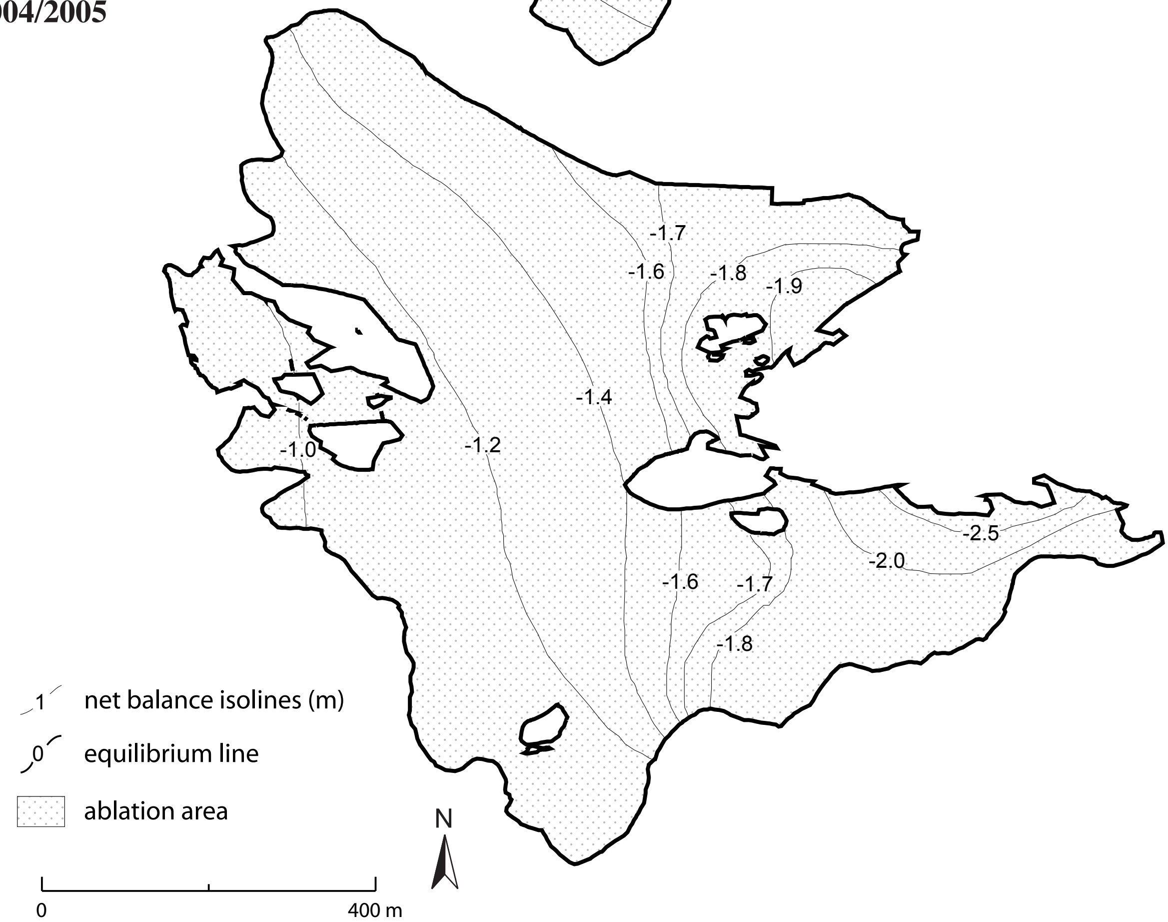
Fontana Bianca (ITALY)

3.8.2 Net balance maps 2003/2004 and 2004/2005

2003/2004

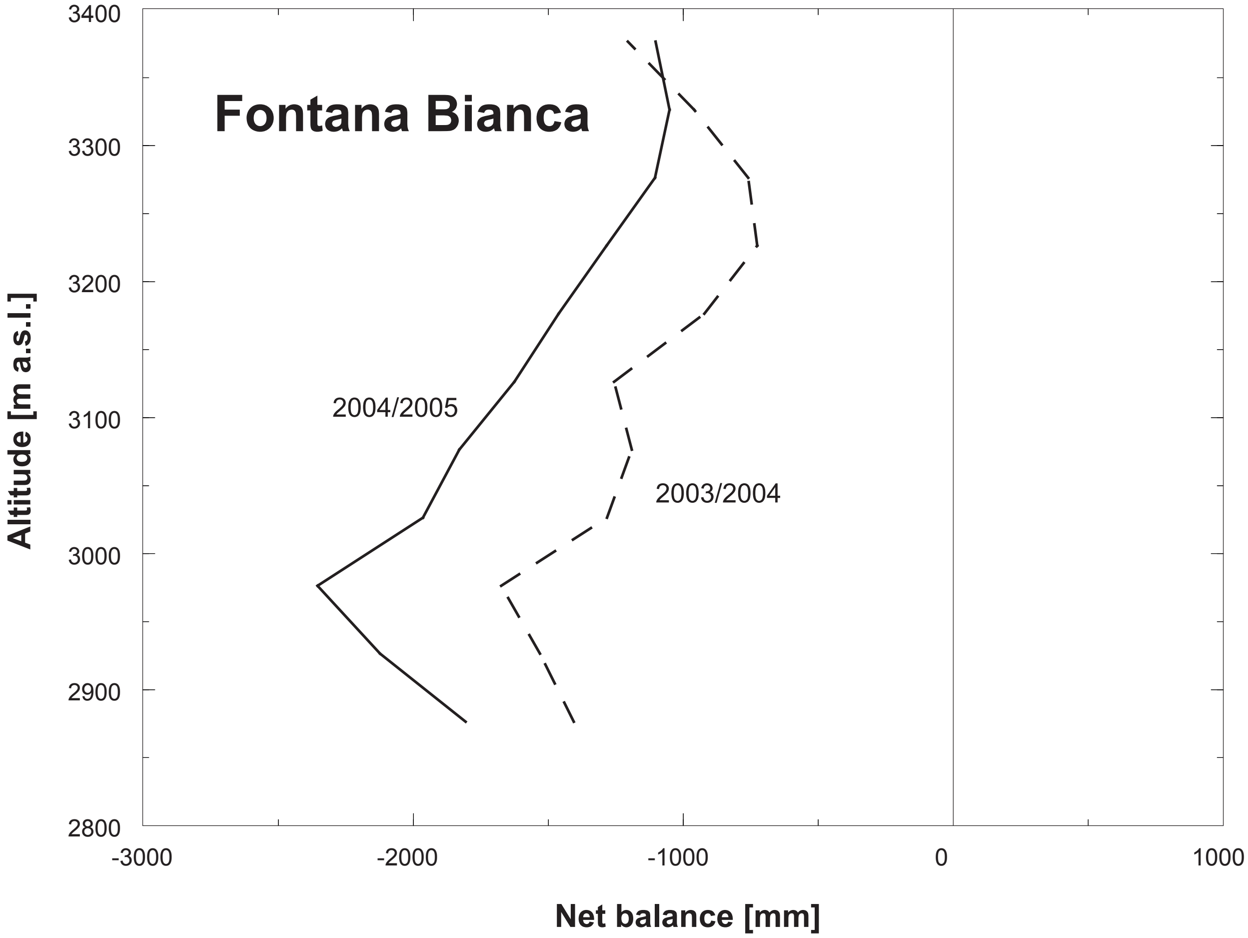


2004/2005

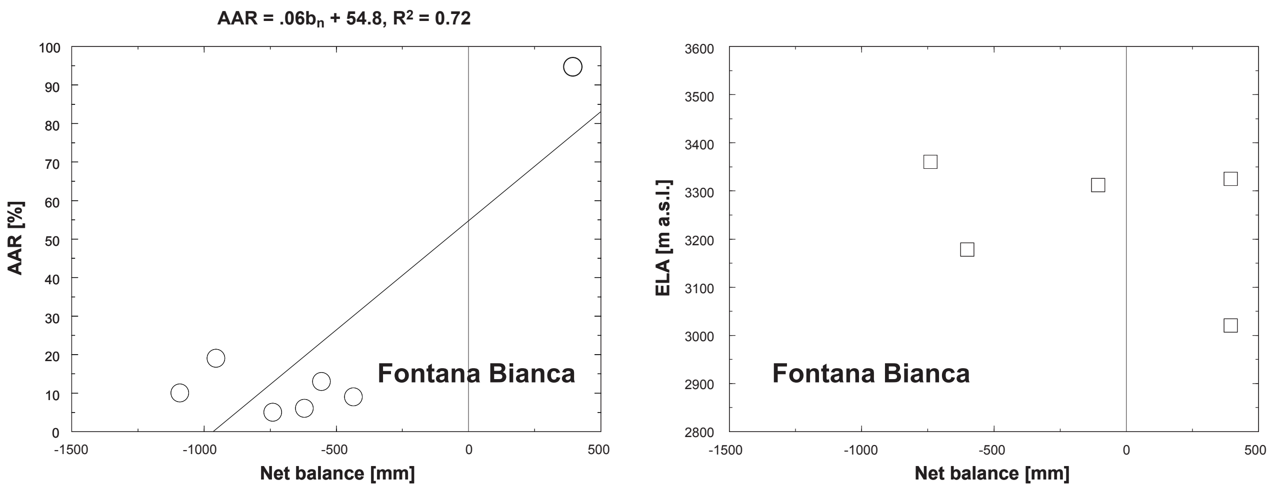


Fontana Bianca (ITALY)

3.8.3 Net balance versus altitude (2003/2004 and 2004/2005)



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



3.9 TSENTRALNIY TUYUKSUYSKIY (KAZAKHSTAN/TIEN SHAN)

COORDINATES: 43.05 N / 77.08 E

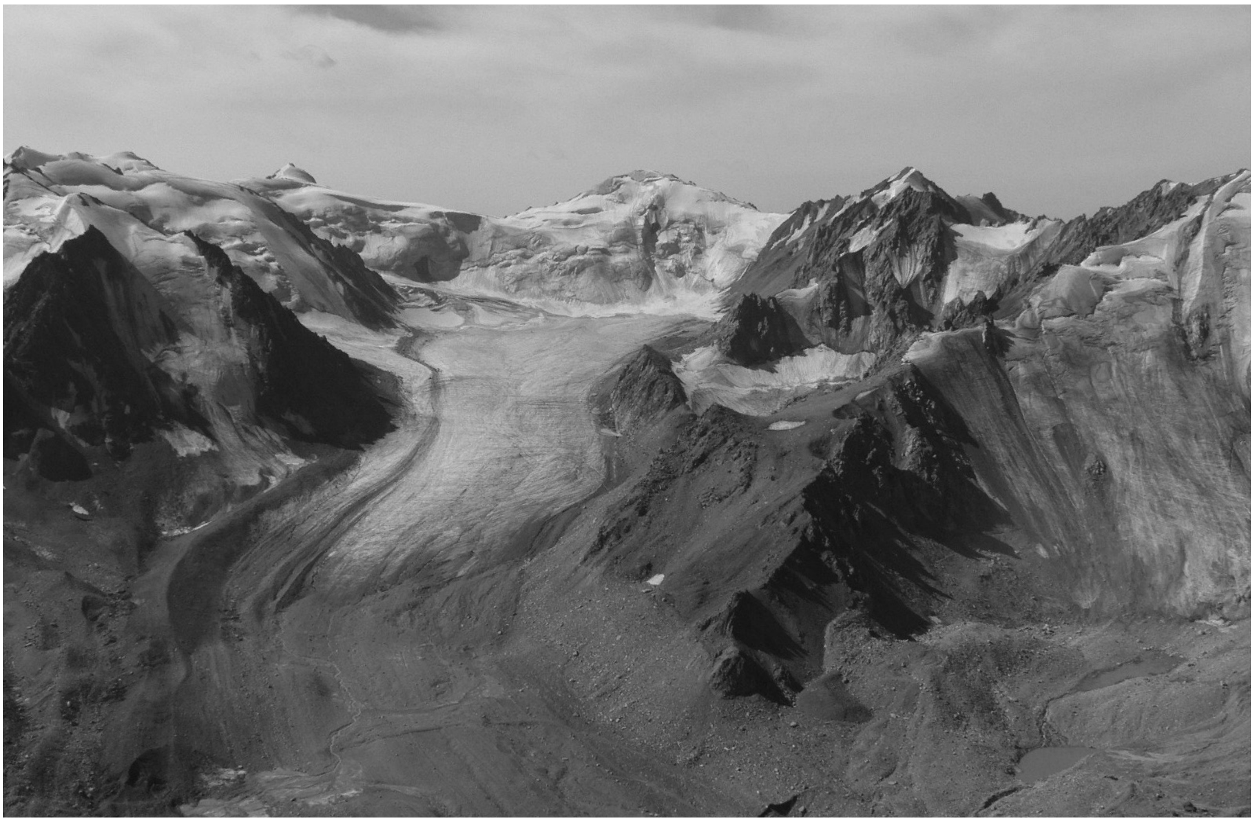


Photo taken by V.N. Vinokhodov, August 2006.

