GLACIER MASS BALANCE BULLETIN

Bulletin No. 8 (2002–2003)

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)

IUGG (CCS) – UNEP – UNESCO – WMO

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wgms

Edited by

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The cover page shows Tsentralniy Tuyuksuyskiy in the Zailiyskiy Alatau Range of the Kazakh Tien Shan. Photo taken by V.P. Blagoveshchenskiy in September 2003.

PREFACE

Past and present glacier fluctuations provide important information on the ranges of natural variability and rates of change in respect of long-term energy fluxes at the earth's surface. The spectacular losses in length, area and volume of mountain glaciers during the 20th century are a major reflection of the fact that rapid secular change in the energy balance of the earth's surface is taking place on a global scale. The historical beginning of this tendency to rapid secular glacier retreat was probably little affected by human activity. The observed evolution may, however, contain an increasing amount of anthropogenic influence. The recent shrinking of glaciers now, for the first time, coincides with a man-induced climate forcing which could be responsible for a major part of the additional energy flux responsible for the observed melt rate. The characteristic value of this melt rate (on average a few decimetres of ice depth lost per year or a few W/m^2 for the corresponding exchange in latent heat) is broadly consistent with the estimated radiative forcing and changes in sensible heat as calculated by numerical climate models. In order to further document the evolution and to clarify the physical processes and relationships involved, the World Glacier Monitoring Service (WGMS) of the Union Commission on Cryospheric Sciences (CCS/IUGG; former International Commission on Snow and Ice, ICSI/IAHS) 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 the GCOS/GTOS Plan for Terrestrial Climate-related Observation (GCOS 32, version 2.0, WMO/TD-796, UNEP/DEIA/TR, 97-7) clearly recognise 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 about 60 glaciers, 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. In accordance with an agreement made with the countries involved, mass balance values for selected glaciers are now made available one year after the end of the measurement year 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)

The present Glacier Mass Balance Bulletin reporting the results of the balance years 2001/2002 and 2002/2003 is the eighth 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. Corrected and updated information can be found in the Fluctuations of Glaciers series.

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

Zurich, Spring 2005

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 85 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 analysing 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 from which data has been 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 85 glaciers of which basic information for the years 2002 and 2003 is reported. Additionally, 23 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	2002/2003	Antarctica	Antarctic Peninsula	63.82 S	57.43 W
2	Martial Este	2000/2003	Argentina	Andes Fueguinos	54.78 S	68.40 W
3	Filleckkess	1964/1980	Austria	E Alps	47.13 N	12.60 E
4	Hintereisferner	1953/2003	Austria	E Alps	46.80 N	10.77 E
5	Jamtalferner	1989/2003	Austria	E Alps	46.87 N	10.17 E
6	Kesselwandferner	1953/2003	Austria	E Alps	46.84 N	10.79 E
7	Sonnblickkees	1959/2003	Austria	E Alps	47.13 N	12.60 E
8	Vernagtferner	1965/2003	Austria	E Alps	46.88 N	10.82 E
9	Wurtenkees	1983/2003	Austria	E Alps	47.04 N	13.01 E
10	Chacaltaya	1992/2003	Bolivia	Tropical Andes	16.35 S	68.12 W
11	Charquini Sur	2003/2003	Bolivia	Tropical Andes	16.17 S	68.09 W
12	Zongo	1992/2003	Bolivia	Tropical Andes	16.25 S	68.17 W
13	Baby Glacier	1960/1992	Canada	High Arctic	79.43 N	90.97 W
14	Devon Ice Cap	1961/2000	Canada	High Arctic	75.42 N	83.25 W
15	Helm	1975/2003	Canada	Coast Mountains	49.97 N	123.00 W
16	Meighen Ice Cap	1976/2000	Canada	High Arctic	79.95 N	99.13 W
17	Peyto	1966/2003	Canada	Rocky Mountains	51.67 N	116.53 W
18	Place	1965/2003	Canada	Coast Mountains	50.43 N	122.60 W
19	Sentinel	1966/1989	Canada	Coast Mountains	49.90 N	122.98 W
20	White	1960/2003	Canada	High Arctic	79.45 N	90.67 W

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
21	Echaurren Norte	1976/2003	Chile	Central Andes	33.10 S	70.53 W
22	Urumqihe S. No. 1	1959/2003	China	Tien Shan	43.08 N	86.82 E
23	Antizana 15 alpha	1995/2003	Ecuador	E Cordillera	0.47 S	78.15 W
24	Saint Sorlin	1957/2003	France	W Alps	45.17 N	06.15 E
25	Sarennes	1949/2003	France	W Alps	45.14 N	06.14 E
26	Breidamerkurjökull	1998/2003	Iceland	SE Iceland	64.22 N	16.33 W
27	Brúarjökull	1994/2003	Iceland	E Iceland	64.67 N	16.17 W
28	Eyjabakkajökull	1994/2003	Iceland	E Iceland	64.65 N	15.58 W
29	Hofsjökull East	1989/2003	Iceland	Central Iceland	64.80 N	18.58 W
30	Hofsjökull North	1988/2003	Iceland	Central Iceland	64.95 N	18.92 W
31	Hofsjökull Southwest	1990/2003	Iceland	Central Iceland	64.72 N	19.05 W
32	Koldukvislarjökull	1995/2003	Iceland	Central Iceland	64.58 N	17.83 W
33	Langjökull, S dome	1997/2003	Iceland	Central Iceland	64.62 N	20.30 W
34	Tungnaárjökull	1994/2003	Iceland	Central Iceland	64.32 N	18.07 W
35	Caresèr	1967/2003	Italy	Central Alps	46.45 N	10.70 E
36	Ciardoney	1992/2003	Italy	W Alps	45.52 N	07.40 E
37	Fontana Bianca	1983/2003	Italy	Central Alps	46.48 N	10.77 E
38	Pendente	1996/2003	Italy	Central Alps	46.97 N	11.24 E
39	Hamaguri Yuki	1981/2000	Japan	N Japan Alps	36.60 N	137.62 E
40	Igli Tuyuksu	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
41	Manshuk Mametov	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
42	Mayakovskiy	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
43	Molodezhniy	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
44	Ordzhonikidze	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
45	Partizan	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
46	Shumskiy	1967/1991	Kazakhstan	Dzhungarskiy	45.08 N	80.23 E
47	Ts. Tuyuksuyskiy	1957/2003	Kazakhstan	Tien Shan	43.05 N	77.08 E
48	Visyachiy-1-2	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
49	Zoya Kosmodemya	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
50	Lewis	1979/1996	Kenya	E Africa	0.15 S	37.30 E
51	Abramov	1968/1998	Kyrgyzstan	Pamir Alai	39.63 N	71.60 E
52	Golubin	1969/1994	Kyrgyzstan	Tien Shan	42.47 N	74.50 E
53	Kara-Batkak	1957/1998	Kyrgyzstan	Tien Shan	42.10 N	78.30 E

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
54	Ålfotbreen	1963/2003	Norway	W Norway	61.75 N	05.65 E
55	Austdalsbreen	1987/2003	Norway	W Norway	61.80 N	07.35 E
56	Austre Brøggerbreen	1967/2003	Norway	Spitsbergen	78.88 N	11.83 E
57	Breidalblikkbrea	2003/2003	Norway	SW Norway	60.10 N	06.40 E
58	Engabreen	1970/2003	Norway	N Norway	66.65 N	13.85 E
59	Gråfjelsbrea	2003/2003	Norway	SW Norway	60.10 N	06.40 E
60	Gråsubreen	1962/2003	Norway	S Norway	61.65 N	08.60 E
61	Hansbreen	1989/2003	Norway	Spitsbergen	77.08 N	15.67 E
62	Hansebreen	1986/2003	Norway	W Norway	61.75 N	05.68 E
63	Hardangerjøkulen	1963/2003	Norway	Central Norway	60.53 N	07.37 E
64	Hellstugubreen	1962/2003	Norway	S Norway	61.57 N	08.43 E
65	Irenebreen	2002/2003	Norway	Spitsbergen	78.40 N	12.05 E
66	Kongsvegen	1987/2003	Norway	Spitsbergen	78.80 N	12.98 E
67	Langfjordjøkelen	1989/2003	Norway	N Norway	70.12 N	21.77 E
68	Midre Lovénbreen	1968/2003	Norway	Spitsbergen	78.88 N	12.07 E
69	Nigardsbreen	1962/2003	Norway	W Norway	61.72 N	07.13 E
70	Rundvassbreen	2002/2003	Norway	N Norway	67.30 N	16.10 E
71	Storbreen	1949/2003	Norway	Central Norway	61.57 N	08.13 E
72	Storglombreen	1985/2003	Norway	N Norway	66.67 N	14.00 E
73	Waldemarbreen	1995/2003	Norway	Spitsbergen	78.67 N	12.00 E
74	Djankuat	1968/2003	Russia	N Caucasus	43.20 N	42.77 E
75	Garabashi	1984/2003	Russia	N Caucasus	43.30 N	42.47 E
76	Kozelskiy	1973/1997	Russia	Kamchatka	53.23 N	158.82 E
77	Leviy Aktru	1977/2003	Russia	Altay	50.08 N	87.72 E
78	Maliy Aktru	1962/2003	Russia	Altay	50.08 N	87.75 E
79	No. 125 (Vodopadniy)	1977/2003	Russia	Altay	50.10 N	87.70 E
80	Maladeta	1992/2003	Spain	Pyrenées	42.65 N	00.64 E
81	Mårmaglaciären	1990/2003	Sweden	N Sweden	68.83 N	18.67 E
82	Rabots glaciär	1982/2003	Sweden	N Sweden	67.90 N	18.55 E
83	Riukojietna	1986/2003	Sweden	N Sweden	68.08 N	18.08 E
84	Storglaciären	1946/2003	Sweden	N Sweden	67.90 N	18.57 E
85	Basòdino	1992/2003	Switzerland	W Alps	46.42 N	08.48 E
86	Gries	1962/2003	Switzerland	W Alps	46.44 N	08.34 E
87	Limmern	1948/1985	Switzerland	W Alps	46.82 N	08.98 E
88	Plattalva	1948/1989	Switzerland	W Alps	46.83 N	08.98 E
89	Silvretta	1960/2003	Switzerland	E Alps	46.85 N	10.08 E
90	Blue Glacier	1956/1999	USA	Olympic Mtns.	47.82 N	123.68 W
91	Columbia (2057)	1986/2003	USA	N Cascade Mtns.	47.97 N	121.35 W
92	Daniels	1986/2003	USA	N Cascade Mtns.	47.57 N	121.17 W

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
93	Easton	1990/2003	USA	N Cascade Mtns.	48.75 N	120.83 W
94	Emmons	2003/2003	USA	Mount Rainier	46.85 N	121.72 W
95	Foss	1986/2003	USA	N Cascade Mtns.	47.55 N	121.20 W
96	Gulkana	1966/2003	USA	Alaska Range	63.25 N	145.42 W
97	Ice Worm	1986/2003	USA	N Cascade Mtns.	47.55 N	121.17 W
98	Lower Curtis	1986/2003	USA	N Cascade Mtns.	48.83 N	121.62 W
99	Lynch	1986/2003	USA	N Cascade Mtns.	47.57 N	121.18 W
100	Nisqually	2003/2003	USA	Mount Rainier	46.82 N	121.74 W
101	Noisy Creek	1993/2003	USA	N Cascade Mtns.	48.67 N	121.53 W
102	North Klawatti	1993/2003	USA	N Cascade Mtns.	48.57 N	121.09 W
103	Rainbow	1986/2003	USA	N Cascade Mtns.	48.80 N	121.77 W
104	Sandalee	1995/2003	USA	N Cascade Mtns.	48.41 N	120.79 W
105	Silver	1993/2003	USA	N Cascade Mtns.	48.97 N	121.24 W
106	South Cascade	1953/2003	USA	N Cascade Mtns.	48.37 N	121.05 W
107	Wolverine	1966/2003	USA	Kenai Mtns.	60.40 N	148.92 W
108	Yawning	1986/2003	USA	N Cascade Mtns.	48.45 N	121.03 W

[1)] Note: Glaciers are new listed in alphabetical order
[2)] Years of first and most recent survey available to the WGMS
[3)] Note: Coordinates new in decimal notation

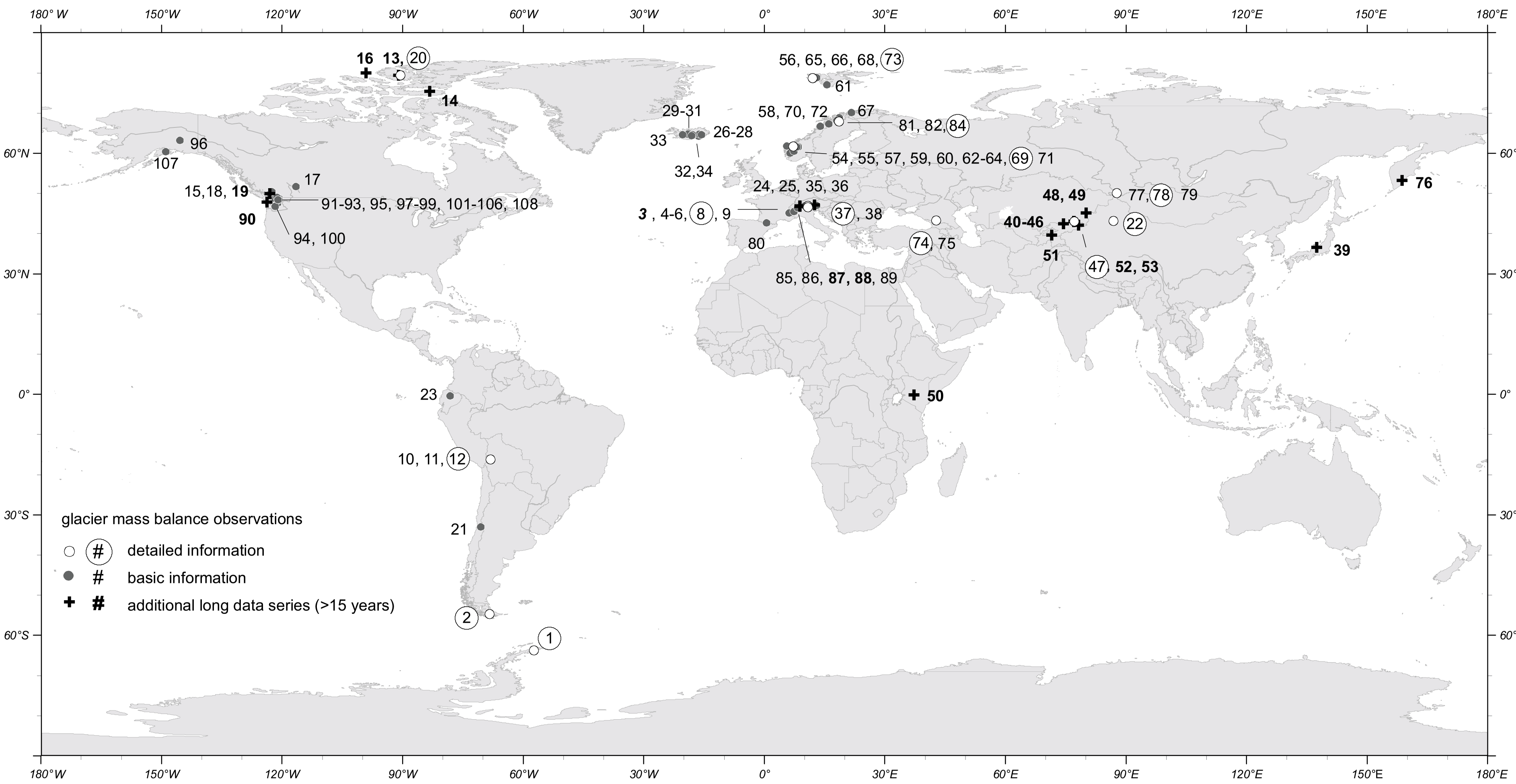


Figure 1.1: Location of the 85 glaciers of which basic information is reported. Additionally, 23 glaciers with long measument series are marked (i.e. 15 or more years).