The valley-type glacier in Zailiyskiy Alatau range of the Kazakh Tien-Shan is also called the Tuyuksu Glacier. It extends from 4200 to 3441 m a.s.l. and has a surface area of 2.525 km^2 with the exposure being to the north. Mean annual air temperature at the equilibrium line of the glacier (around 3800 m a.s.l. for balanced conditions) is between -6.5 and -7 °C. The glacier is considered to be cold to polythermal and surrounded by continuous permafrost. Average annual precipitation is about 1000-1100 mm at the glacier. Characteristic features of the high continental climatic conditions are stable winter anticyclones with low air temperatures and summer precipitation of 26 % of the annual sum in 2003/04 and 42 % in 2004/05.

In the summer season 2004/05, the air temperature in July was higher than normal and ablation on the tongue was very intensive. The winter precipitation was equal to 74 % of the annual sum in 2003/04 and 58 % in 2004/05. This is highest average value for the 33 years observation period. As a result of these conditions, the glacier mass balance was +62 mm w.e. in 2003/04 and -340 mm w.e. in 2004/05. The glacier is continuing its retreat.

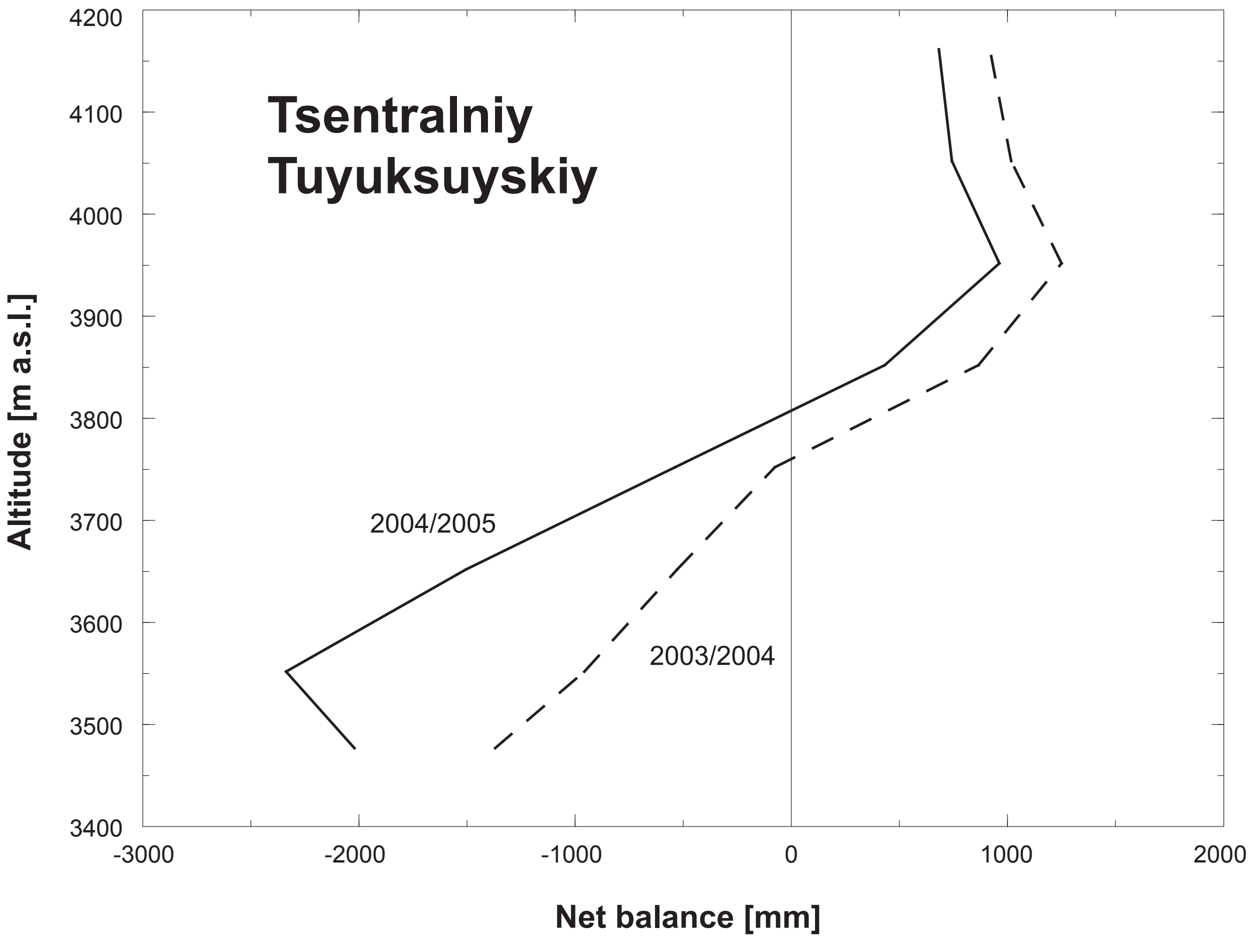
3.9.1 Topography and observation network

Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

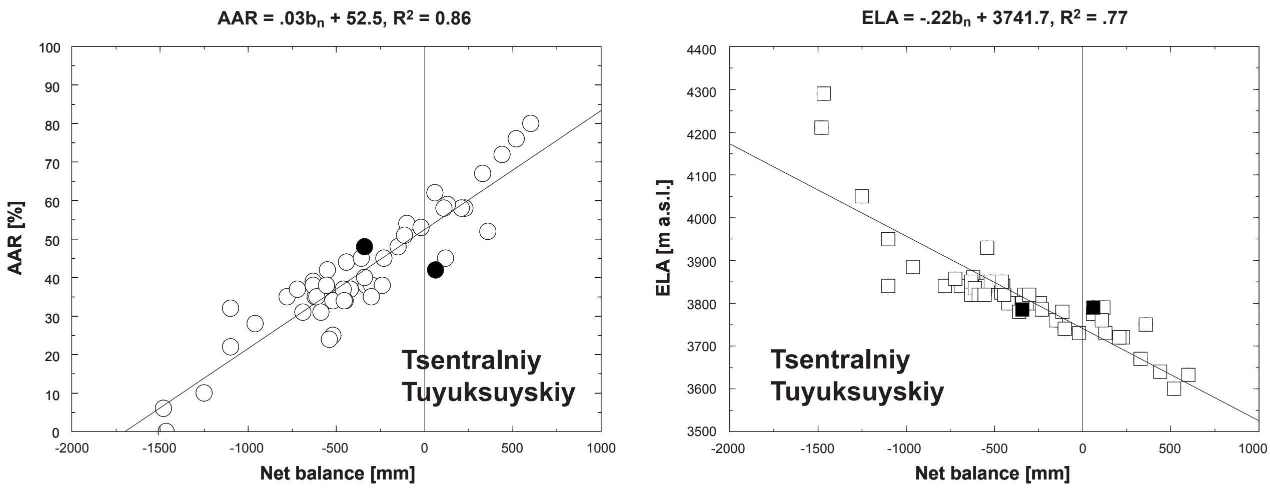
3.9.2 Net balance maps 2003/2004 and 2004/2005

Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.9.3 Net balance versus altitude (2003/2004 and 2004/2005)



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



3.10 NIGARDSBREEN (NORWAY/WEST NORWAY)

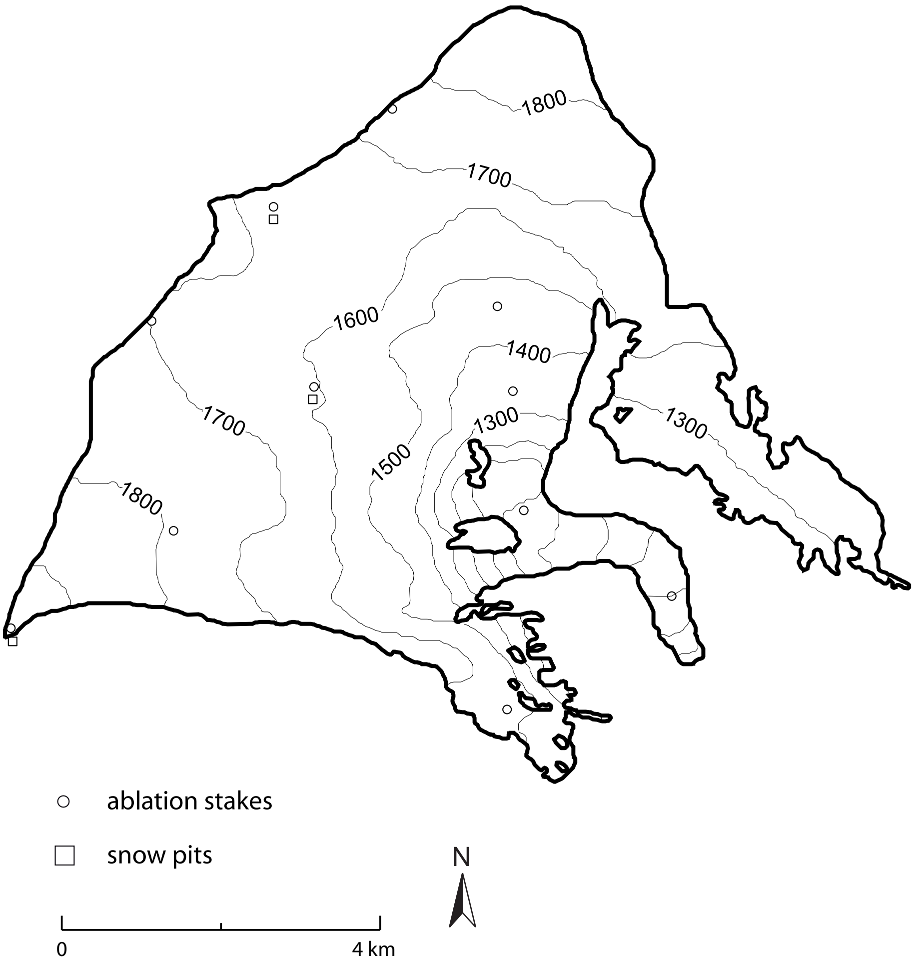
COORDINATES: 61.72 N / 07.13 E

Photo taken by B. Kjøllmoen, 31st of July 2002.

Nigardsbreen is one of the largest outlet glaciers (47.8 km^2) of the Jostedalsbreen Ice Cap in Southern Norway and reaches from 1960 to 320 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 is 1380 mm and mean annual air temperature at the equilibrium line (about 1375 m a.s.l. for balanced conditions) is estimated at -3 °C. Since the beginning of detailed mass balance measurements in 1962, glacier thickness has greatly increased, especially after 1988.

In 2003/04, the winter balance was 1970 mm w.e. (83 % of the mean value for the total observation period) and summer balance was -2010 mm w.e. (102 % of the average 1962-2003). The resulting mass balance is -43 mm w.e. and the calculated equilibrium line altitude is about 1530 m a.s.l. In 2004/05, the winter balance was 2800 mm w.e. (118 % of the average for the period 1962-2004) and summer balance was -1700 mm w.e. (86 % of the long-term mean). The resulting mass balance was +1098 mm w.e. The calculated equilibrium line altitude is about 1395 m a.s.l. Since 1962, the cumulative mass balance has been calculated as 18400 mm w.e.

3.10.1 Topography and observation network

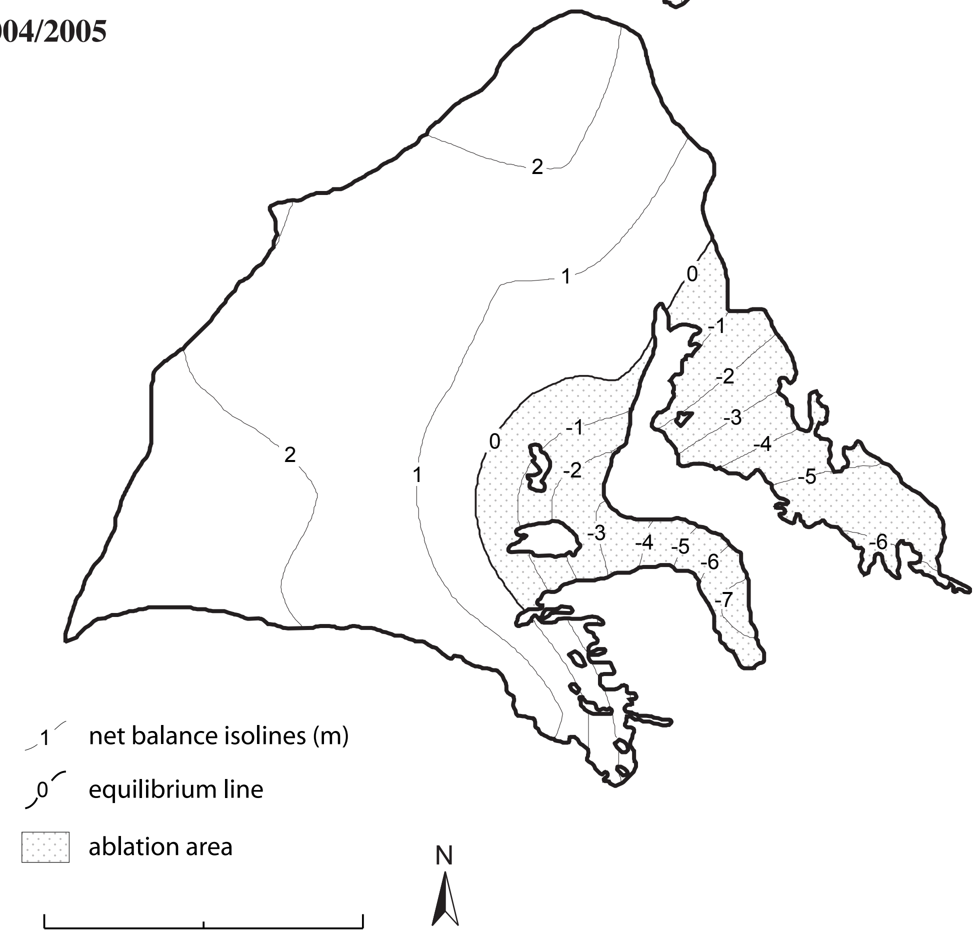


Nigardsbreen (NORWAY)

3.10.2 Net balance maps 2003/2004 and 2004/2005

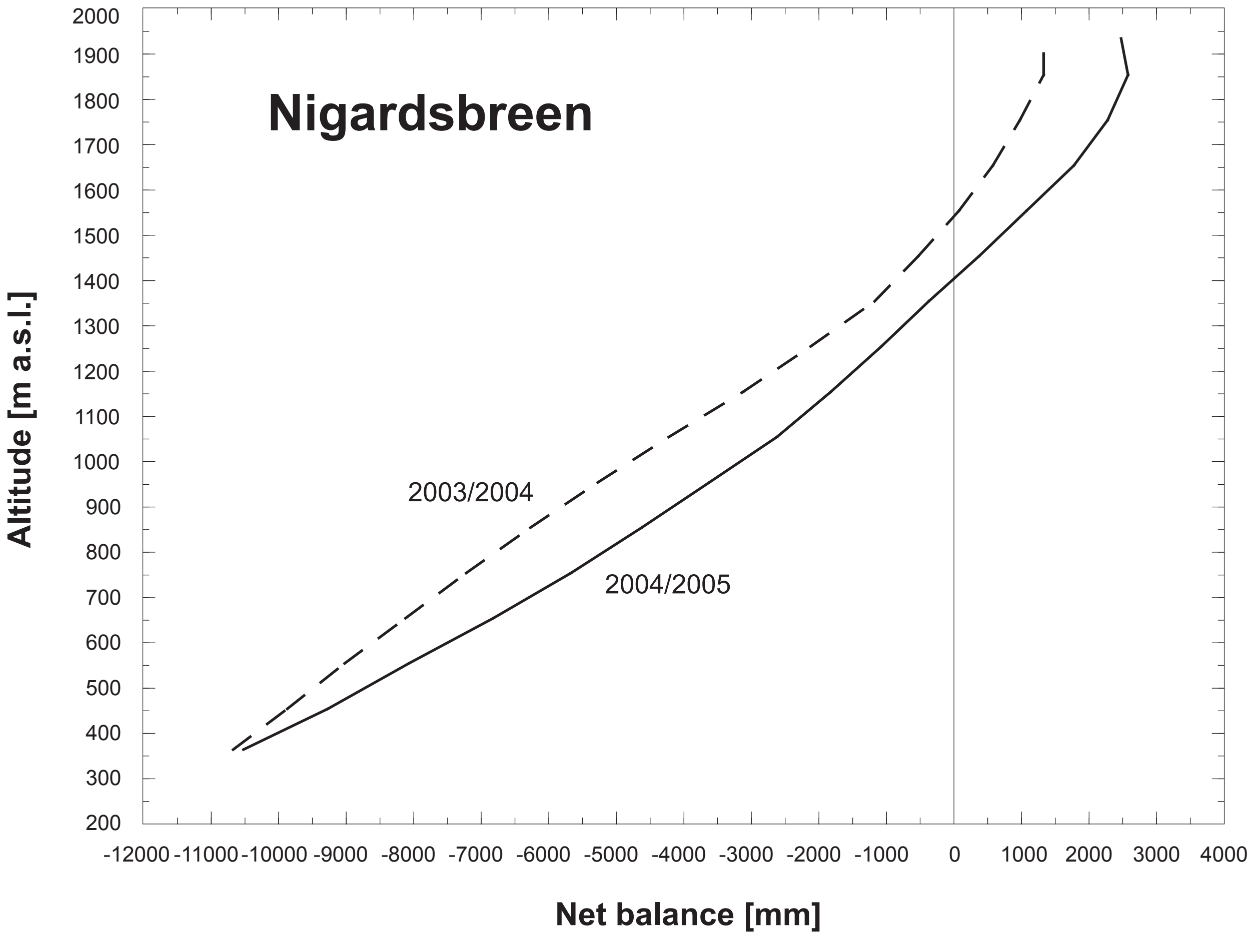
2003/2004

2004/2005

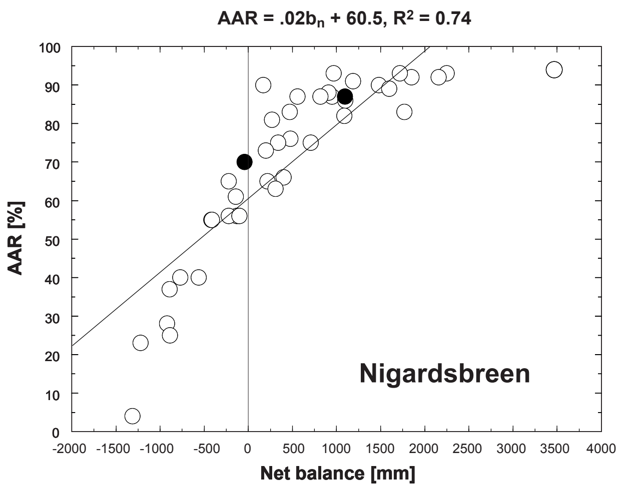


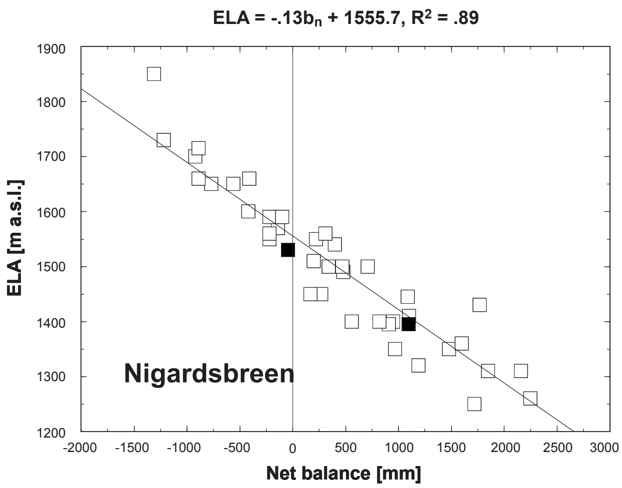
Nigardsbreen (NORWAY)

3.10.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.11 WALDEMARBREEN (NORWAY/SPITSBERGEN)

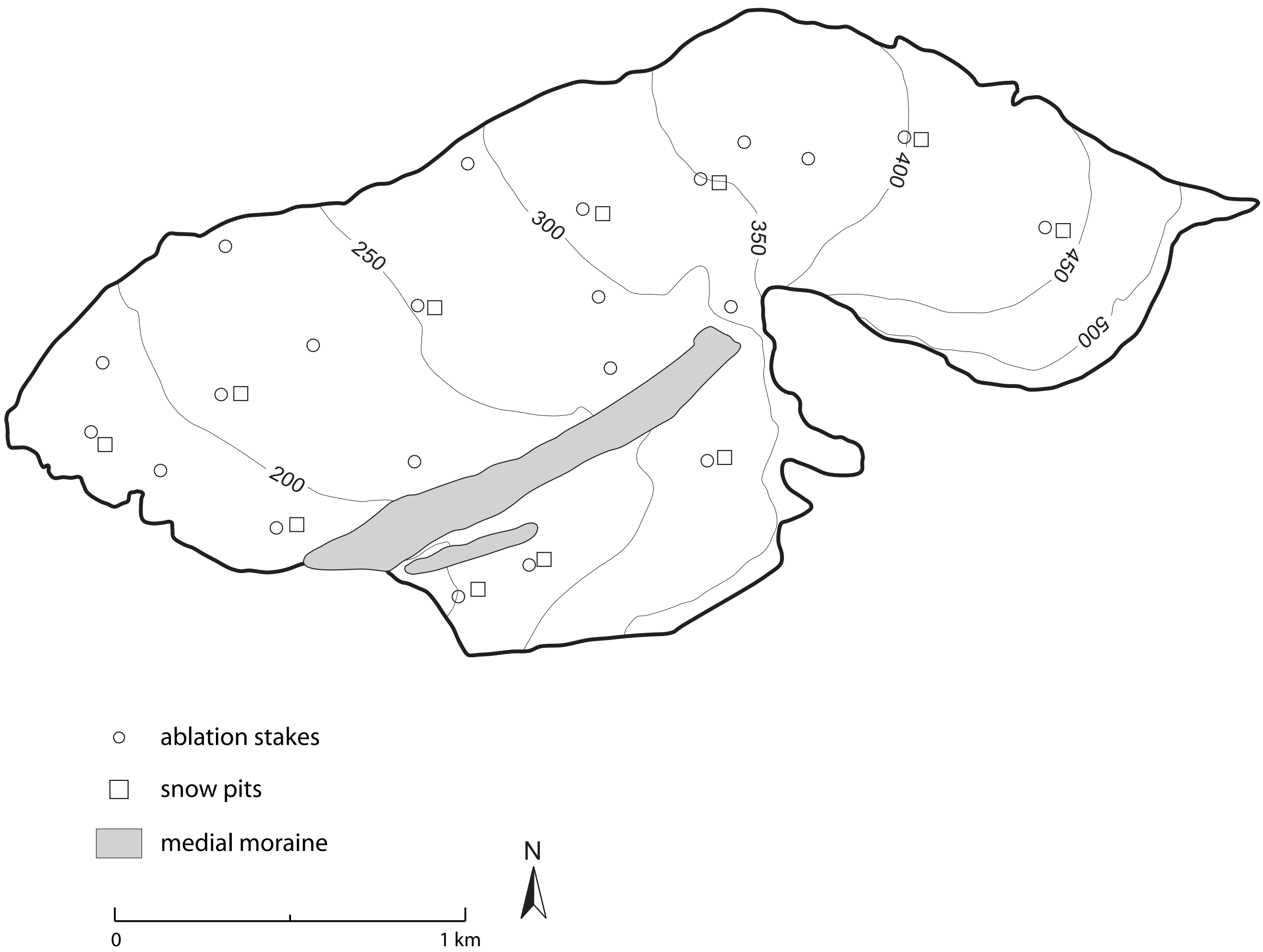
COORDINATES: 78.67 N / 12.00 E

Photo taken by I. Sobota, August 2005.