2 BASIC INFORMATION

Specific net balance (b), equilibrium line altitude (ELA) and accumulation area ratio (AAR) from the balance years 2001/02 and 2002/03 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 6 ELA or AAR values. In extreme years some of the observed glaciers can become entirely ablation or accumulation areas, respectively. 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 calculated and the years 2001/02 and 2002/03 are included.

2.1 SUMMARY TABLE (NET BALANCE, ELA, ELA0, AAR, AAR0)

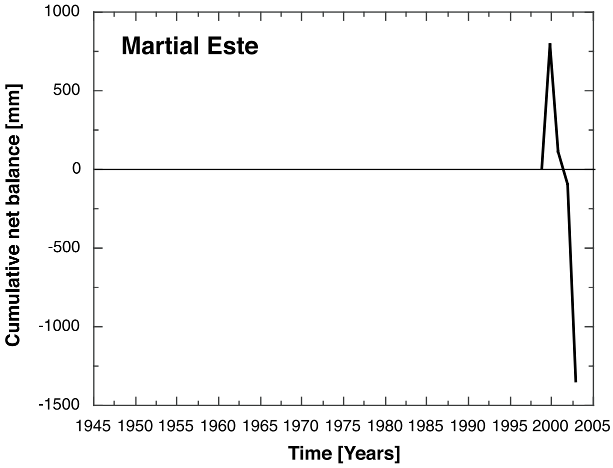
Name	Country	b02 [mm]	b03 [mm]	ELA02 [m a.s.l.]	ELA03 [m a.s.l.]	ELA0 [m a.s.l.]	AAR02 [%]	AAR03 [%]	AAR0 [%]
Bahía del Diablo	Antarctica	- 510	- 150	440	410	—	30	40	—
Martial Este	Argentina	- 202	- 1256	1195	1140	—	40	0	—
Hintereisferner	Austria	- 647	- 1814	3050	>3750 1)	2977	51	3	56
Jamtalferner	Austria	- 671	- 2229	2910	–	2756	28	0	60
Kesselwandferner	Austria	+ 17	- 1546	3120	>3500 1)	3118	75	0	69
Sonnblickkees	Austria	- 485	- 2870	2845	3080	2753	35	1	56
Vernagtferner	Austria	- 266	- 2133	3120	>3600 1)	3081	53	0	66
Wurtenkees	Austria	- 966	- 2177	3020	3070	2884	20	3	38
Chacaltaya	Bolivia	- 1827	- 507	5518	5329	5237	0	6	44
Charquini Sur	Bolivia	—	- 883	—	5170	—	—	40	—
Zongo	Bolivia	0	- 100	5246	5137	5233	64	80	67
Helm	Canada	- 2544	- 1895	>2150 1)	>2150 1)	2002	0	0	39
Peyto	Canada	- 500	- 1370	2688	>3190 1)	2610	37	0	53
Place	Canada	- 123	- 995	2070	>2610 1)	2081	38	0	49
White	Canada	+ 32	- 106	848	1120	901	80	58	72
Echaurren Norte	Chile	+ 80	+ 2060	—	—	—	—	—	—
Urumqihe S. No. 1	China	- 834	- 384	4141	4074	4025	35	38	55
Antizana 15 alpha	Ecuador	- 769	- 1362	5145	5225	5030	50	42	72
Saint Sorlin	France	- 1690	- 2950	3003	—	2881	—	—	—
Sarennes	France	- 2320	- 3140	—	—	—	—	—	—
Breidamerkurjökull	Iceland	- 976	- 900	1120	1010	—	52	58	—
Brúarjökull	Iceland	+ 143	- 460	1220	1220	1206	59	59	59
Eyjabakkajökull	Iceland	- 1090	- 1095	1120	1170	1065	45	35	57
Hofsjökull East	Iceland	- 640	- 1210	1250	1320	1175	43	35	53
Hofsjökull North	Iceland	- 960	- 1270	1340	1420	1264	38	33	50
Hofsjökull Southwest	Iceland	- 640	- 1170	1320	1340	1263	51	47	44
Koldukvislarjökull	Iceland	- 280	- 1120	1375	1425	1300	54	51	59
Langjökull, S dome	Iceland	- 1656	- 1946	1100	1120	989	28	23	55
Tungnaárjökull	Iceland	- 1300	- 1300	1300	1300	1132	41	41	64
Caresèr	Italy	- 1217	- 3316	3280	3691	3099	2	0	37
Ciardoney	Italy	- 400	- 3000	3070	>3150 1)	2977	30	0	56
Fontana Bianca	Italy	- 435	- 2950	>3400 1)	>3400 1)	3320	9	0	55
Pendente	Italy	- 1294	- 2074	>3110 1)	2801	2864	0	61	36
Ts. Tuyuksuyskiy	Kazakhstan	- 300	+ 360	3820	3750	3744	35	52	53
Ålfotbreen	Norway	- 1530	- 2510	>1382 1)	>1382 1)	1189	0	0	54
Austdalsbreen	Norway	- 2010	- 2340	>1757 1)	>1757 1)	1427	0	0	64
Austre Brøggerbreen	Norway	- 580	- 900	465	528	281	5	1	53
Breidalblikkbrea	Norway	—	- 2270	—	>1659 1)	—	—	0	—
Engabreen	Norway	- 590	- 600	1200	1195	1157	54	55	59

Name	Country	b02 [mm]	b03 [mm]	ELA02 [m a.s.l.]	ELA03 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR02 [%]	AAR03 [%]	AAR_0 [%]
Gråfjelsbrea	Norway	—	- 2170	—	>1659 [1)]	—	—	0	—
Gråsubreen	Norway	- 1420	- 1390	—	—	2131	0	0	30
Hansbreen	Norway	- 600	- 560	380	380	293	25	25	55
Hansebreen	Norway	- 1930	- 2670	>1327 [1)]	>1327 [1)]	1152	0	0	58
Hardangerjøkulen	Norway	- 710	- 1360	1750	>1860 [1)]	1671	47	0	67
Hellstugubreen	Norway	- 1410	- 1530	2080	>2200 [1)]	1848	7	0	56
Irenebreen	Norway	- 613	- 630	380	420	—	29	25	—
Kongsvegen	Norway	- 220	- 350	589	608	539	31	25	49
Langfjordjøkelen	Norway	- 1540	- 1070	>1050 [1)]	>1050 [1)]	715	0	0	64
Midre Lovénbreen	Norway	- 520	- 790	436	517	299	9	1	58
Nigardsbreen	Norway	- 890	- 1160	1715	>1960 [1)]	1557	25	0	60
Rundvassbreen	Norway	- 1050	- 1070	1320	1360	—	40	28	—
Storbreen	Norway	- 1780	- 1570	>2100 [1)]	2025	1724	0	2	58
Storglombreen	Norway	- 1230	- 1100	>1580 [1)]	>1580 [1)]	1114	0	0	60
Waldemarbreen	Norway	- 514	- 727	390	430	389	20	14	22
Djankuat	Russia	+ 430	+ 280	3110	3130	3192	69	67	60
Garabashi	Russia	+ 260	+ 160	3760	3810	3793	67	61	60
Leviy Aktru	Russia	- 370	- 400	3260	3260	3157	56	56	61
Maliy Aktru	Russia	- 410	- 370	3290	3280	3148	50	53	70
No. 125 (Vodopadniy)	Russia	- 290	- 320	3250	3260	3203	66	64	69
Maladeta	Spain	- 811	- 1102	3142	>3200 [1)]	3061	10	0	39
Mårmaglaciären	Sweden	- 660	- 1420	1643	1663	1595	15	6	34
Rabots glaciär	Sweden	- 880	- 1440	1508	1720	1368	14	1	51
Riukojietna	Sweden	- 1830	- 1780	>1460 [1)]	>1460 [1)]	1339	0	0	53
Storglaciären	Sweden	- 830	- 1040	1496	1582	1462	37	29	45
Basòdino	Switzerland	- 356	- 2043	2880	3300	2884	50	0	49
Gries	Switzerland	- 600	- 2630	2975	3310	2861	45	0	56
Silvretta	Switzerland	- 240	- 1674	2809	3019	2776	45	5	52
Columbia (2057)	USA	+ 600	- 1170	—	—	—	86	23	—
Daniels	USA	- 180	- 1520	—	—	—	64	21	—
Easton	USA	+ 180	- 980	—	—	—	74	46	—
Emmons	USA	—	- 2822	—	3425	—	—	11	—
Foss	USA	+ 100	- 1350	—	—	—	70	25	—
Gulkana	USA	- 1060	- 20	1833	1718	1727	53	67	63
Ice Worm	USA	+ 50	- 1400	—	—	—	72	0	—
Lower Curtis	USA	+ 130	- 1250	—	—	—	68	55	—
Lynch	USA	- 130	- 1200	—	—	—	65	38	—
Nisqually	USA	—	- 2379	—	4075	—	—	11	—
Noisy Creek	USA	+ 462	+ 448	1750	1920	1801	86	0	61
North Klawatti	USA	+ 224	- 1367	2100	2400	2099	72	0	69
Rainbow	USA	+ 120	- 980	—	—	—	73	45	—
Sandalee	USA	+ 752	- 1155	2200	>2350 [1)]	2190	90	0	45
Silver	USA	- 147	- 1421	2340	2400	2259	54	37	55
South Cascade	USA	+ 550	- 2100	1820	>2125 [1)]	1887	84	7	50
Wolverine	USA	- 690	- 340	1193	1176	1151	62	63	63
Yawning	USA	+ 260	- 1850	—	—	—	77	10	—

[1)] Above glacier maximum elevation

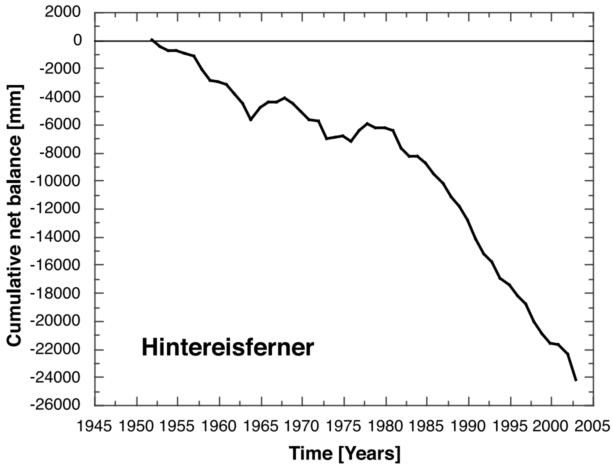
2.1 CUMULATIVE SPECIFIC NET BALANCE GRAPHS

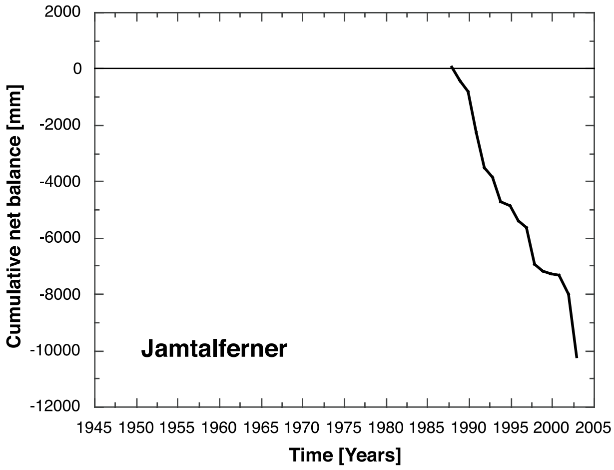
ARGENTINA

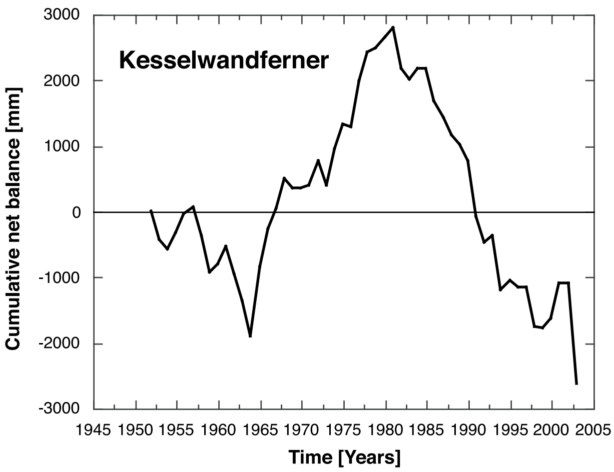


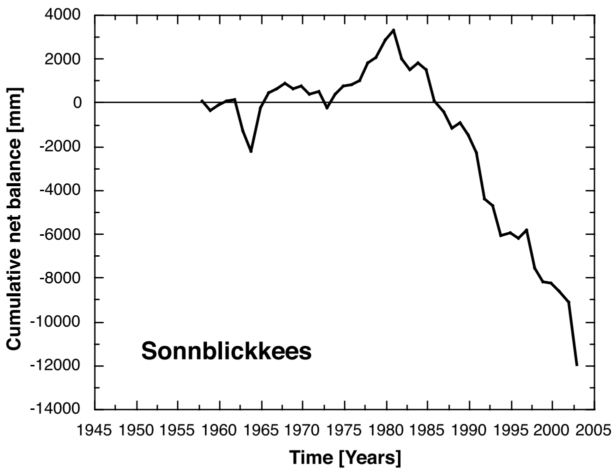
Note: Missing values in balance series are marked with *.

AUSTRIA

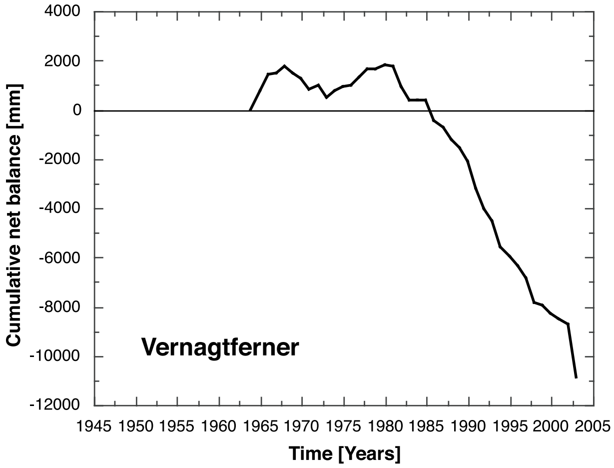


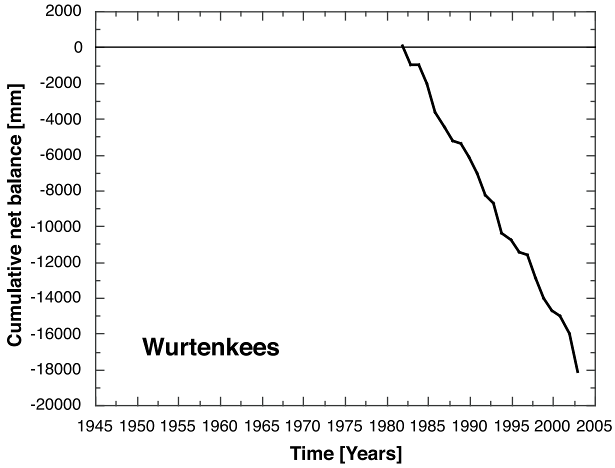




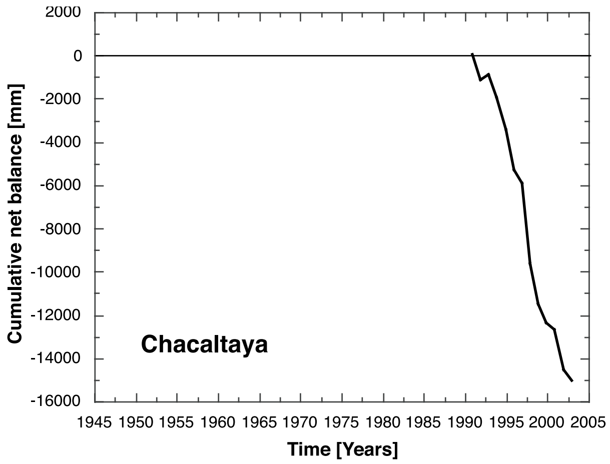


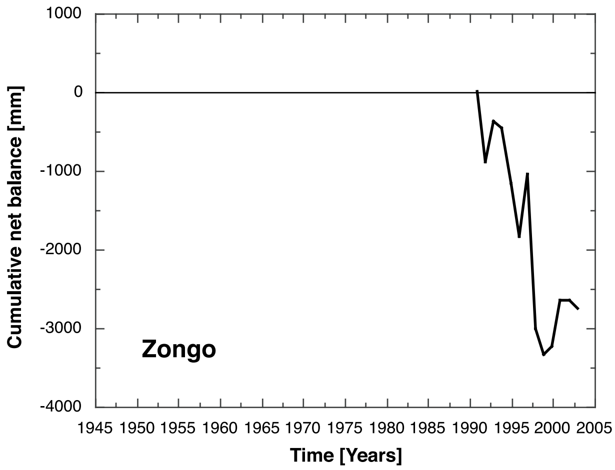
AUSTRIA



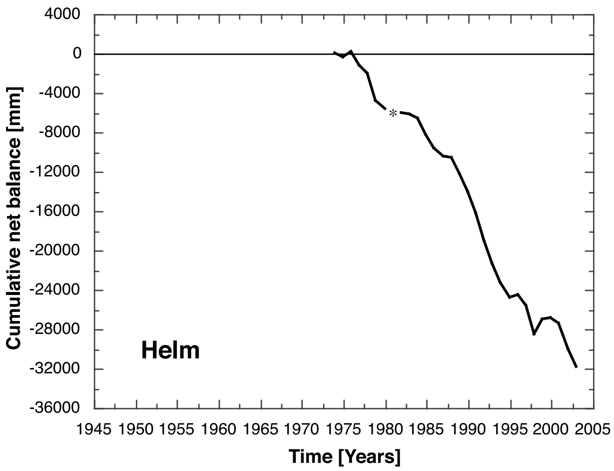


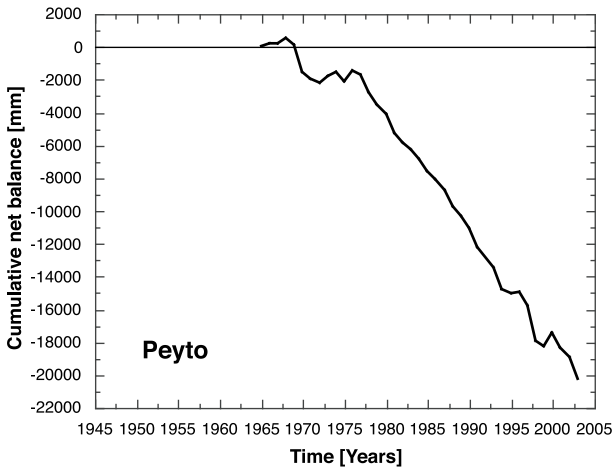
BOLIVIA



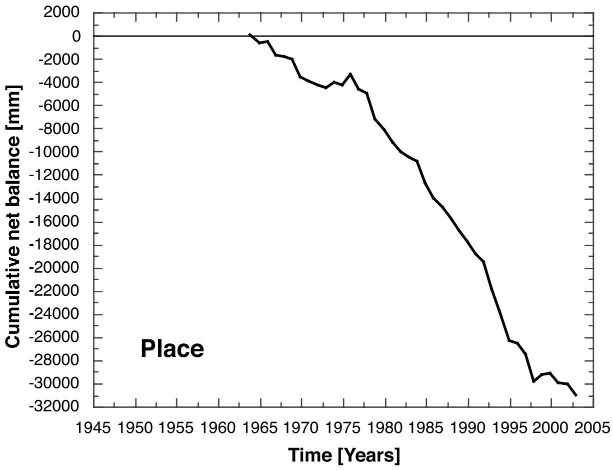


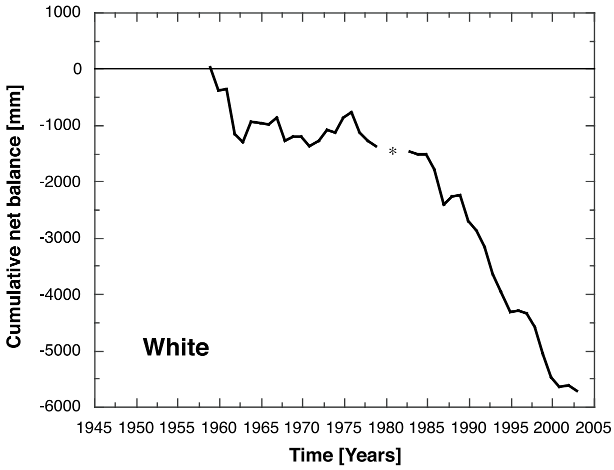
CANADA



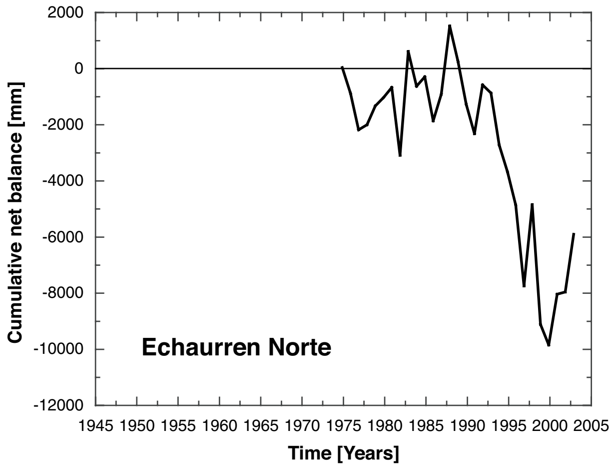


CANADA

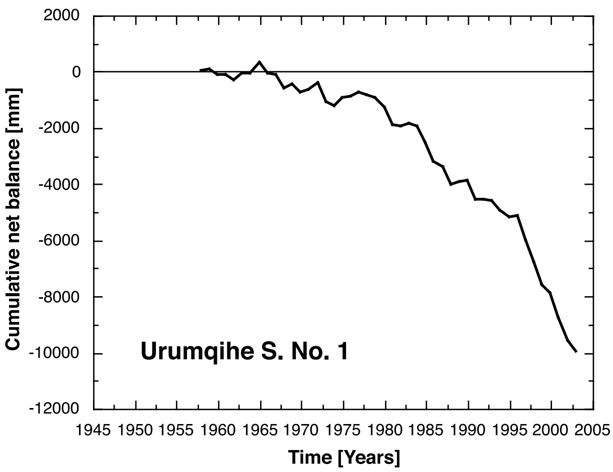




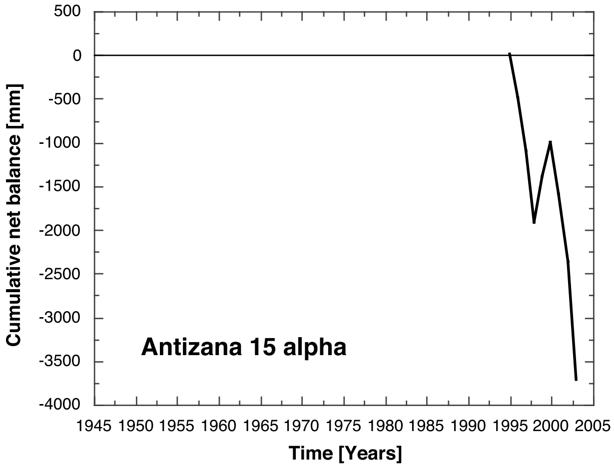
CHILE



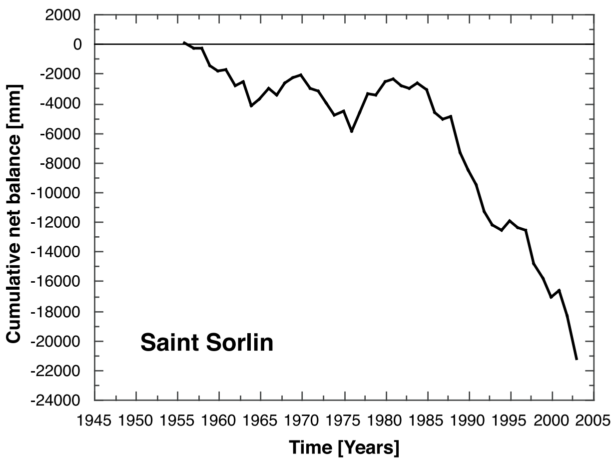
CHINA

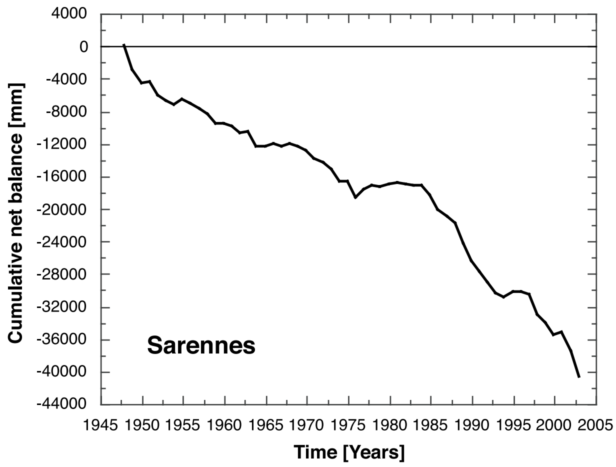


ECUADOR

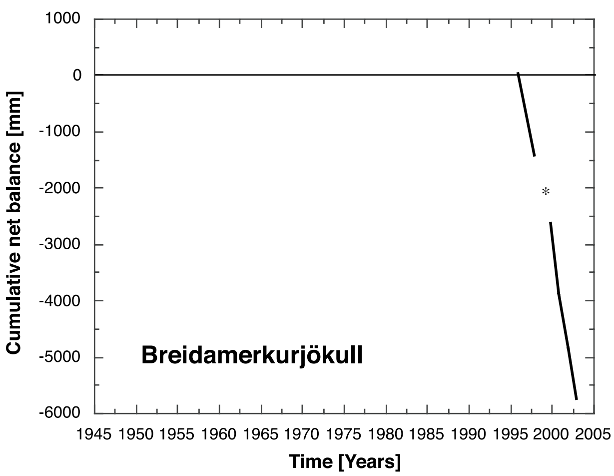


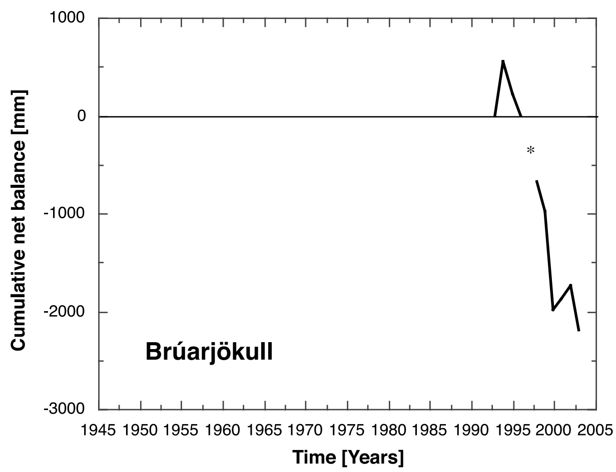
FRANCE



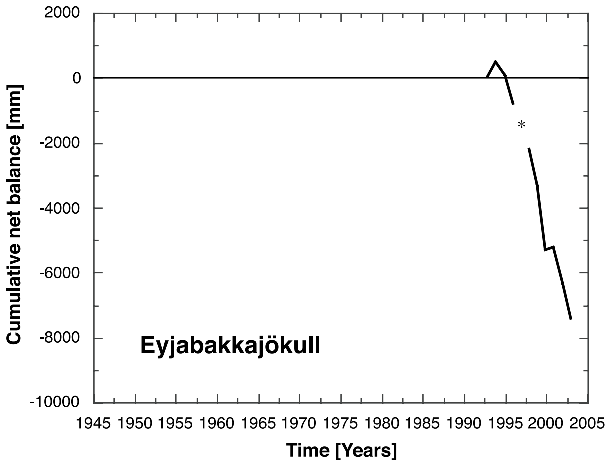


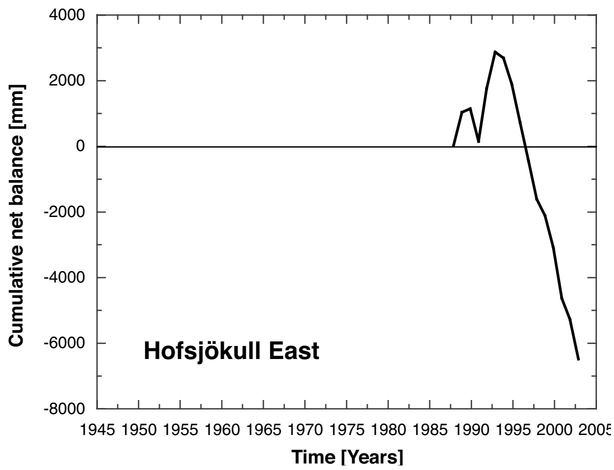
ICELAND

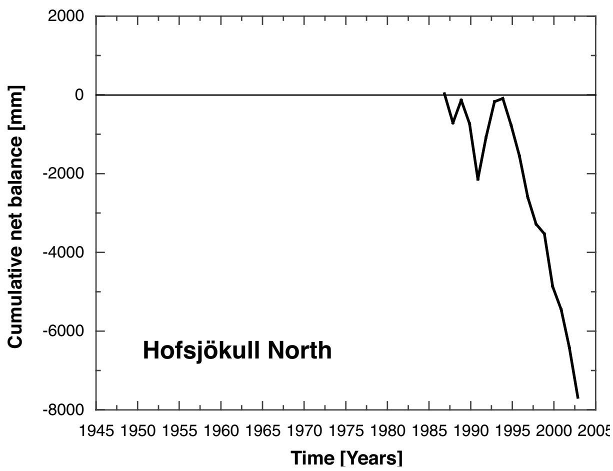


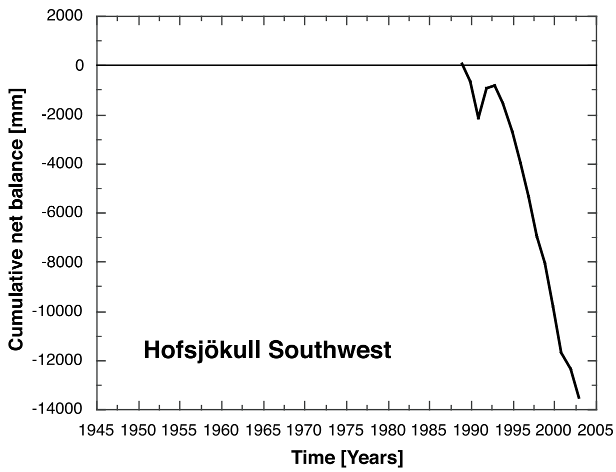


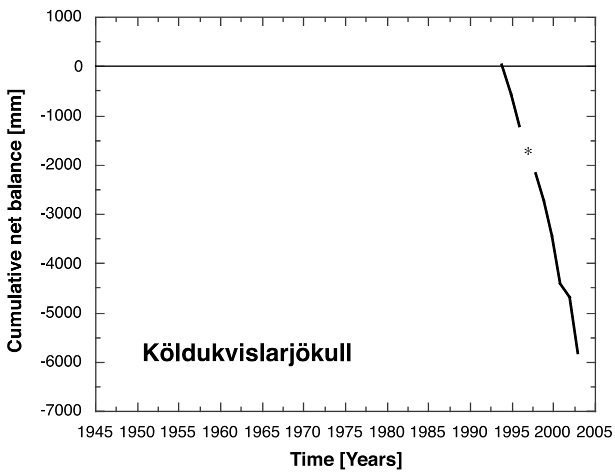
ICELAND

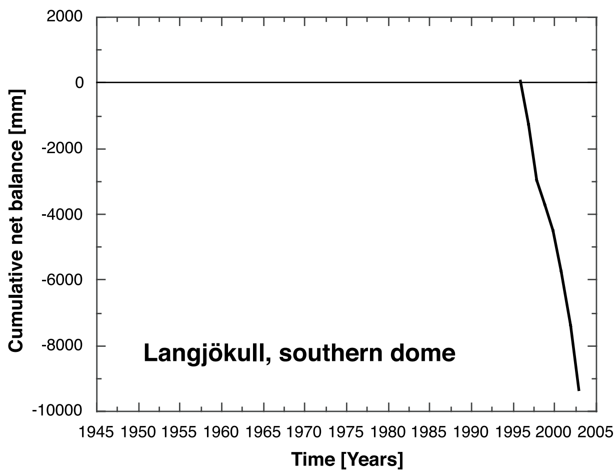

Eyjabakkajökull
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]


Hofsjökull East
Cumulative net balance [mm]
4000
2000
0
-2000
-4000
-6000