Waldemarbreen is located in the Oscar II Land, northwestern Spitsbergen and flows downvalley to the Kaffiøyra plane. The glacier is composed of two parts separated by a 1600 m long medial moraine. It occupies an area of 2.6 km^2 and extends from 510 m to 135 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 periglacial permafrost is assumed to be widespread. Since the 19^{th} century the surface area of the Kaffiøyra glaciers has decreased by approximately 30 %. The Waldemarbreen has been retreating recently. Detailed mass balance investigations have been conducted since 1995.

The balance in 2003/2004 showed a net mass loss of -641 mm w.e., winter accumulation +496 mm w.e. and summer ablation -1137 mm w.e. The ablation in 2004/2005 was higher than normal (-1156 mm w.e.) and the accumulation was +434 mm w.e., resulting in a balance of -722 mm w.e. The mean value of the mass balance for the period 1995-2005 is -552 mm w.e.

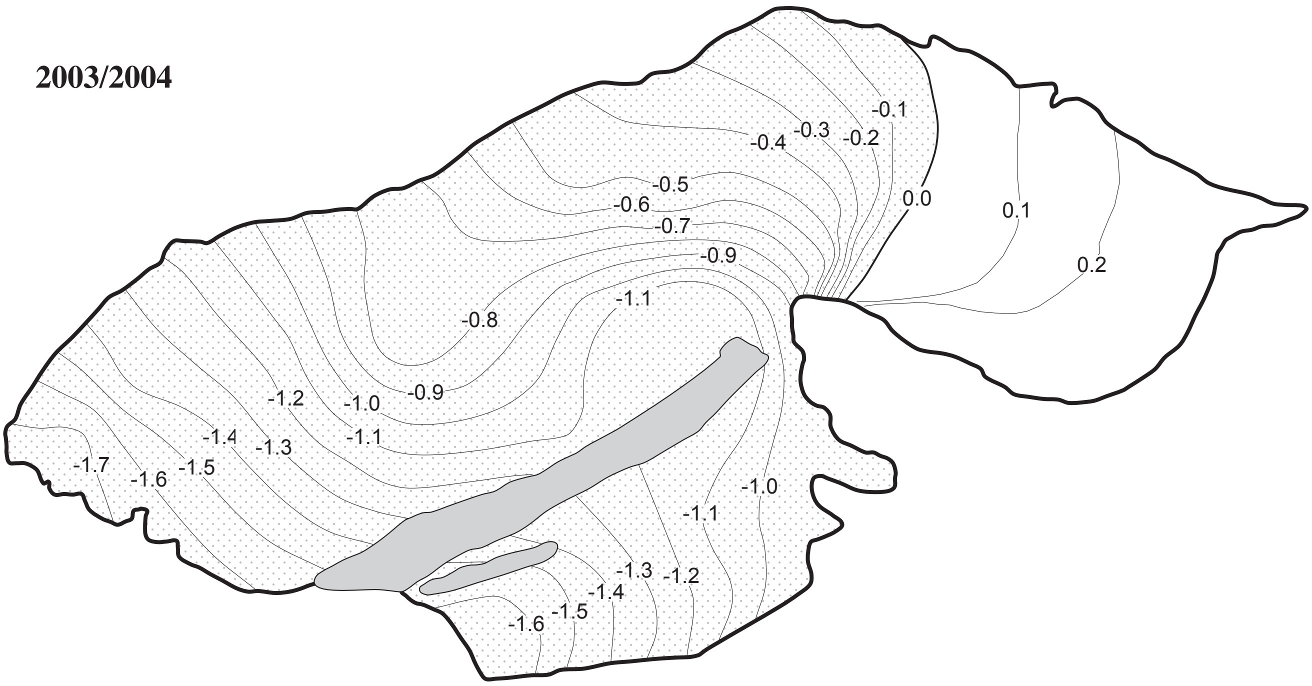
3.11.1 Topography and observation network



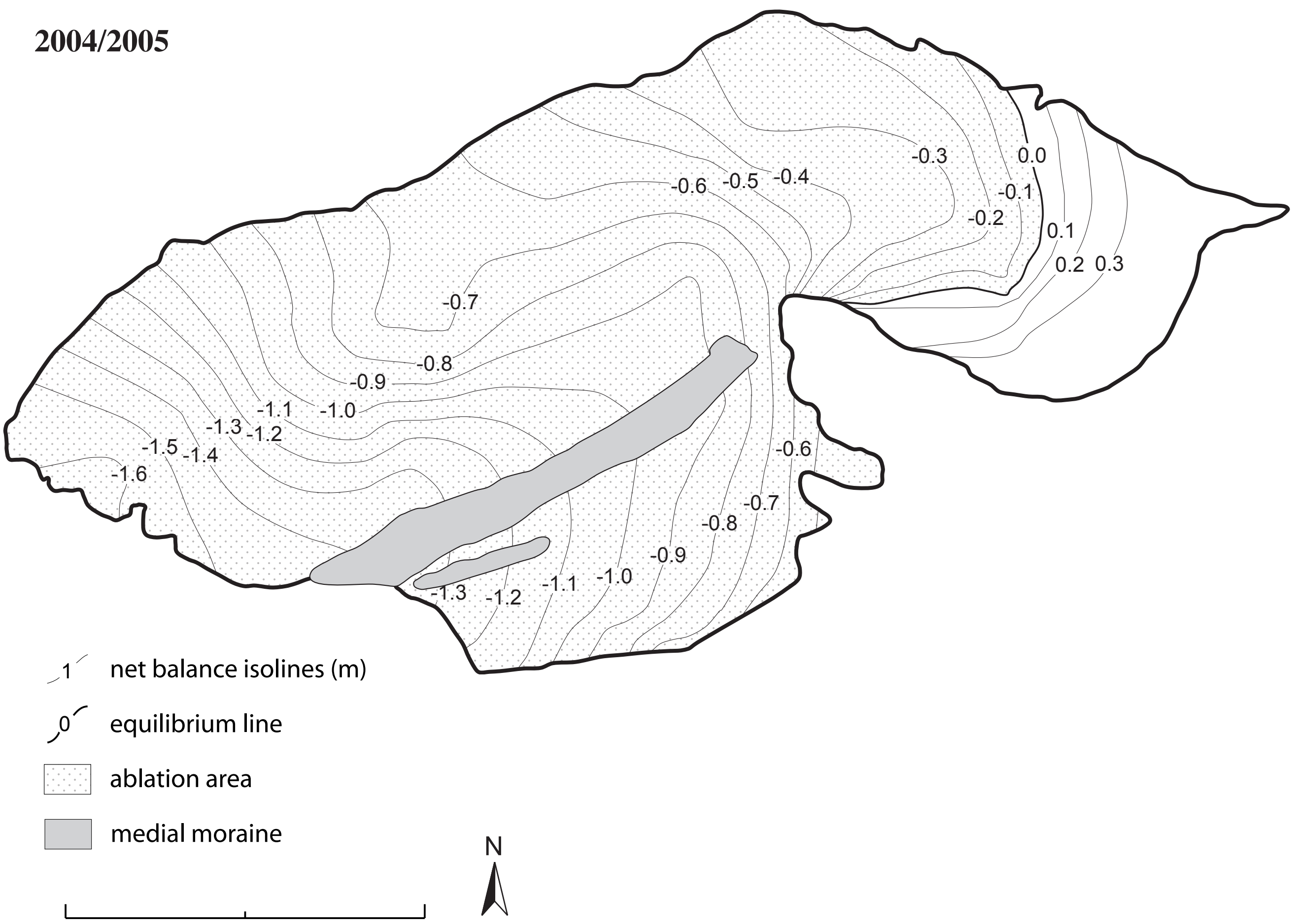
Waldemarbreen (NORWAY)

3.11.2 Net balance maps 2003/2004 and 2004/2005

2003/2004

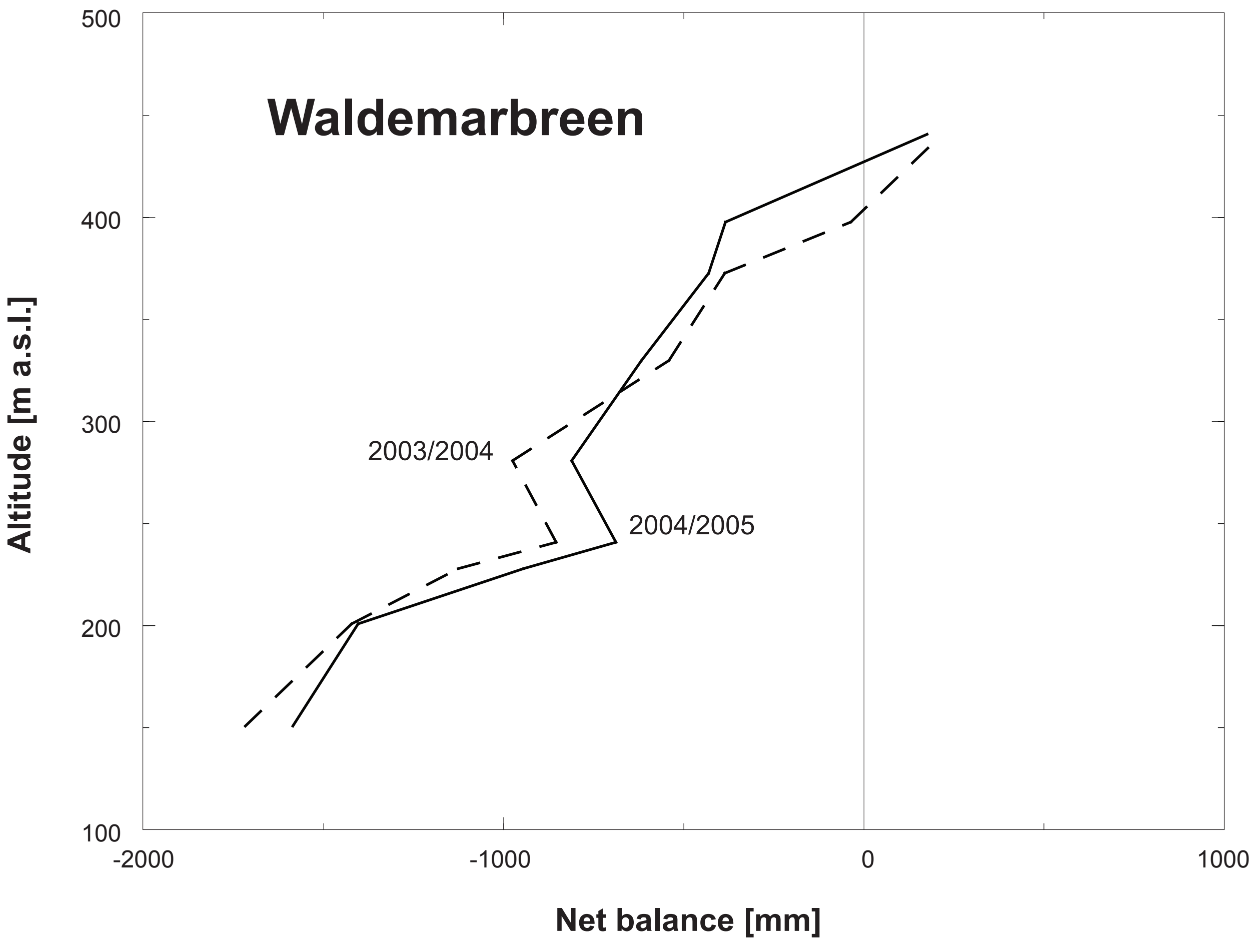


2004/2005

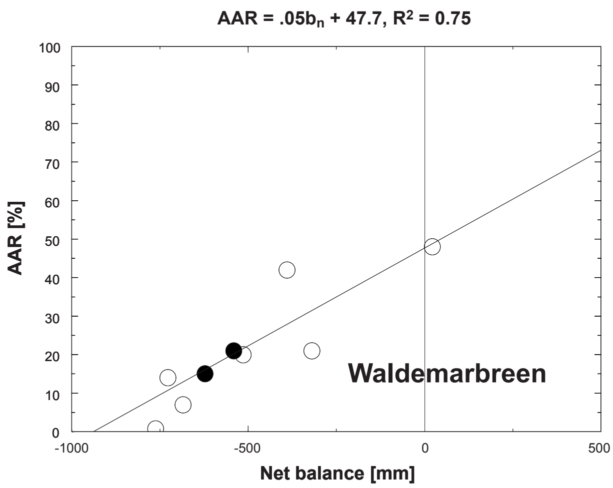


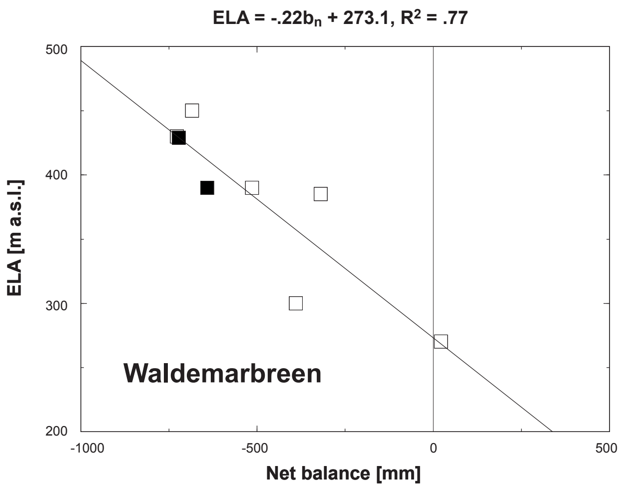
Waldemarbreen (NORWAY)

3.11.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





3.12 DJANKUAT (RUSSIA/N CAUCASUS)

COORDINATES: 43.20 N / 42.77 E

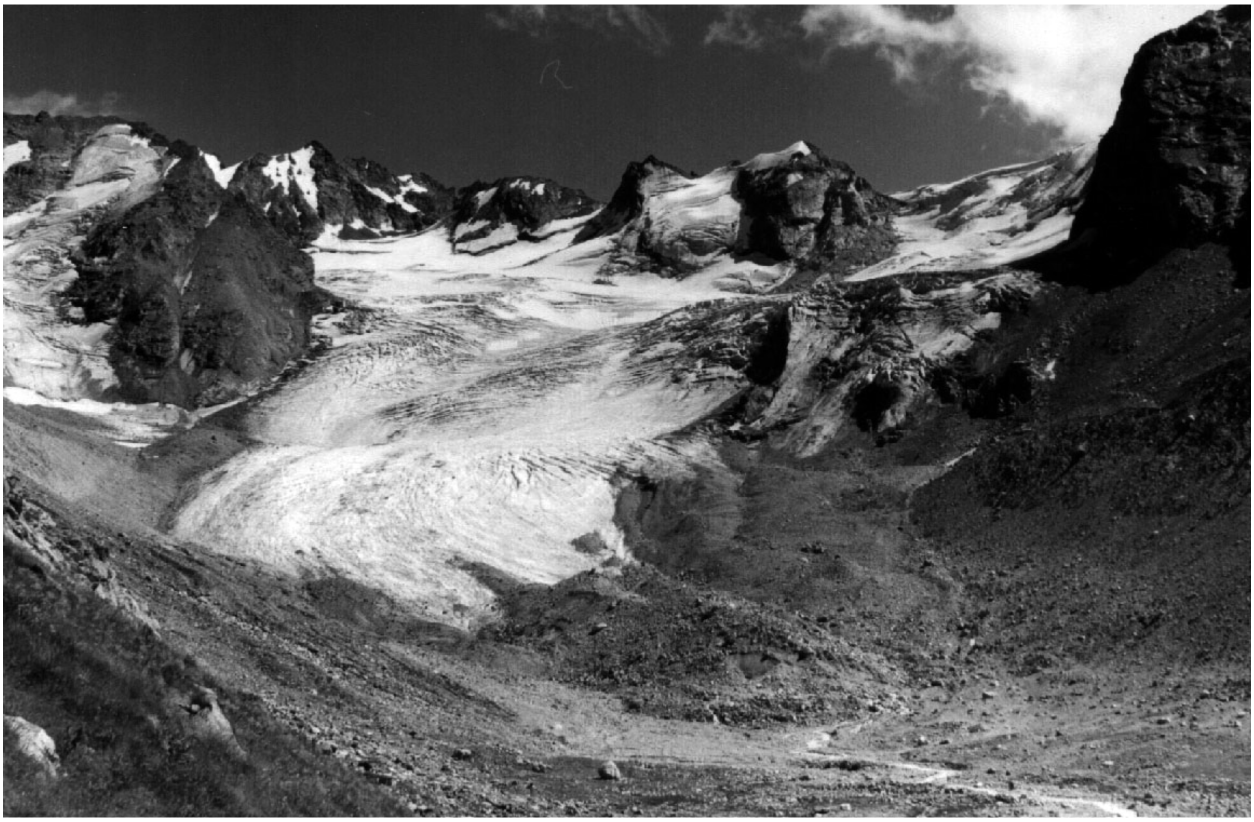
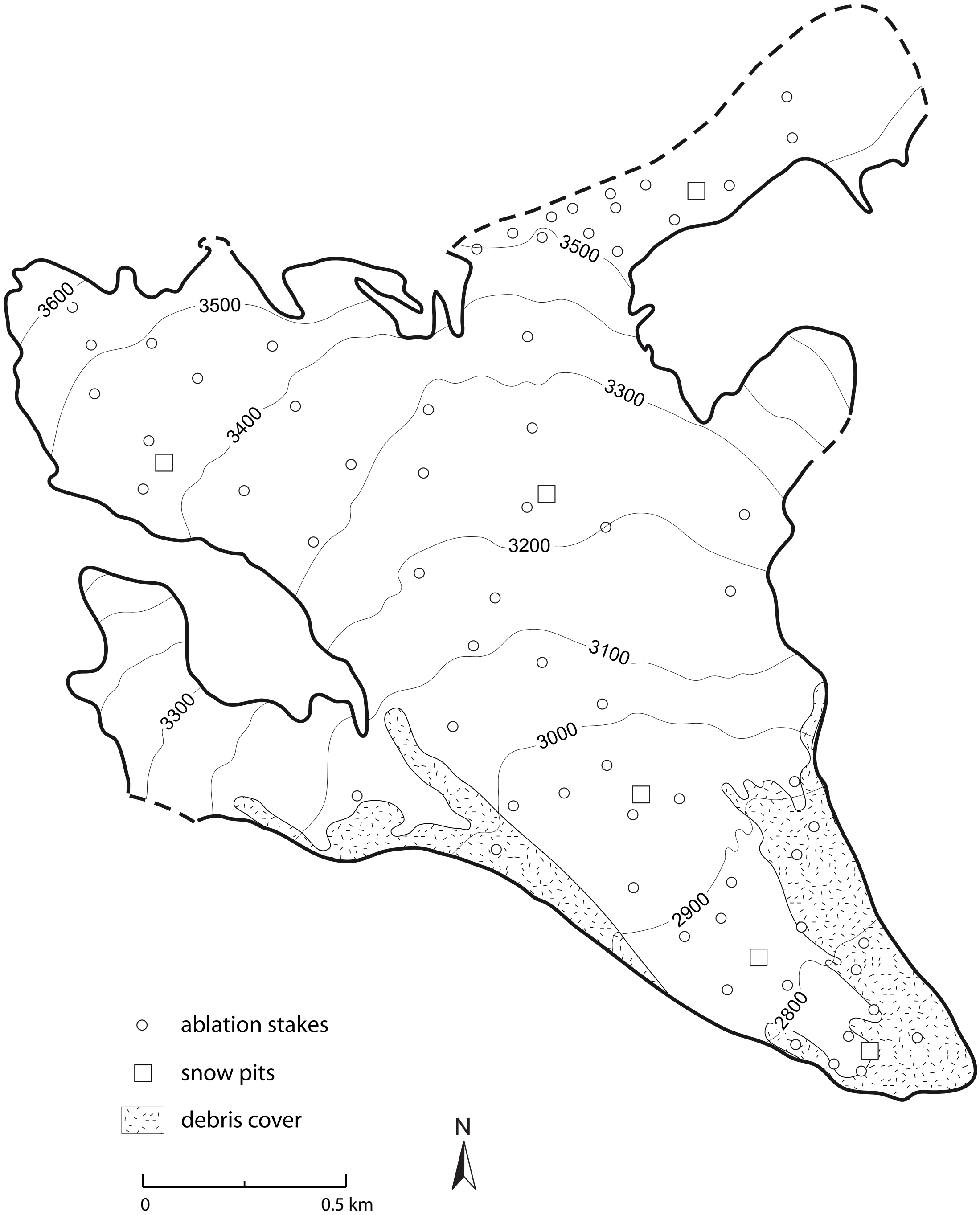


Photo taken by V. Popovnin in August 2001.

The valley-type glacier is located on the northern slope of the central section of the Main Caucasus Ridge and extends from 3750 to 2700 m a.s.l. Its surface area is 3.01 km^2 and the exposure is to the northwest. Mean annual air temperature at the ELA (ca. 3200 m a.s.l. for balanced conditions) is -3 to -4.5 °C and the glacier is temperate. Periglacial permafrost is highly discontinuous. Average annual precipitation as measured near the snout is 1100 to 1200 mm but roughly three times this amount at the ELA. Six 1:10000 topographic maps (from 1968, 1974, 1984, 1992, 1996 and 1999) exist at Moscow State University but are not yet published. The peculiarity of the glacier is the migration of the ice divide on the firn plateau of the crest zone, redistributing mass flux between adjacent slopes of the main ridge.

Both reported years were very much alike. They were favourable for the glacier and were characterized by positive mass balances, like the two previous balance years. Mass gain of +730 and +390 mm w.e., respectively, were cuased mainly by increased winter accumulation: in 2003/04 its value was the second highest throughout the whole observation period since 1968 (32 % anomaly), and 2004/05 took the fourth place (27 %). That year was notable because of the huge snow avalanches, which distorted the accumulation and mass balance spatial pattern considerably. Some avalanche snow patches survived the melt season on the snout. Ablation was slightly below average in 2003/04 and 7 % above in 2004/05. Series of 4 consecutive years (2002-2005) of positive mass balance values followed 4 years of negative ones (1998-2001), but cumulatively they compensated only about half of those losses.