-8000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

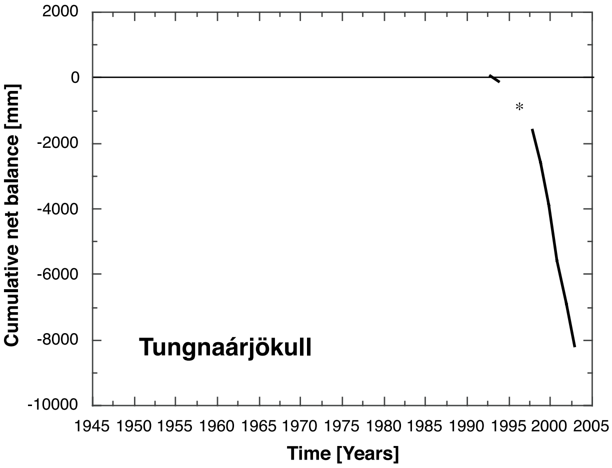

Hofsjökull North
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]


Hofsjökull Southwest
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

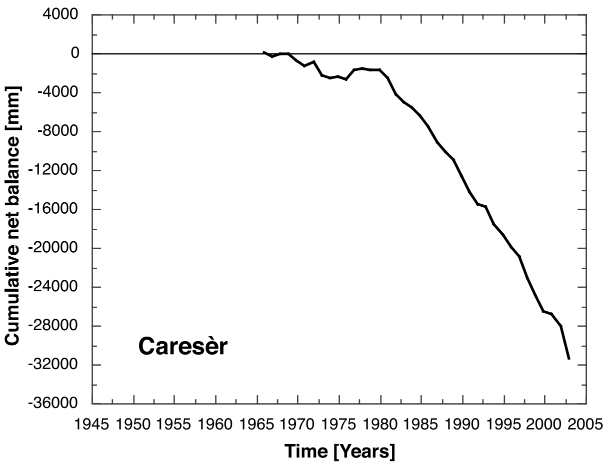

Köldukvislarjökull
Cumulative net balance [mm]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

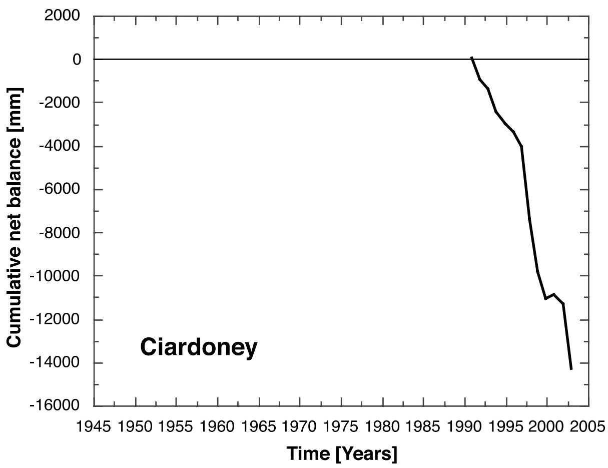

Langjökull, southern dome
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

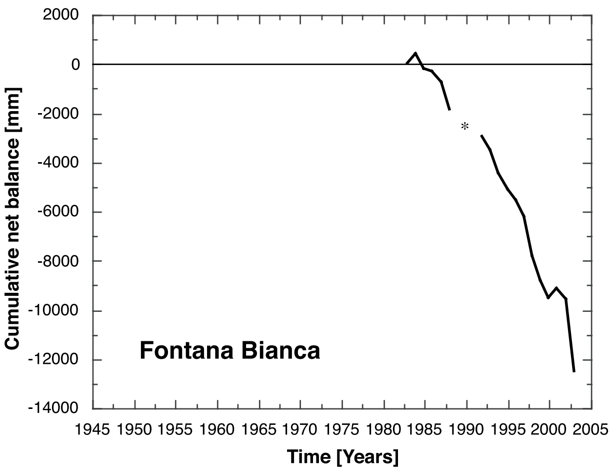
ICELAND

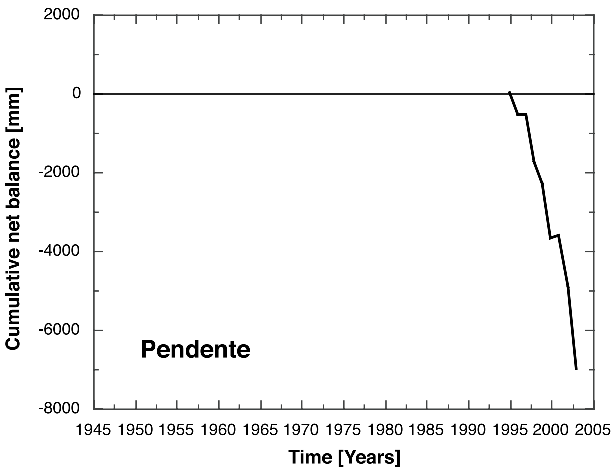


ITALY

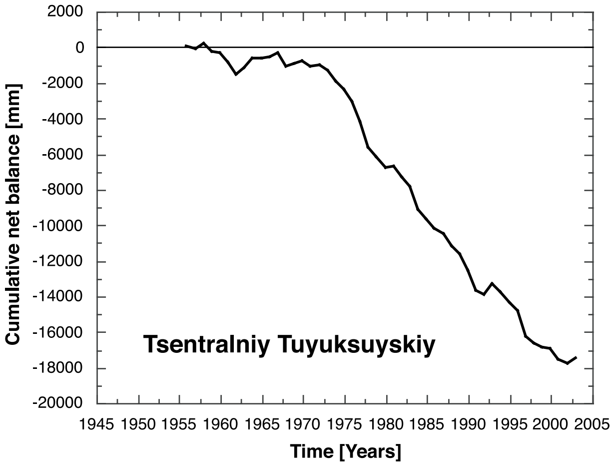




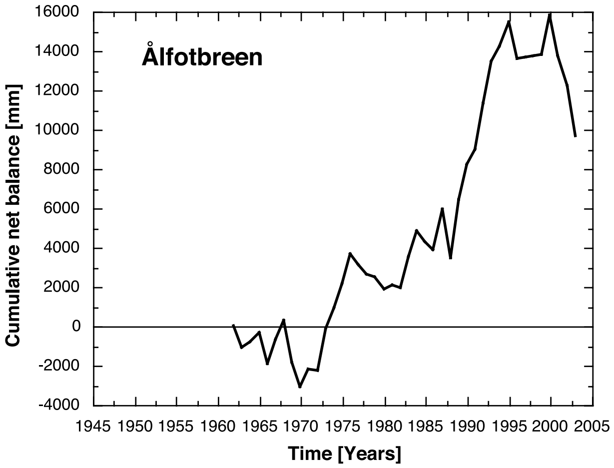


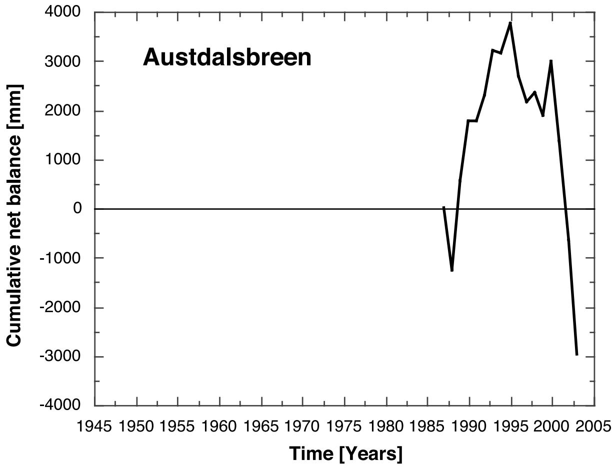


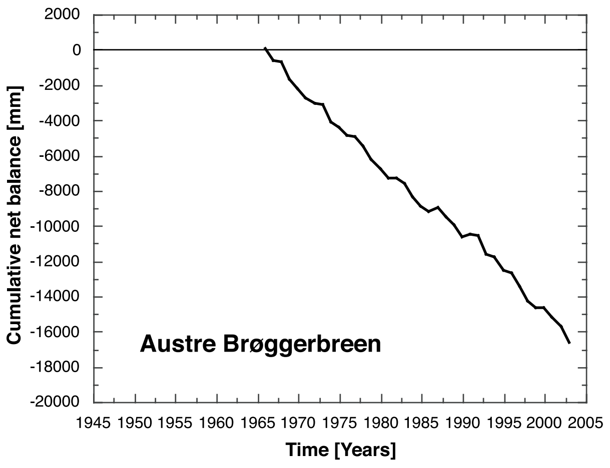
KAZAKHSTAN

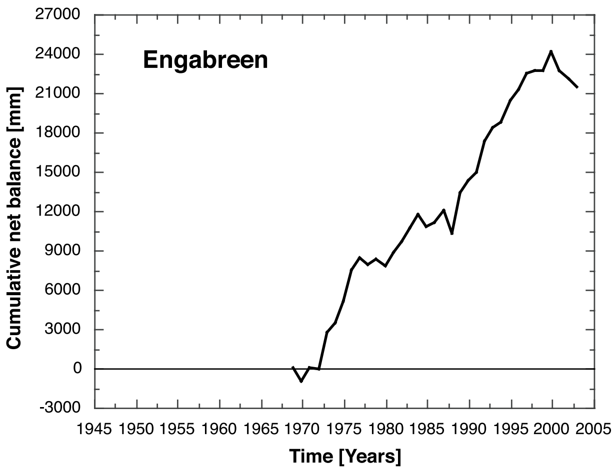


NORWAY

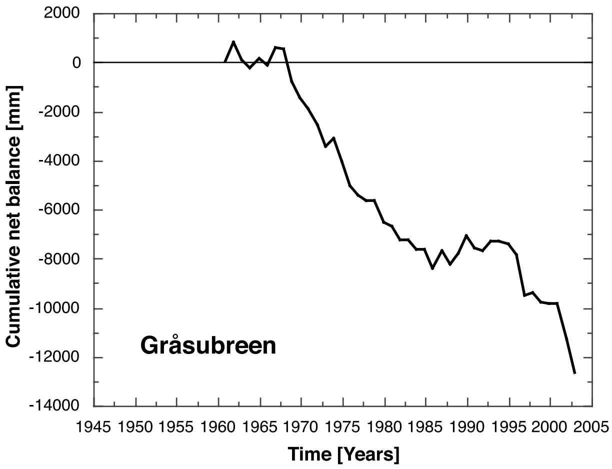


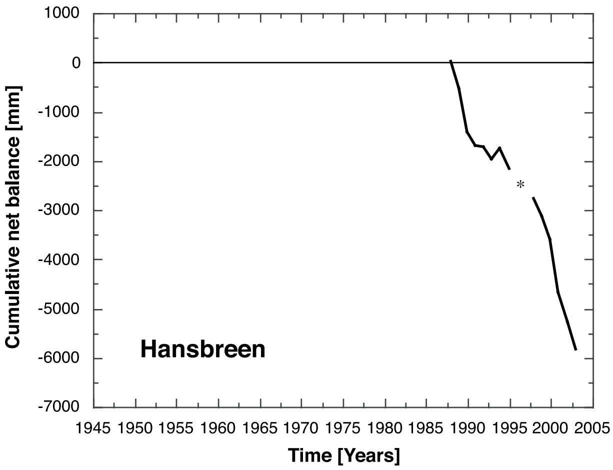


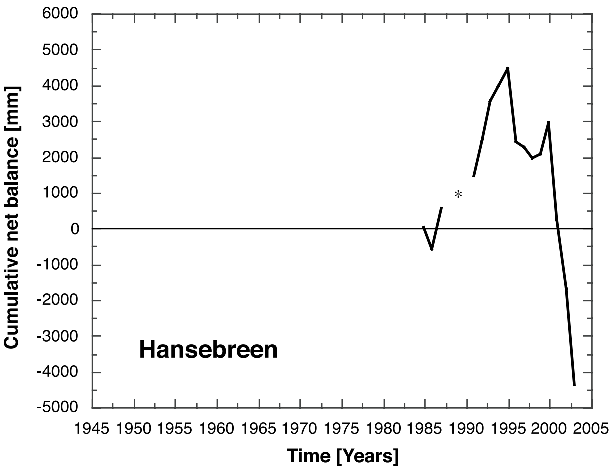


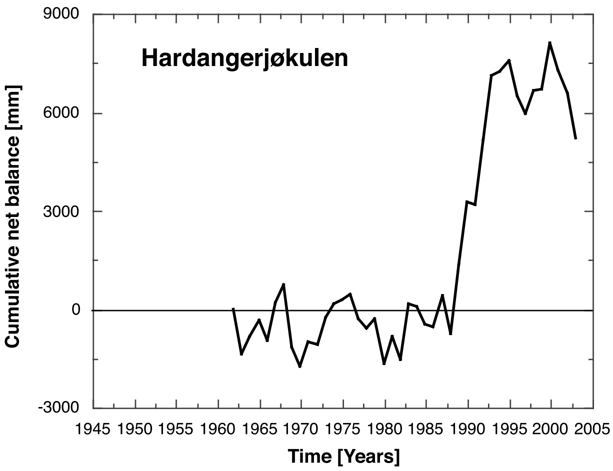


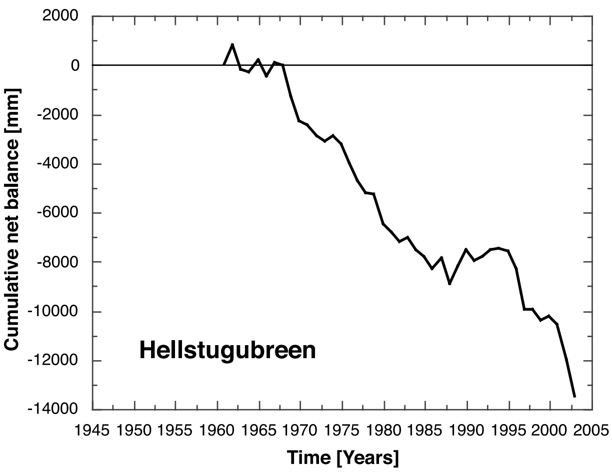
NORWAY

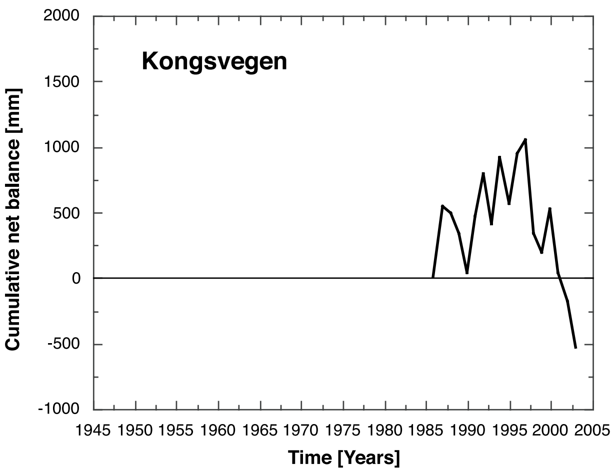

Gråsubreen
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]


Hansbreen
Cumulative net balance [mm]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
*
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

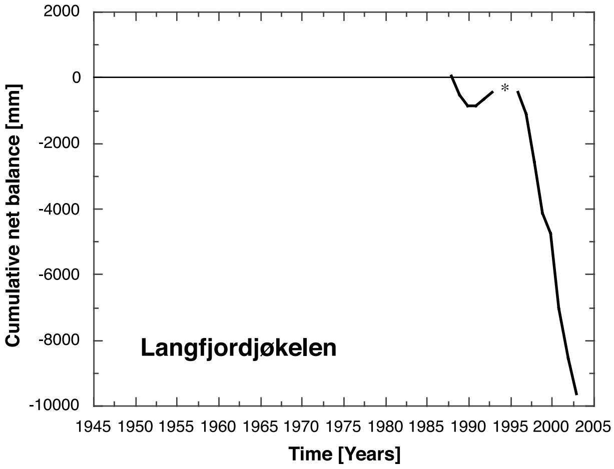

Hansebreen
Cumulative net balance [mm]
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
*
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

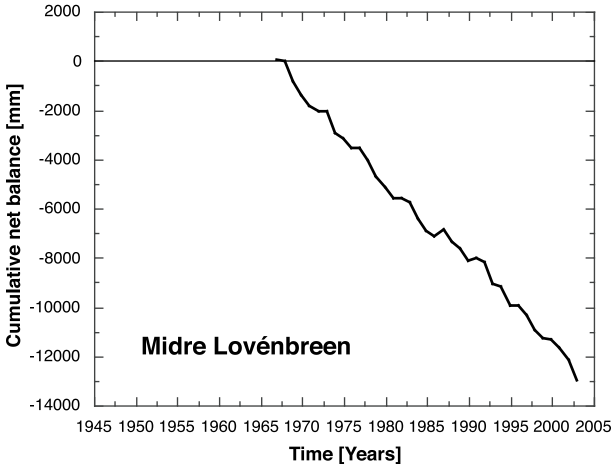

Hardangerjøkulen
Cumulative net balance [mm]
9000
6000
3000
0
-3000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

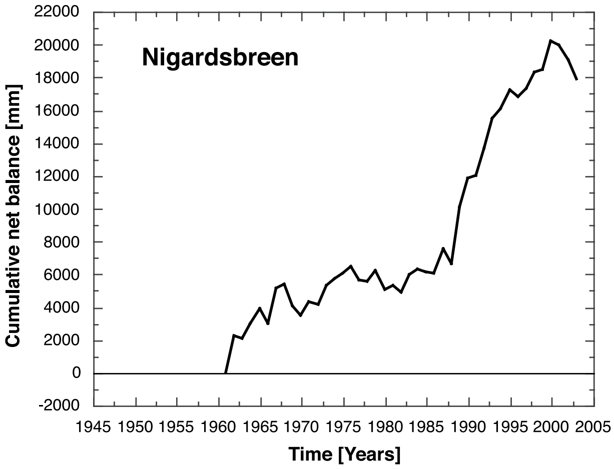

Hellstugubreen
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

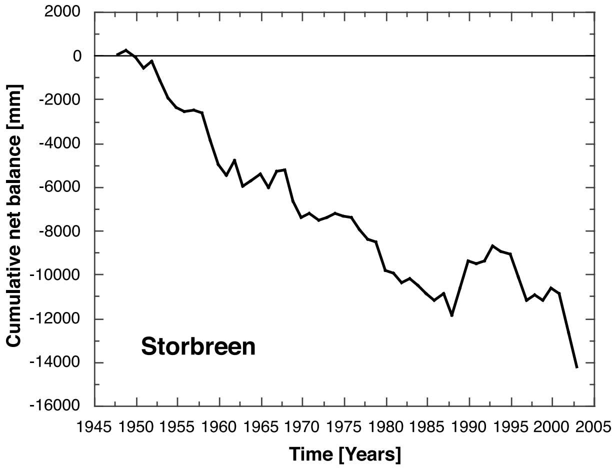

Kongsvegen
Cumulative net balance [mm]
2000
1500
1000
500
0
-500
-1000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

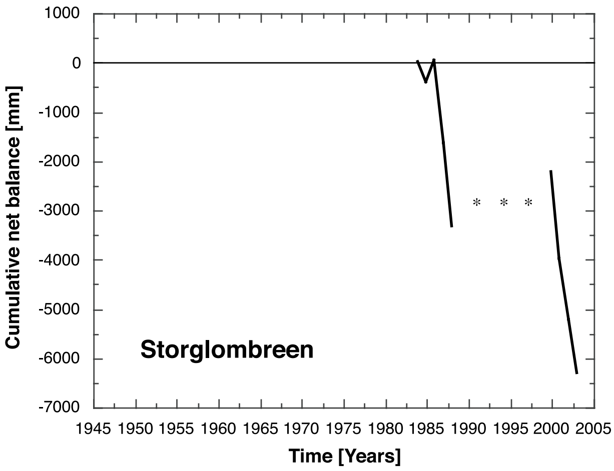
NORWAY

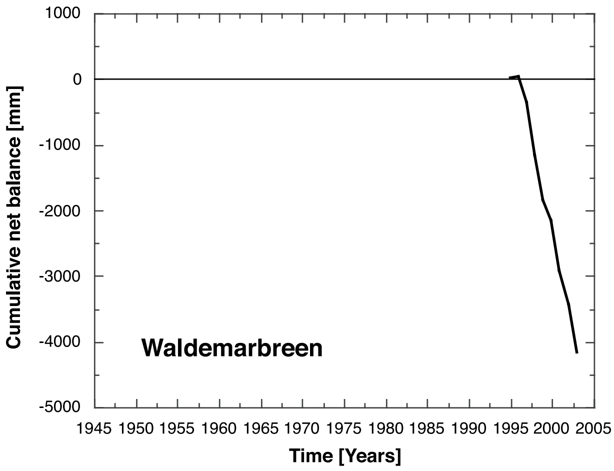

Langfjordjøkelen
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
*
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]


Midre Lovénbreen
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

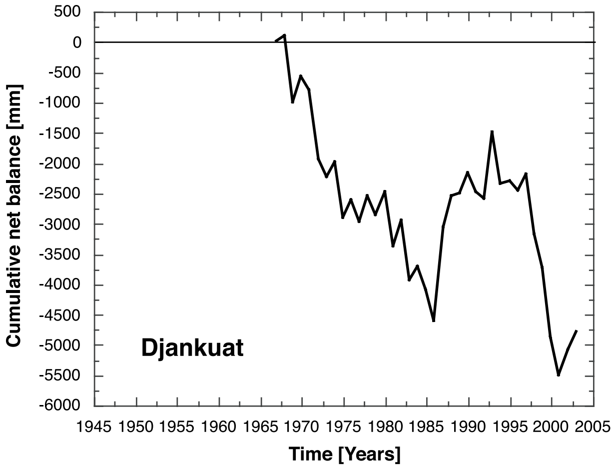

Nigardsbreen
Cumulative net balance [mm]
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

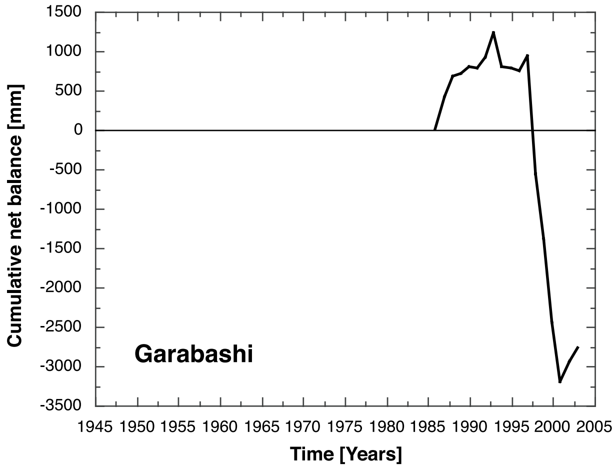

Storbreen
Cumulative net balance [mm]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
-16000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

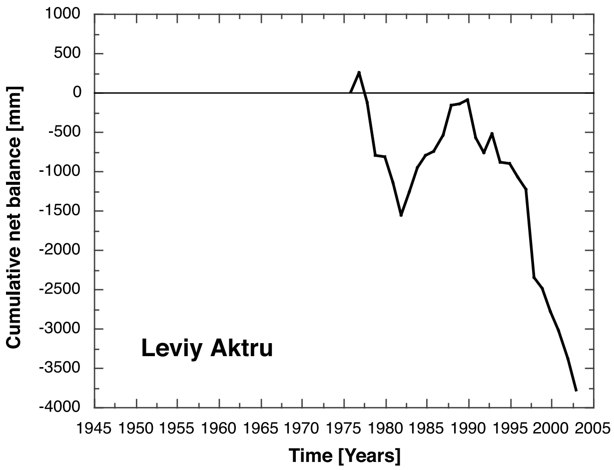

Storglombreen
Cumulative net balance [mm]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
* * *
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

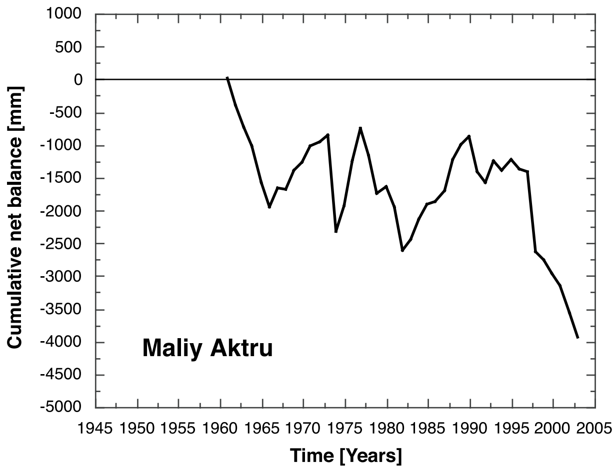

Waldemarbreen
Cumulative net balance [mm]
1000
0
-1000
-2000
-3000
-4000
-5000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Time [Years]

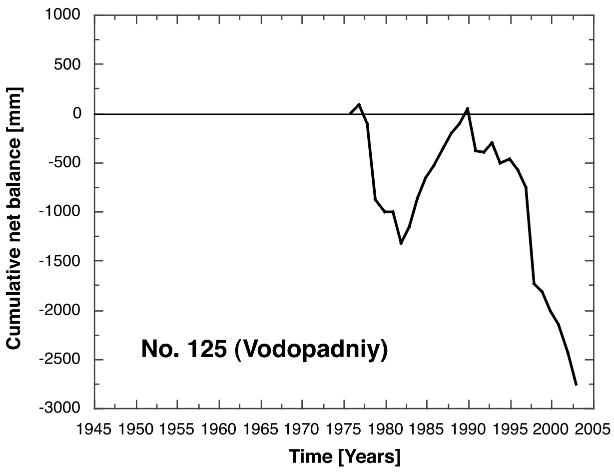
RUSSIA


Djankuat
Cumulative net balance [mm]
Time [Years]

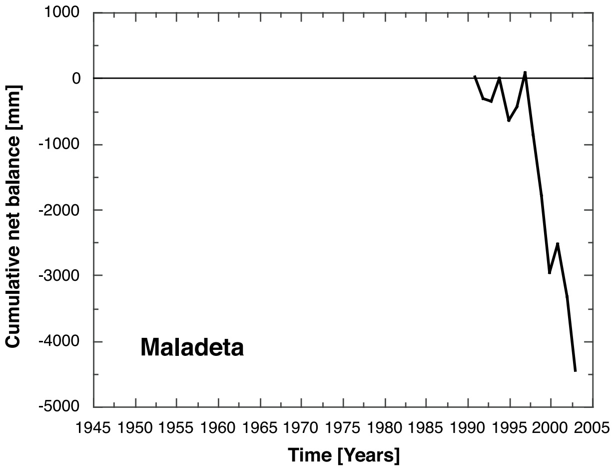

Garabashi
Cumulative net balance [mm]
Time [Years]


Leviy Aktru
Cumulative net balance [mm]
Time [Years]

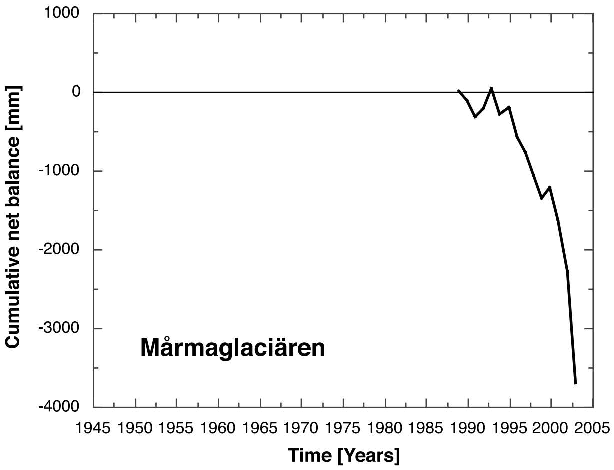

Maliy Aktru
Cumulative net balance [mm]
Time [Years]