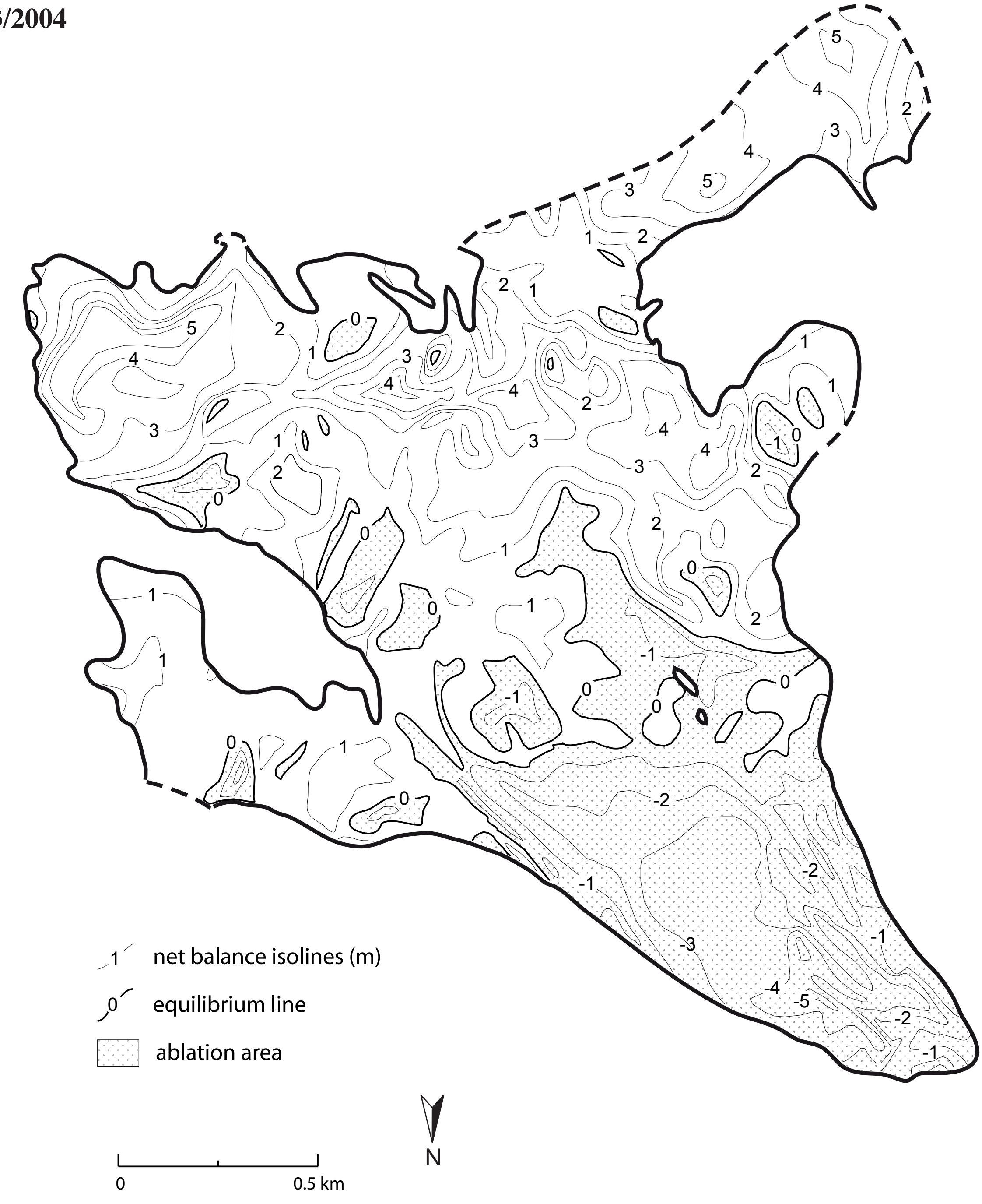
3.12.1 Topography and observation network



Djankuat (RUSSIA)

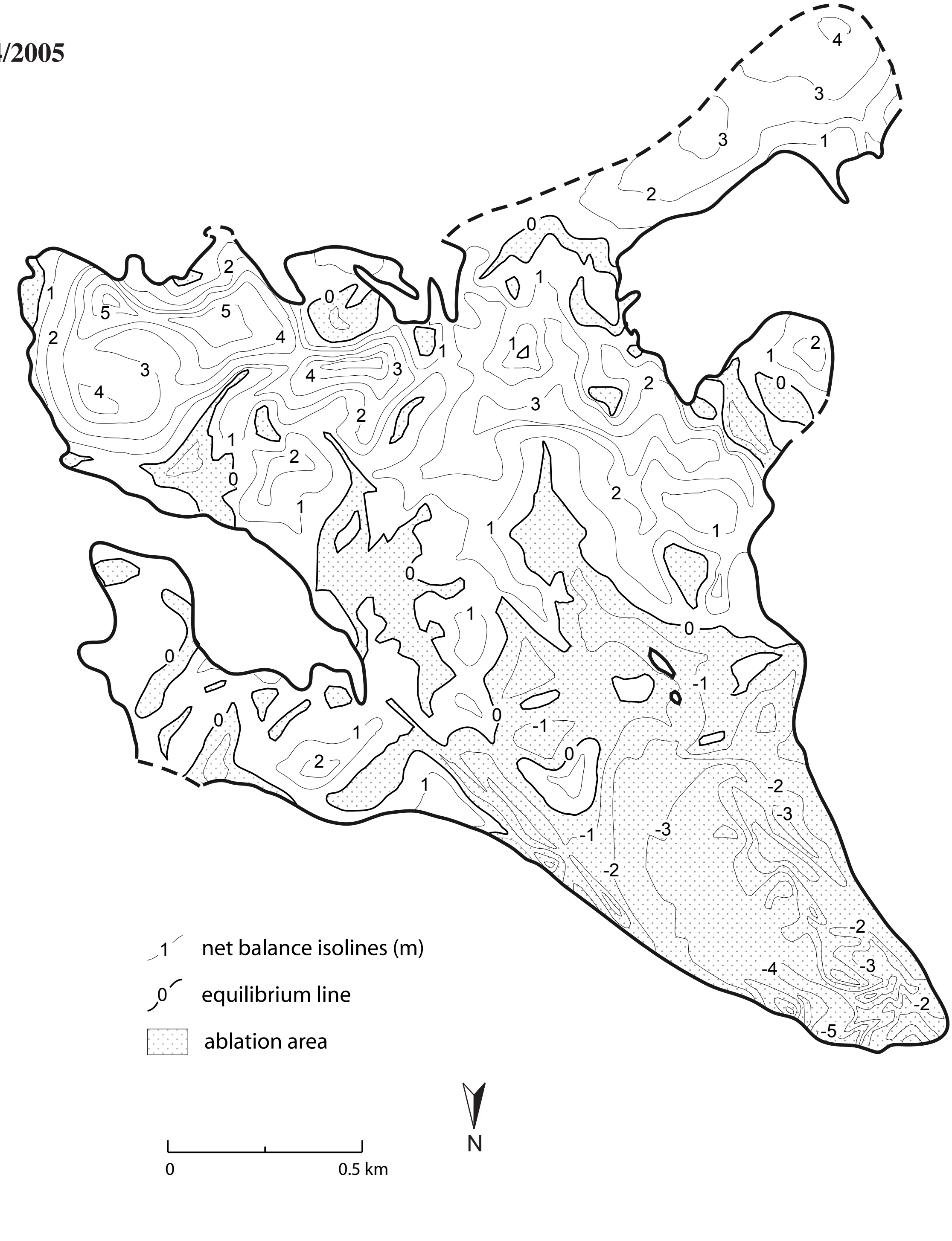
3.12.2 Net balance maps 2003/2004 and 2004/2005

2003/2004



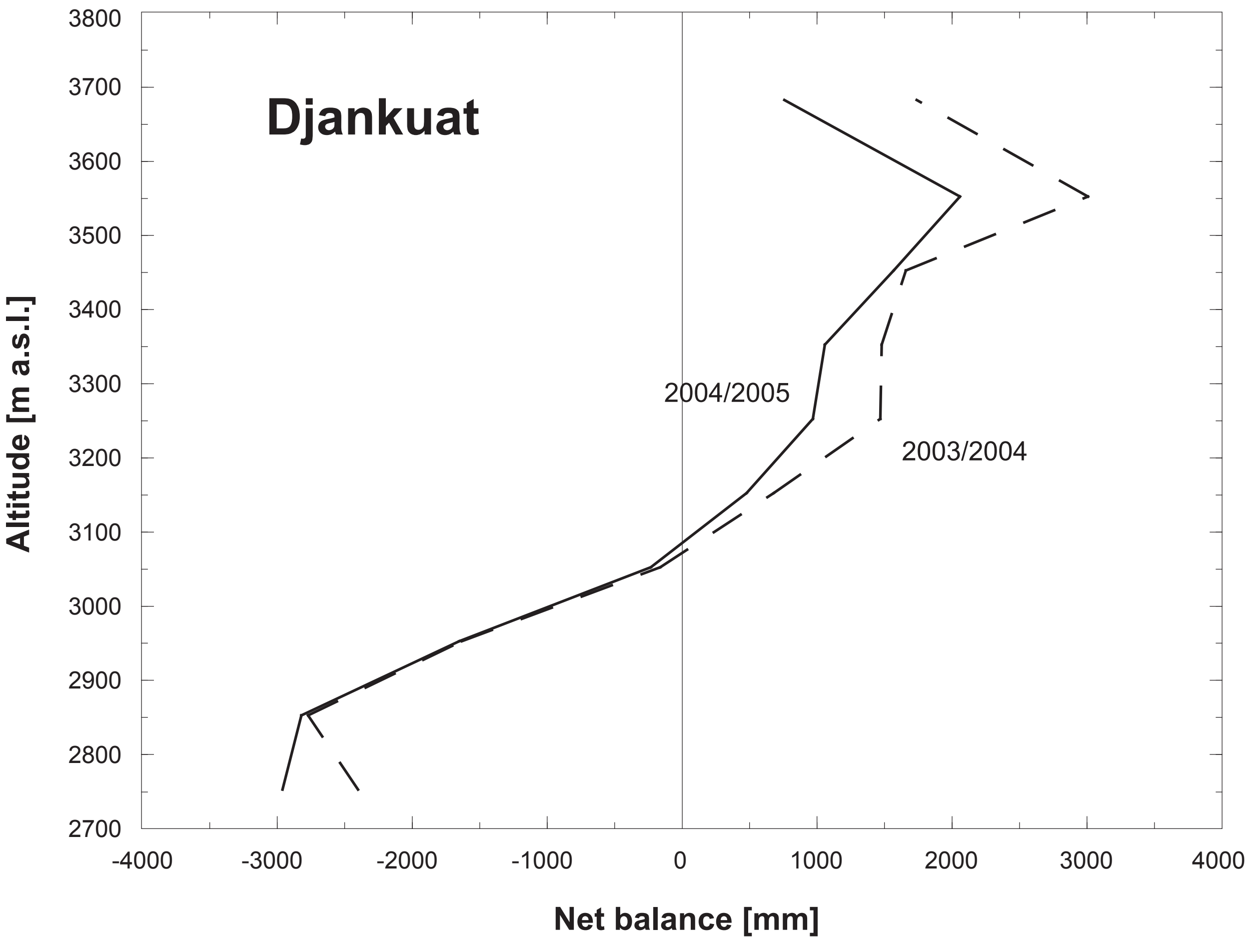
Djankuat (RUSSIA)

2004/2005

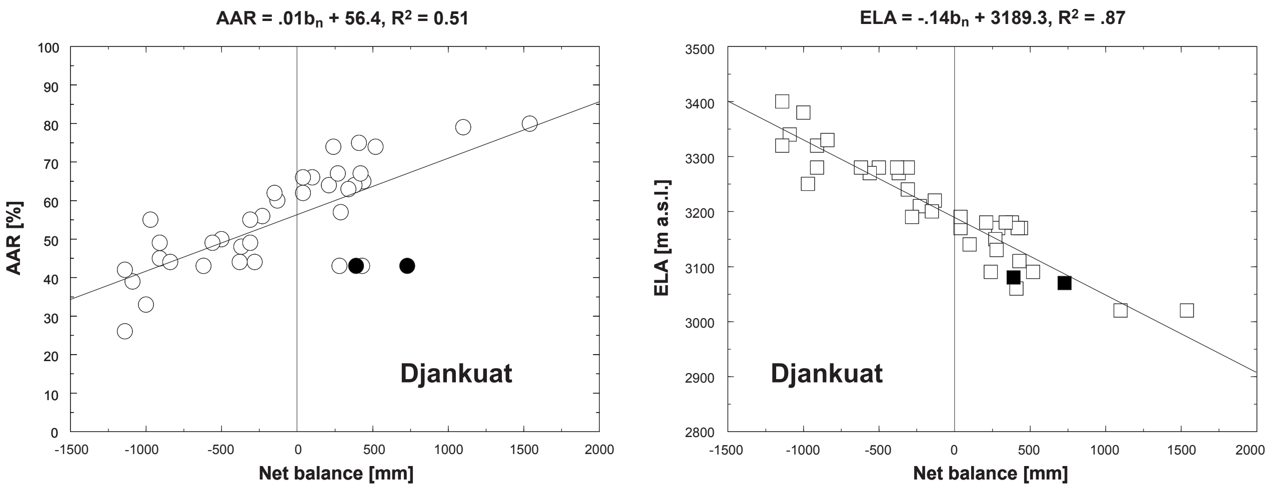


Djankuat (RUSSIA)

3.12.3 Net balance versus altitude (2003/2004 and 2004/2005)



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



3.13 MALIY AKTRU (RUSSIA/ALTAY)

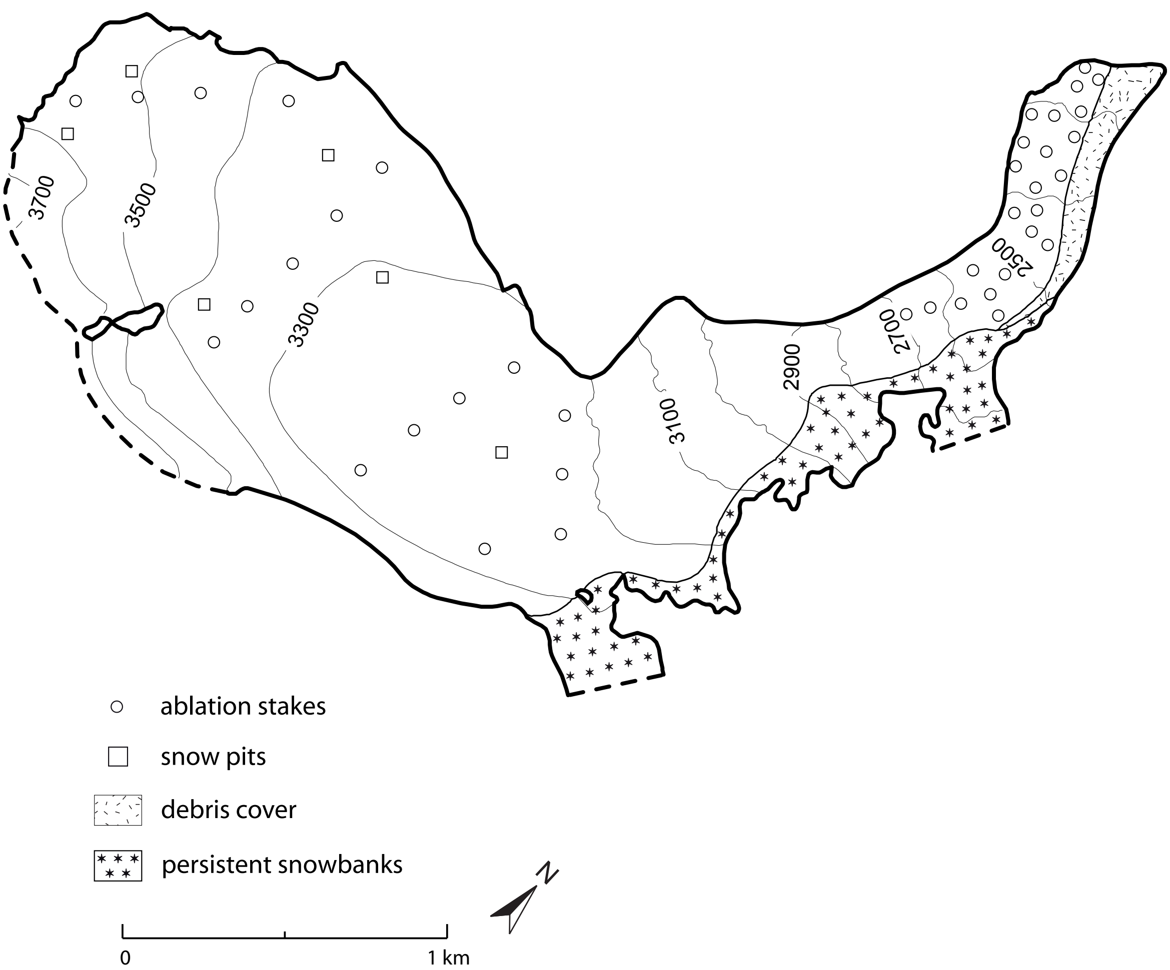
COORDINATES: 50.08 N / 87.75 E

Photo taken by Y.K. Narozhniy, 2nd of July 1992.

The valley-type glacier is located on the northern slope of the North Chuyskiy Range of the Russian Altai Mountains. It extends from 3714 to 2246 m a.s.l., has a surface area of 2.72 km^2 and is exposed to the east and north. It has an average thickness of 90 m (max. 234 m) and its total volume is estimated to be 0.25 km^3. Mean annual air temperature at the equilibrium line of the glacier (around 3160 m a.s.l. for balanced conditions) is -9 to -10 °C. The glacier is polythermal and surrounded by continuous to discontinuous permafrost. Average annual precipitation as measured at 2130 m a.s.l., is about 540 mm. Mass balances of three glaciers within the same basin are being determined.

Weather conditions differed greatly in 2003/04 and 2004/05. The first period was characterized by a warmer summer (+0.4 °C) without any anomaly in precipitation. As a result, accumulation turned out to be close to its long-term norm, ablation was 10 % higher than usual, and total mass loss came to -150 mm w.e. On the contrary, in 2004/05 precipitation was 15 % higher and summer air temperature was 0.3 °C lower than average. Thus, accumulation exceeded and ablation yielded to their norms (by 13 and 10 %, respectively), and mass balance became positive with the absolute value approximately the same as for the previous year. The long (since 1996) period of continuous mass losses was interrupted. The main peculiarity of both years was strongly increased seismic activity in the region: the earthquake began on 27 September 2003 and it is still going on until the present with varying intensity (magnitude fluctuating from 1 to 4). The glacier did not surge, but a number of ice collapses, mainly from the snout, occurred. Frontal retreat accelerated by several multiples and became as high as 10-30 m/year. Snow and ice/snow avalanches as well as short-term floods and small debris flows from the valley slopes became more frequent.

3.13.1 Topography and observation network

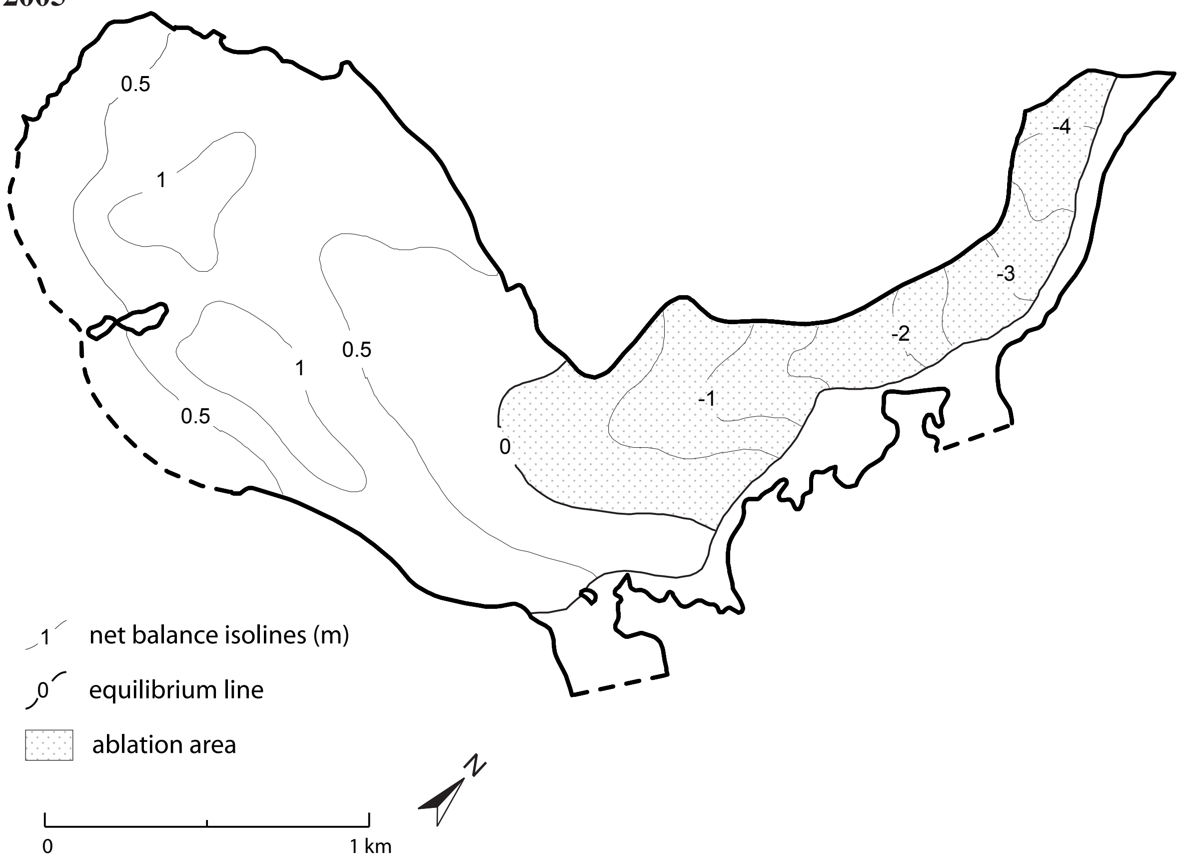


Maliy Aktru (RUSSIA)