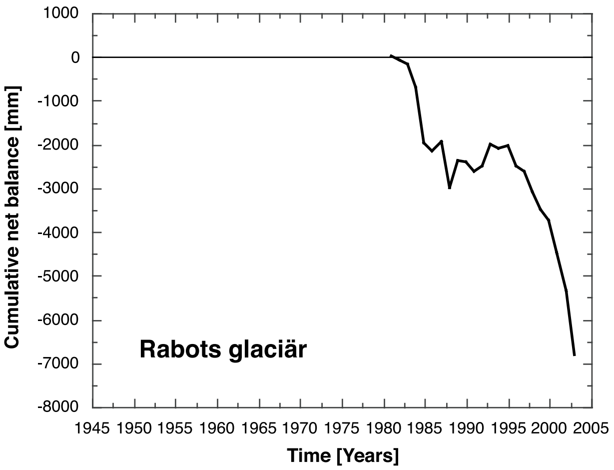

No. 125 (Vodopadniy)
Cumulative net balance [mm]
Time [Years]

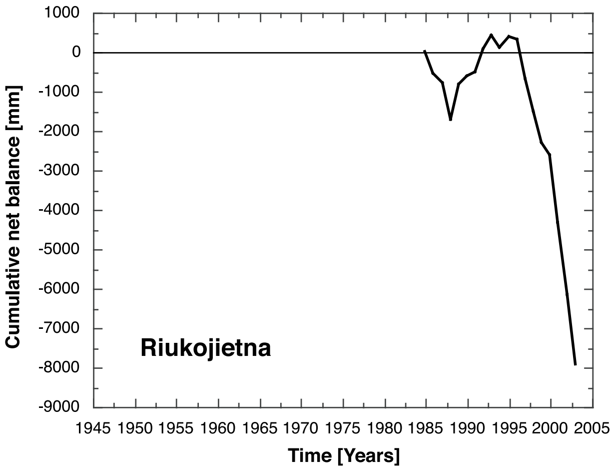
SPAIN

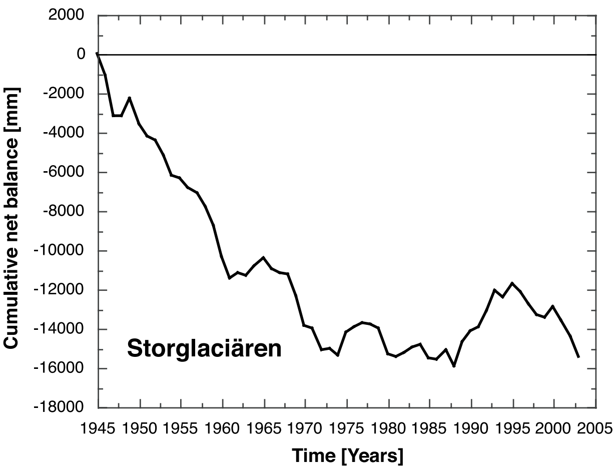


SWEDEN

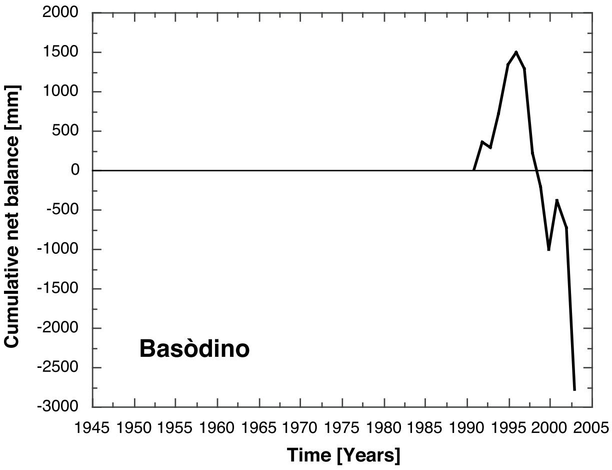


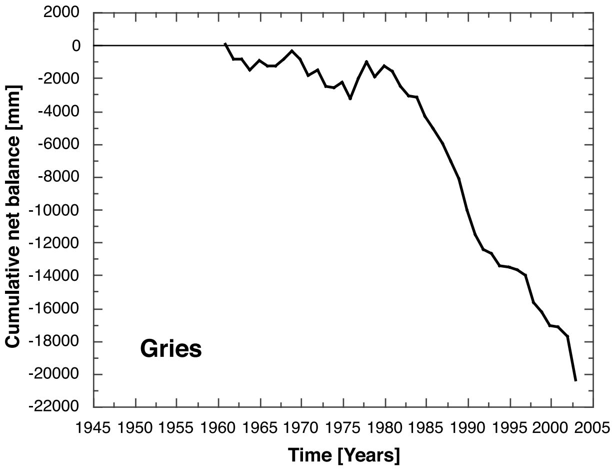


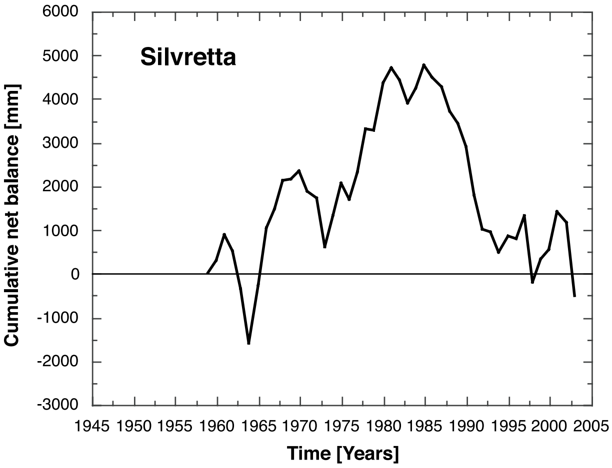




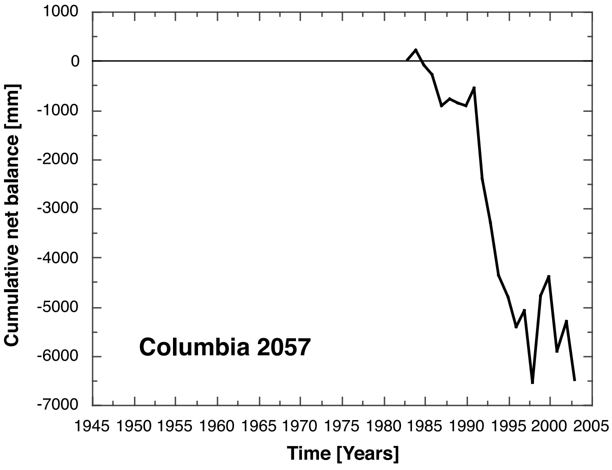
SWITZERLAND

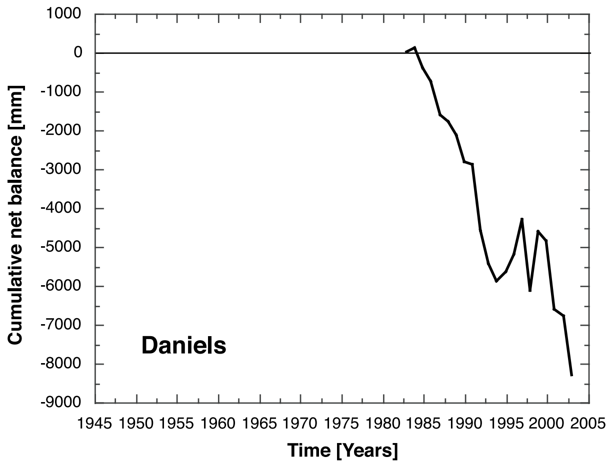




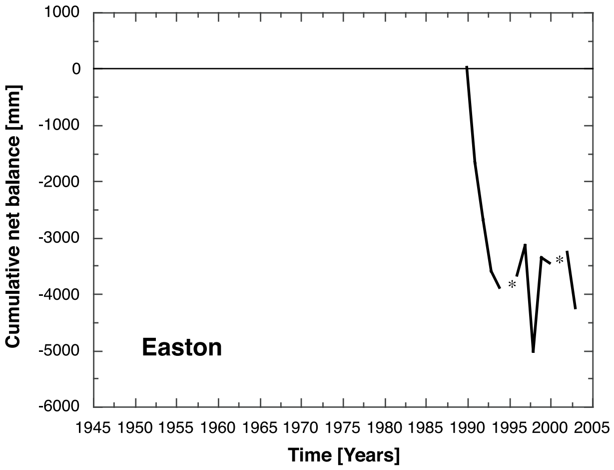


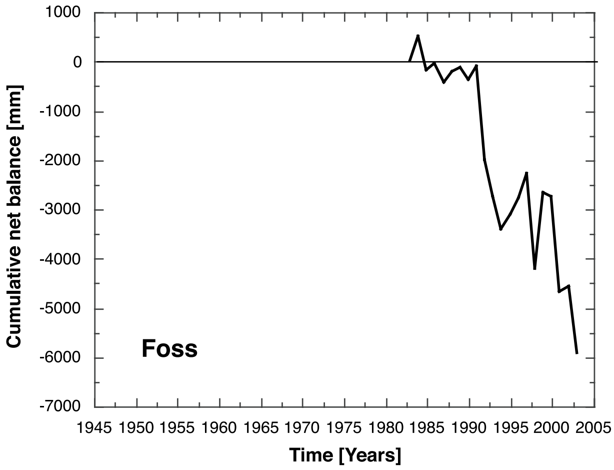
USA

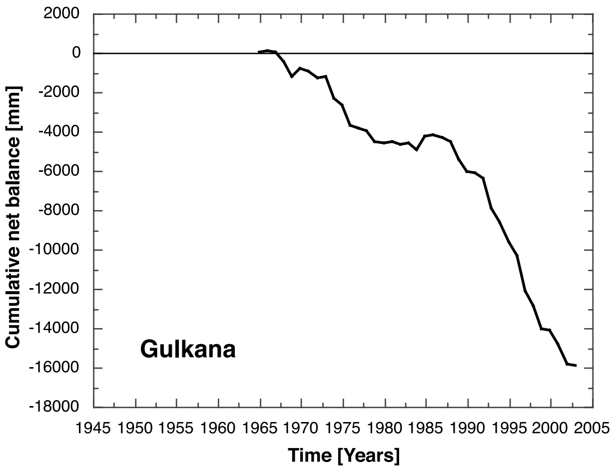


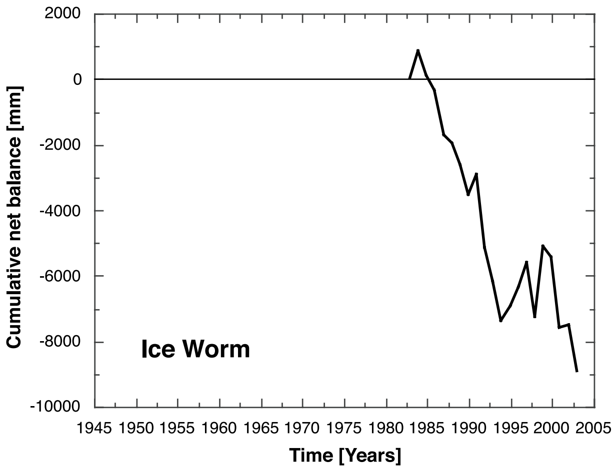


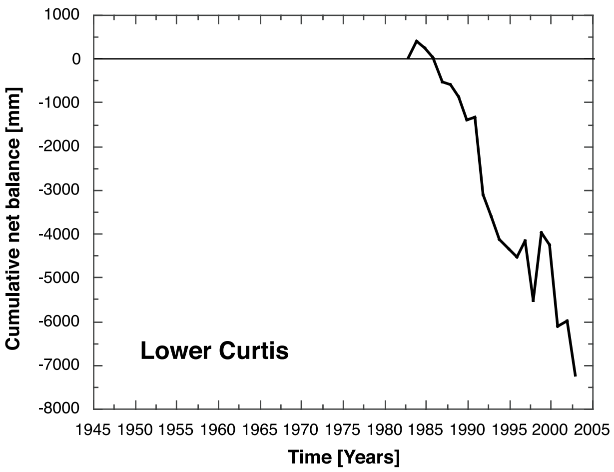
USA

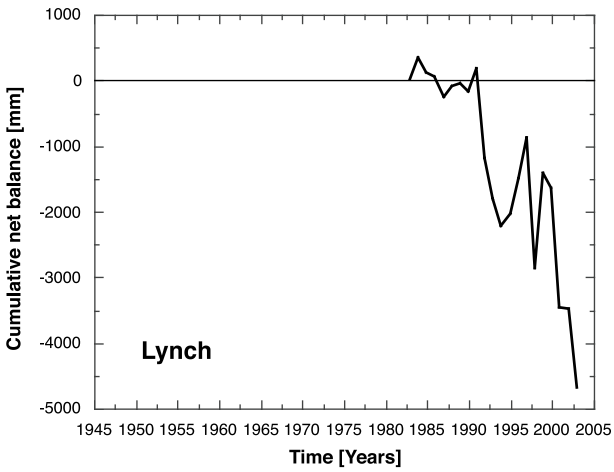

Cumulative net balance [mm]
Time [Years]
Easton


Cumulative net balance [mm]
Time [Years]
Foss

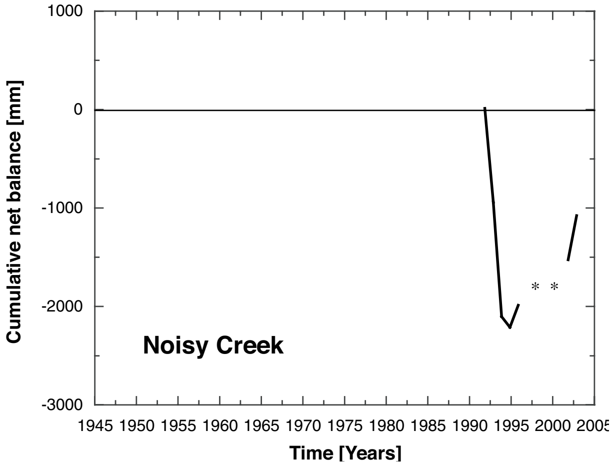

Cumulative net balance [mm]
Time [Years]
Gulkana

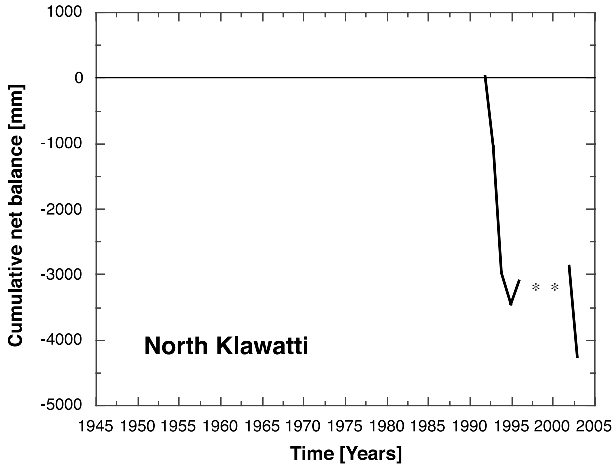

Cumulative net balance [mm]
Time [Years]
Ice Worm

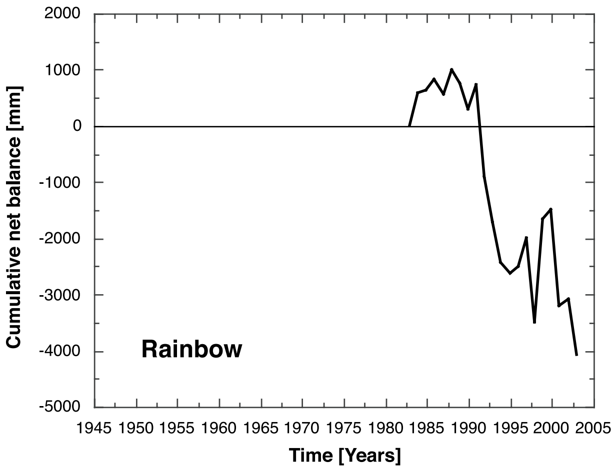

Cumulative net balance [mm]
Time [Years]
Lower Curtis

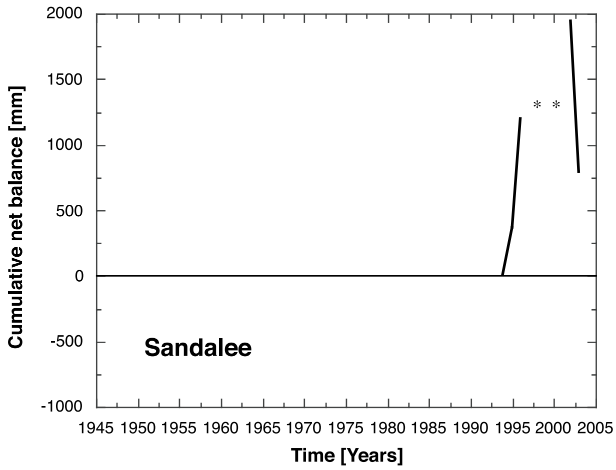

Cumulative net balance [mm]
Time [Years]
Lynch

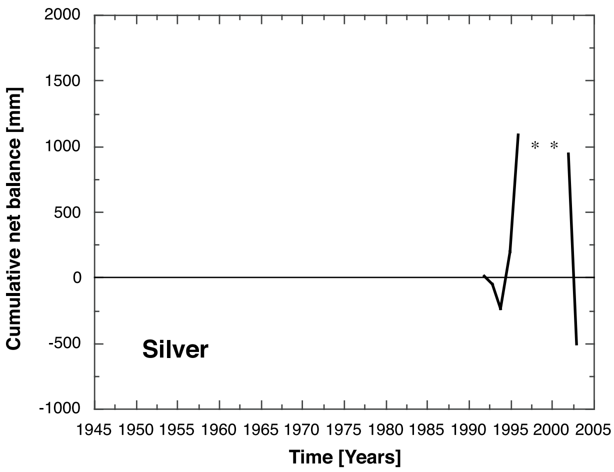
USA

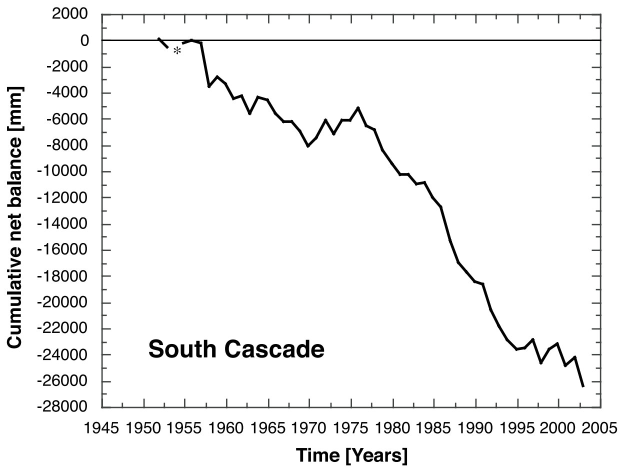

Noisy Creek
Cumulative net balance [mm]
Time [Years]


North Klawatti
Cumulative net balance [mm]
Time [Years]

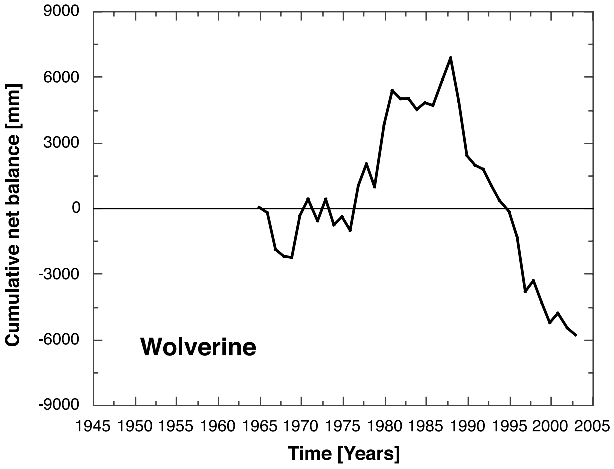

Rainbow
Cumulative net balance [mm]
Time [Years]

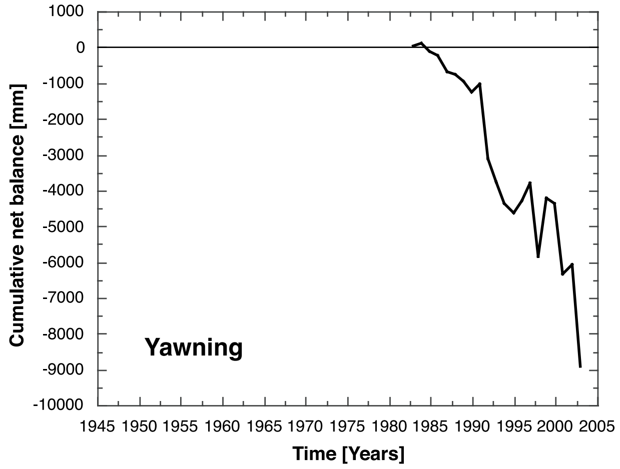

Sandalee
Cumulative net balance [mm]
Time [Years]


Silver
Cumulative net balance [mm]
Time [Years]


South Cascade
Cumulative net balance [mm]
Time [Years]

USA


Wolverine
Cumulative net balance [mm]
Time [Years]
9000
6000
3000
0
-3000
-6000
-9000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005


Yawning
Cumulative net balance [mm]
Time [Years]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005