3.13.2 Net balance maps 2003/2004 and 2004/2005

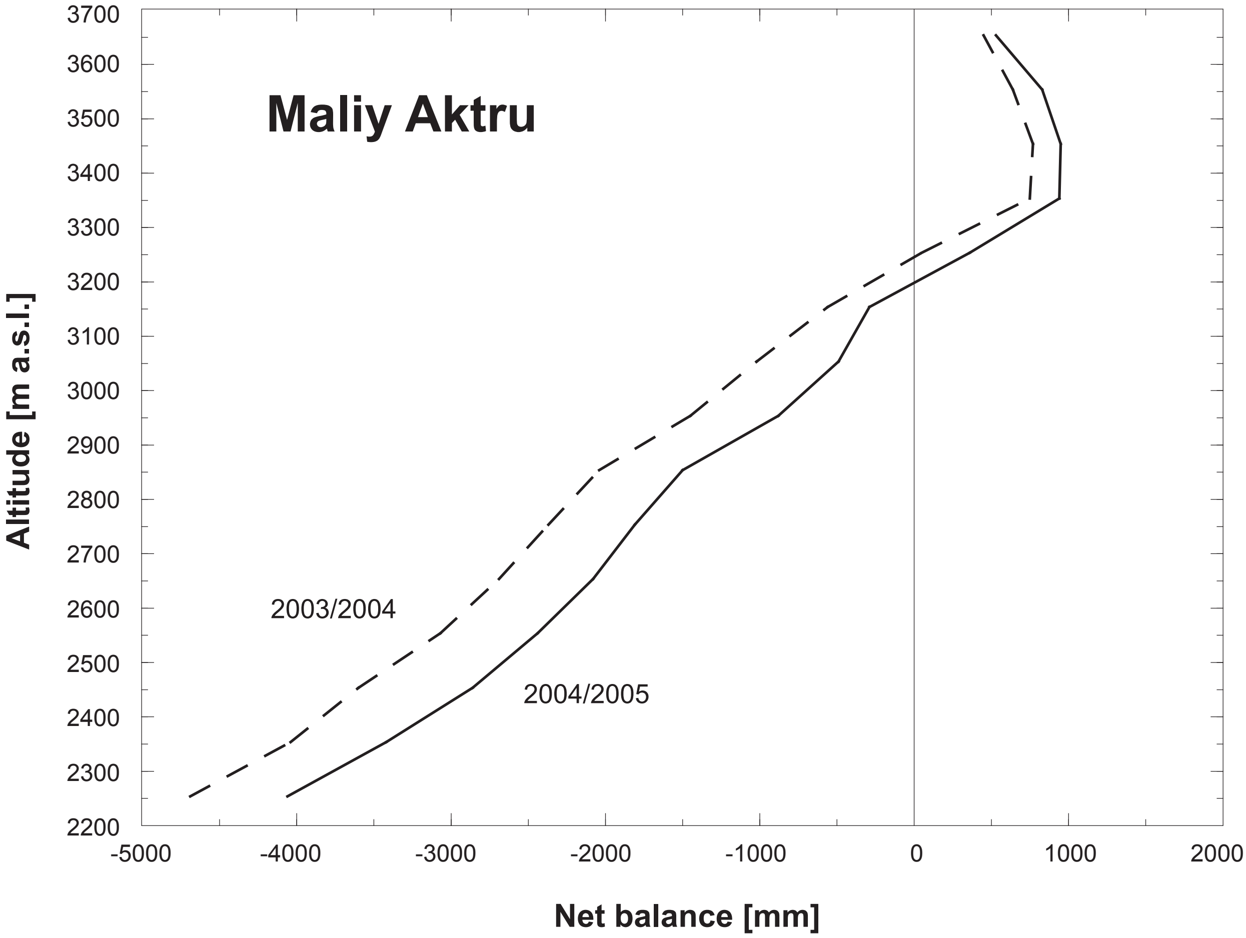
2003/2004

2004/2005

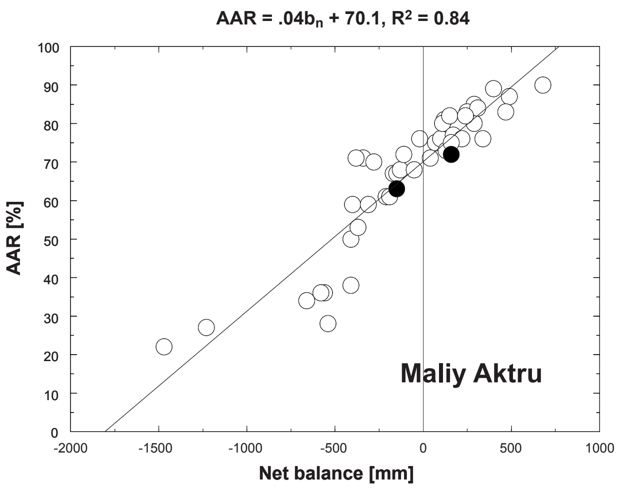


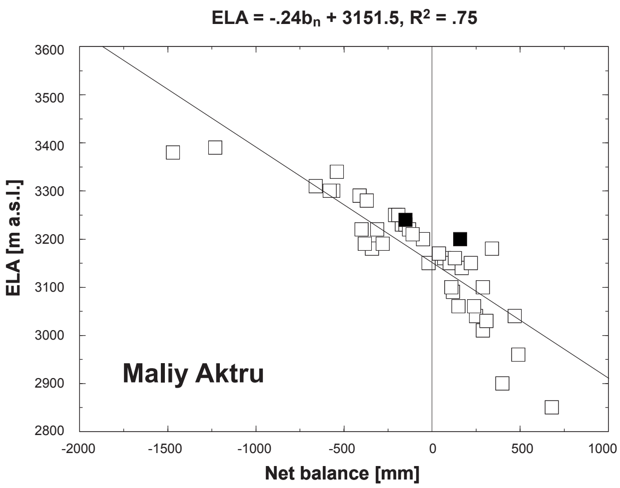
Maliy Aktru (RUSSIA)

3.13.3 Net balance versus altitude (2003/2004 and 2004/2005)



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





4 FINAL REMARKS AND ACKNOWLEDGEMENTS

Continuous mass balance records for the period 1980–2005 are now available for 30 glaciers (29 in 2005) from 9 mountain ranges. Corresponding results from this sample of glaciers in North America, South America and Eurasia are summarized in Table 4.1 (all mm-values in water equivalent):

Table 4.1: Summarized mass balance data. The mean specific (annual) net balance of 30 glaciers averaged for the years 2000–2005 compared to the mean of the annual means of the last 20 years is shown in the upper table. A statistical overview of the 30 glaciers during the two reported years is given in the lower table.

		1980–1999			2000–2005[1)]	
mean specific (annual) net balance	-	286 mm		-	600 mm	
standard deviation of means	±	256 mm		±	404 mm	
minimum mean value	-	712 mm	(1998)	-	1238 mm	(2003)
maximum mean value	+	112 mm	(1983)	-	49 mm	(2000)
range		825 mm			1189 mm	
positive mean balances		15 %			0 %	
positive balances		33 %			22 %	

		2003/2004			2004/2005[1)]	
mean specific (annual) net balance	-	743 mm		-	563 mm	
standard deviation	±	950 mm		±	1042 mm	
minimum value	-	2820 mm	Sarennes	-	3280 mm	Sarennes
maximum value	+	817 mm	Engabreen	+	1098 mm	Nigardsbreen
range		3637 mm			4378 mm	
positive balances		20 %			28 %	

[1)] in 2005, no data were received from Wolverine Glacier (US)

Taking the two reported years together, the mean mass balance was -653 mm w.e. per year. This is two thirds of a meter ice thickness loss per year and more than twice the average of 1980–1999 (-286 mm w.e. or one-third of a meter ice loss per year) but considerably less than the record value (-965 mm w.e. or nearly one meter ice loss per year) reported for the previous two-year time period. Since the turn of the century (2000–2005) the mean mass balance is now –600 mm w.e. (close to the average of the two reported years). During this most recent time interval, the maximum loss of the 1980–1999 time period (-712 mm w.e. in 1998) was already exceeded for the second time (-1238 mm w.e. in 2003, -743 mm w.e. in 2004) and there were only 22 % positive annual balances in comparison with 36 % in the 1980s and 29 % in the 1990s (or 33 % during 1980-1999). The melt rate and loss in glacier thickness continues to be extraordinary. This development further confirms the accelerating trend in worldwide glacier disappearance, which has become more and more obvious during the past two decades.

The mean of all glaciers included in the analysis is strongly 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 9 mountain ranges concerned (Table 4.2). In its general trend and magnitude, this second average closely follows the evolution in time (Figure 4.1) of the straight average as discussed above, and is in good agreement with the results from a moving-sample-averaging of all available data (cf. Kaser et al., 2006).

The evolution with time can be described by means of Figure 4.1:

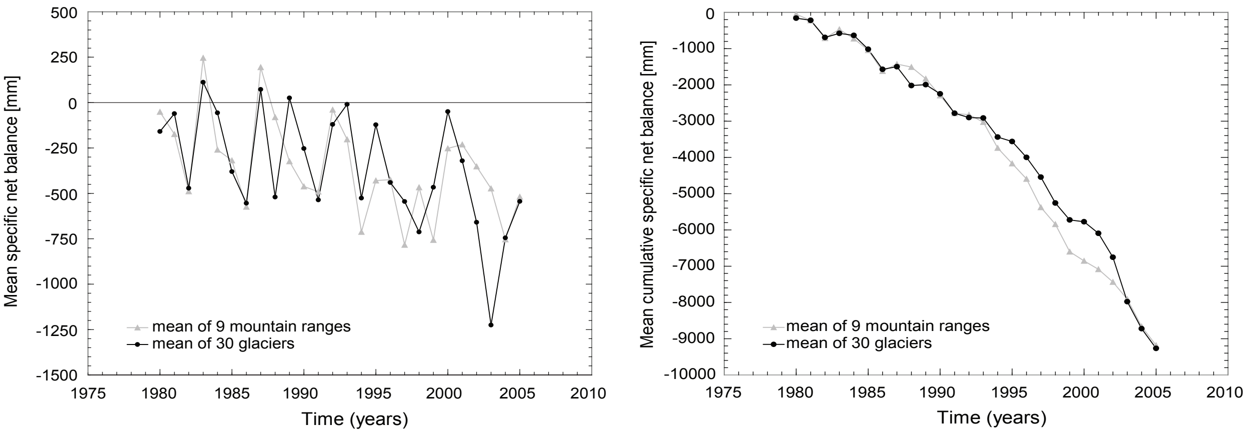


Figure 4.1: Mean specific net balance (left) and mean cumulative specific net balance (right) of 30 (29 in 2005) glaciers and 9 mountain ranges since 1980.

The dynamic response of glaciers to changes in climatic conditions – growth/reduction in area mainly through the advance/retreat of glacier tongues – tends towards an equilibrium condition of ice geometry when the mass balance is zero. 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 indicate trends of climatic forcing. With constant climatic conditions (no forcing), balances would tend towards zero. Long-term non-zero balances are, therefore, an expression of ongoing climate change and continued 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. Many of the relatively small glaciers, measured within the framework of the present 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 might 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 marked 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 than by continental glaciers. For the same reason, the mean balance values calculated above are predominantly influenced by

Table 4.2: Mass balance data for 9 mountain regions 1980–2005

Year	Cascade Mnts.	Alaska	Andes	Svalbard	Scandinavia	Alps	Altai	Caucasus	Tien Shan	Mean
1980	-972	1400	300	-475	-1055	453	-10	380	-483	-51
1981	-967	775	360	-505	194	-28	-213	-910	-271	-174
1982	-337	-245	-2420	-10	-185	-825	-460	420	-338	-489
1983	-606	15	3700	-220	756	-438	197	-970	-220	246
1984	-109	-395	-1240	-705	194	68	307	210	-667	-260
1985	-1541	515	340	-515	-451	-457	200	-380	-581	-319
1986	-1011	-60	-1570	-265	-249	-992	73	-500	-595	-574
1987	-1703	535	950	230	925	-653	183	1540	-258	194
1988	-1305	395	2300	-505	-1215	-626	333	520	-626	-81
1989	-875	-1440	-1260	-345	1911	-886	117	40	-177	-324
1990	-834	-1555	-1300	-585	1196	-1074	107	340	-454	-462
1991	-595	-260	-860	115	80	-1203	-480	-310	-903	-491
1992	-1400	-210	1740	-120	1161	-1161	-127	-130	-109	-39
1993	-1755	-1170	-290	-955	1174	-443	227	1100	287	-203
1994	-1515	-660	-1860	-140	171	-919	-240	-840	-411	-713
1995	-1588	-765	-950	-785	589	-62	60	40	-408	-430
1996	-61	-950	-1180	-75	-643	-414	-140	-150	-207	-424
1997	-129	-2120	-2530	-570	-470	-223	-123	270	-1160	-784
1998	-2155	-135	2890	-725	221	-1614	-1110	-1000	-575	-467
1999	820	-1095	-4260	-350	-123	-621	-113	-560	-511	-757
2000	255	-490	-760	-25	988	-648	-230	-1140	-222	-252
2001	-1165	-120	1810	-405	-787	92	-190	-620	-698	-231
2002	214	-875	80	-550	-1141	-818	-357	430	-151	-352
2003	-1548	-180	2060	-845	-1392	-2453	-363	280	180	-473
2004	-1930	-2285	-570	-1045	-170	-1056	-210	730	-250	-754
2005	-1873	-130	-850	-870	309	-1341	87	390	-392	-519
Mean	-949	-443	-207	-433	77	-706	-95	-32	-392	-353

Cascade Mtns.	Place, South Cascade
Svalbard	Austre Brøggerbreen, Midtre Lovénbreen
Andes	Echaurren Norte
Alaska	Gulkana, Wolverine
Scandinavia	Engabreen, Ålfotbreen, Nigardsbreen, Gråsubreen, Storbreen, Hellstugubreen, Hardangerjøkulen, Storglaciären
Alps	Saint Sorlin, Sarennes, Silvretta, Gries, Sonnblickkees, Vernagtferner, Kesselwandferner, Hintereisferner, Caresèr
Altai	No. 125 (Vodopadniy), Maliy Aktru, Leviy Aktru
Caucasus	Djankuat
Tien Shan	Ts. Tuyuksuyskiy, Urumqihe S. No. 1

maritime glaciers than by continental ones. Maritme glacier 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.

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. By building up over extended time periods, such as a century, the mass balance/

altitude-feedback can, indeed, equal the result from pure atmospheric forcing when combined with albedo effects (e.g., Oerlemans 2001). 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 may, however, increasingly replace processes of tongue retreat with processes of downwasting, coupled with enhanced feedbacks from albedo and balance/altitude effects (Paul et al., 2007). 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 (cf. Haeberli, 2006).

Modern concepts of internationally coordinated glacier monitoring, within the framework of the Global Terrestrial Observing System (GTOS) and as part of global climate-related monitoring (GCOS) enable the integration of data from mass balance, length/area/volume changes and mostly satellite-based glacier inventory data. For the European Alps, for instance, annual losses in overall glacier volume can be estimated at about -0.5 % between 1850 and the 1970s, then at about -1 % until the turn of the century and now -2 to -3 % for the first years of the new millennium (Haeberli et al., 2007). Zemp et al. (2007) provide a global overview, based on similar, though often less detailed, information.

Completion of the present Glacier Mass Balance Bulletin was made possible through the cooperation of the national correspondents to WGMS and the principal investigators of the various glaciers, as listed in Chapter 5. Thanks are due to the Rachel Carr, Luzia Fischer, Susanna Hoinkes, Eva Huintjes, Björn Kröger and Bruno Seiler for their assistance with data collection and editing of this issue, and to Susan Braun for carefully editing the English. Funding is mainly through the WGMS Bridging Credit of the Swiss National Science Foundation and the Department of Geography at the University of Zurich with contributions by GCOS/WMO, FAGS/ICSU, DEWA/UNEP, Federal Office for the Environment (FOEN) and by the Cryospheric Commission of the Swiss Academy of Sciences.

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