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 standardised 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 2002/03. 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 (2001/02 and 2002/03) 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 less measurement years are included).

3.1 BAHIA DEL DIABLO (ANTARCTICA/A. PENINSULA)

COORDINATES: 63.82 S / 57.43 W

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

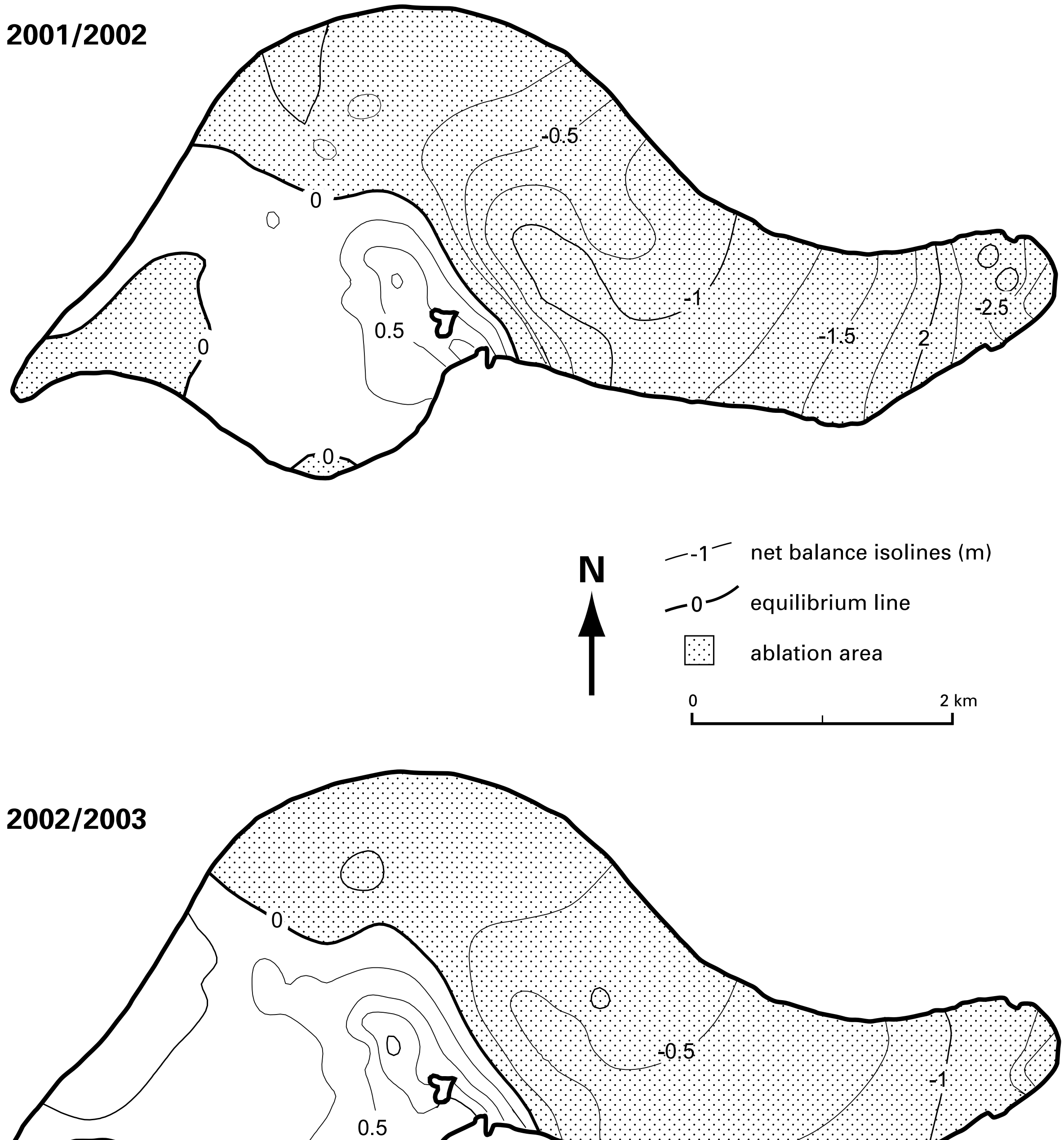
This polythermal outlet-type glacier is located on Vega Island on the north-eastern side of the Antarctic Peninsula. It has an area of 14.3 km^2, extends from 630 to 75 m a.s.l. and is exposed to the north-east. Mean annual air temperature at the equilibrium line (around 400 m a.s.l. for balanced years) is -7 to -8 °C. The snout of the glacier overrides an ice-cored moraine on a periglacial plain with continuous permafrost. Annual precipitation is roughly estimated at 450 mm as inferred from the precipitation record at Esperanza Weather Station that is located 50 km to the north of the glacier. Mass balance measurements were initiated during the austral summer of 1999/00. Because the glacier can only be visited once a year, a combined stratigraphic/fixed date system is applied.

Mass balance was negative throughout the period 1999–2003, with a mean of -320 mm w.e. The balance year 2001/02 had a strong mass loss (-510 mm w.e.) as a consequence of the warm summer recorded in the region. At the end of this summer season, the accumulation area exhibited widespread zones of superimposed ice. Although the summer of 2002/03 was cooler, the glacier mass balance was again negative (-150 mm w.e.). The data collected over four years reveals a strong correlation between annual mass balance of the glacier and mean summer air temperature.

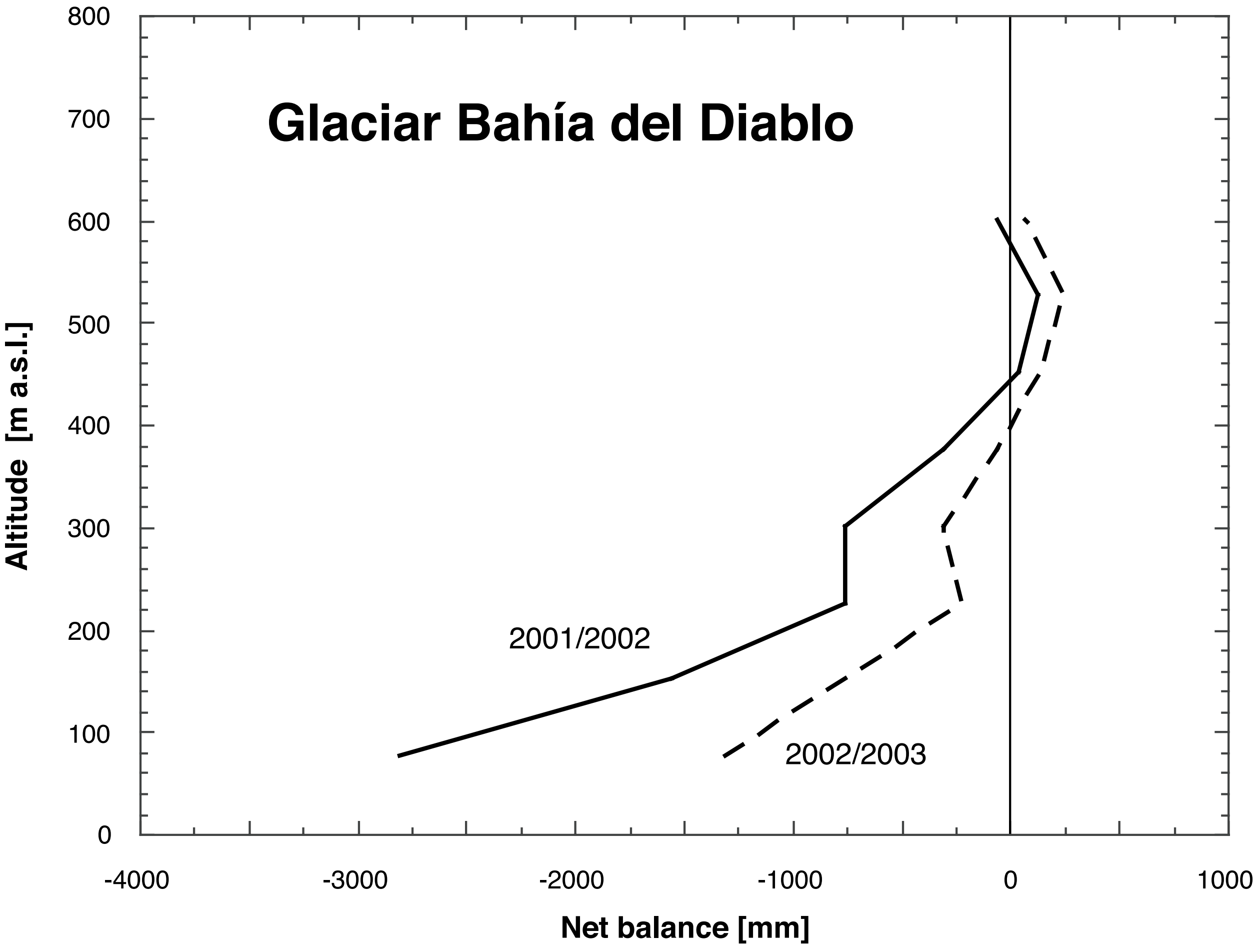
3.1.1 Topography and observational network

Glaciar Bahía del Diablo (ANTARCTICA)

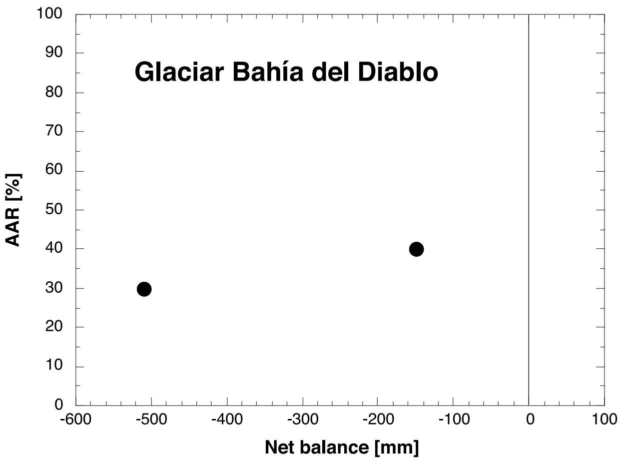
3.1.2 Net balance maps 2001/2002 and 2002/2003

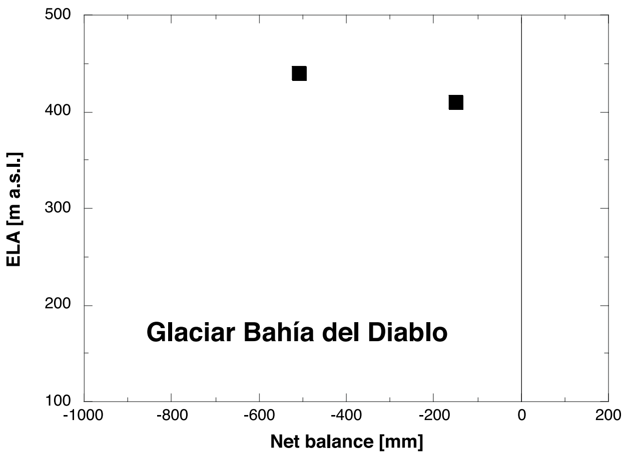


3.1.3 Net balance versus altitude (2001/2002 and 2002/2003)



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)

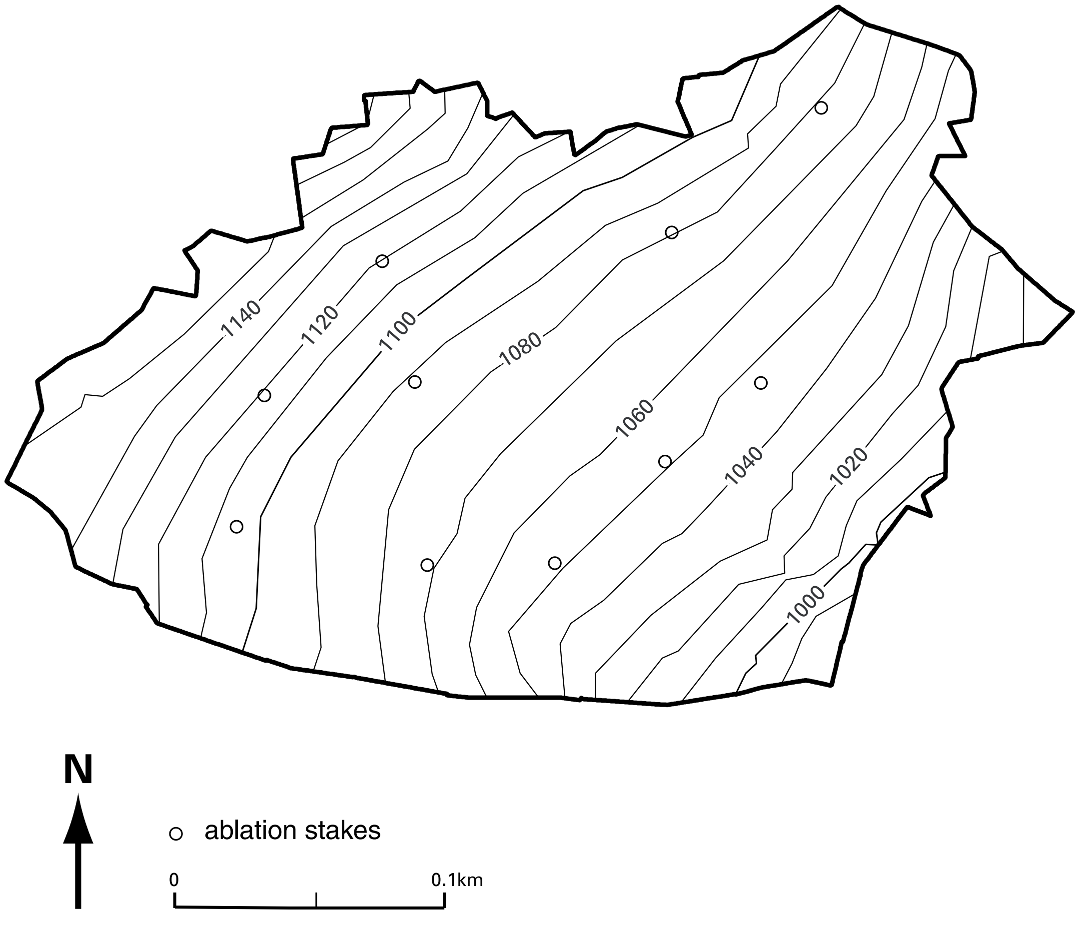
COORDINATES: 54.78 S / 68.40 W

Picture taken by R. Iturraspe in March 2003.

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 stretching 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 the Martial Este Glacier (MEG), extends from 1180 to 1000 m a.s.l. Its surface of 0.1 km^2 has an average slope of 29°, is exposed to the southwest and, of the four ice bodies, receives the smallest amount of direct solar radiation. The glacier is rather wide than long, has a maximum ice thickness of 40 m and an estimated total volume of about 3 x 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 about 75% of their total area. From 1984 to 1998 vertical thinning at the Martial Este Glacier was 7.0 m (450 mm w.e.).

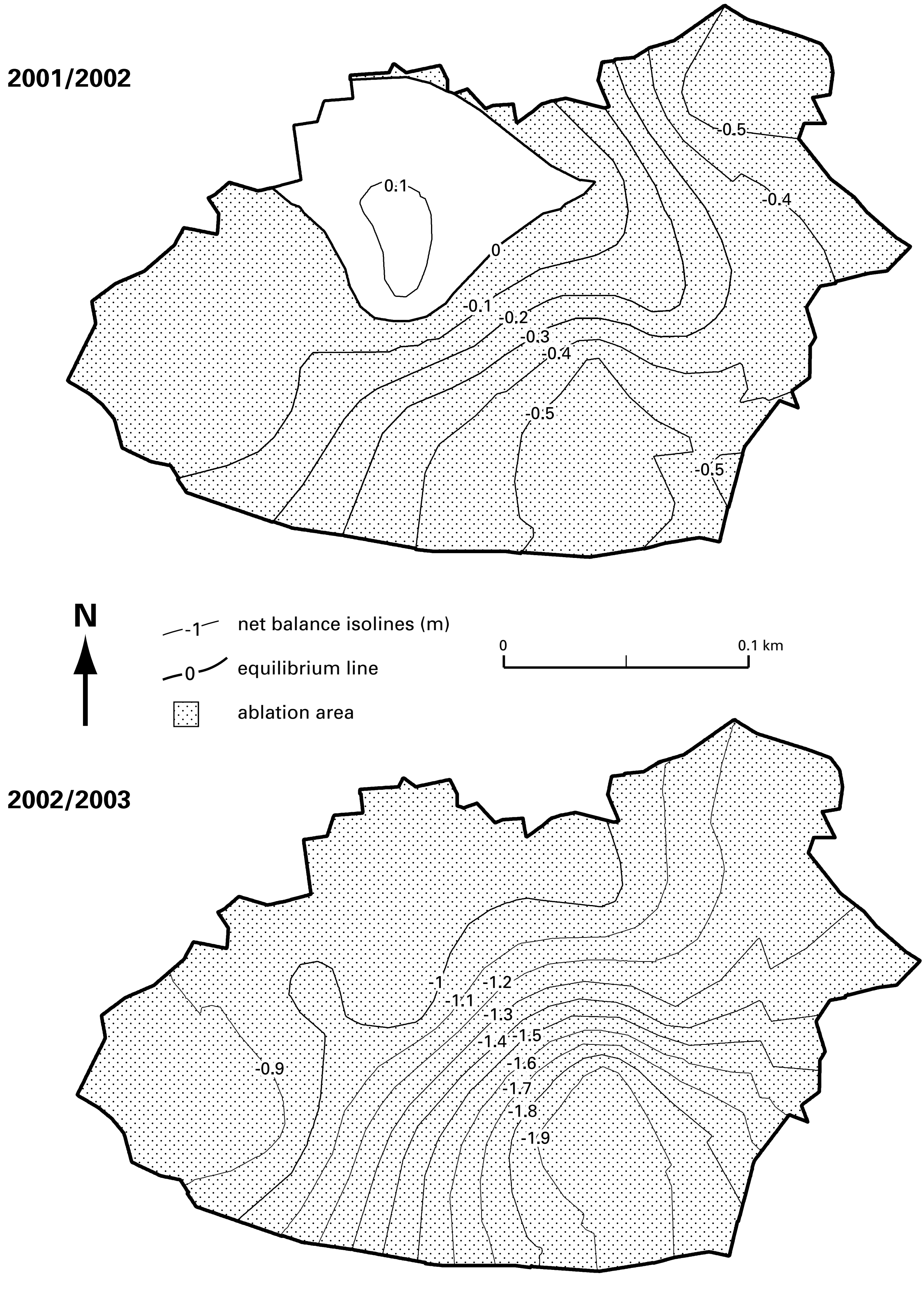
The hydrological year 2000 mass balance of Martial Este was markedly positive reaching 785 mm w.e., with a high winter snow accumulation, followed by a cold and humid summer season. For 2001, winter snow accumulation was poor, followed by a warm and dry summer, determining a negative net mass balance of -702 mm w.e. During 2002 a fairly equilibrated net mass balance of -202 mm w.e. was measured and the very dry and warm summer of 2003 resulted in a markedly negative net mass balance of -1256 mm w.e.

3.2.1 Topography and observational network



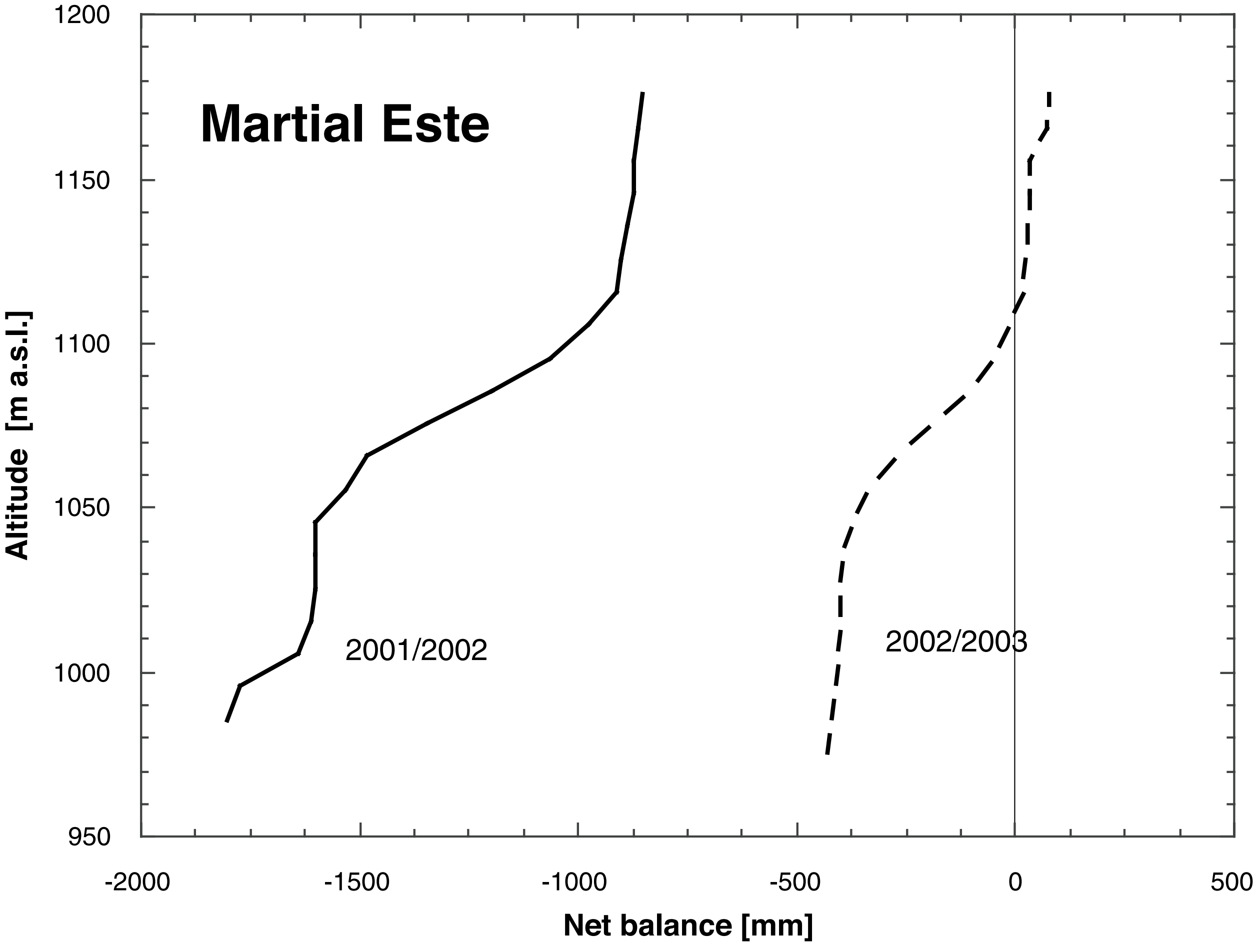
Martial Este (ARGENTINA)

3.2.2 Net balance maps 2002/2003 and 2003/2004

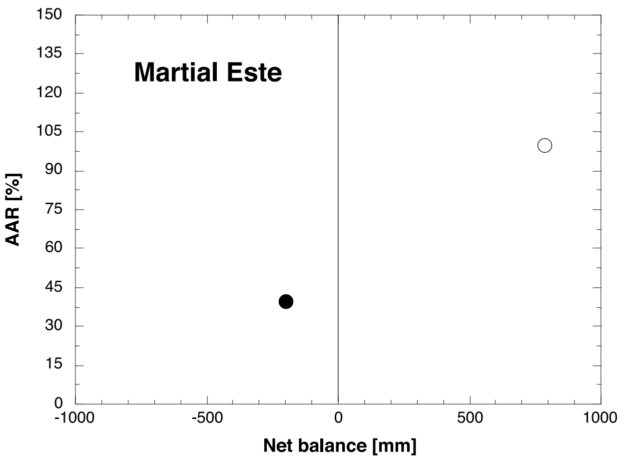


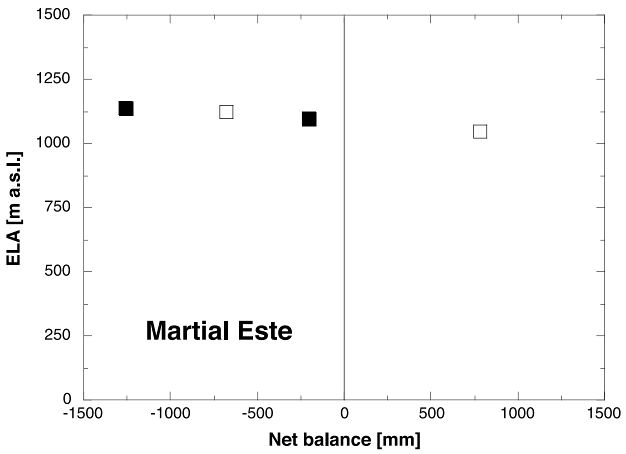
Martial Este (ARGENTINA)

3.2.3 Net balance versus altitude (2001/2002 and 2002/2003)



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)

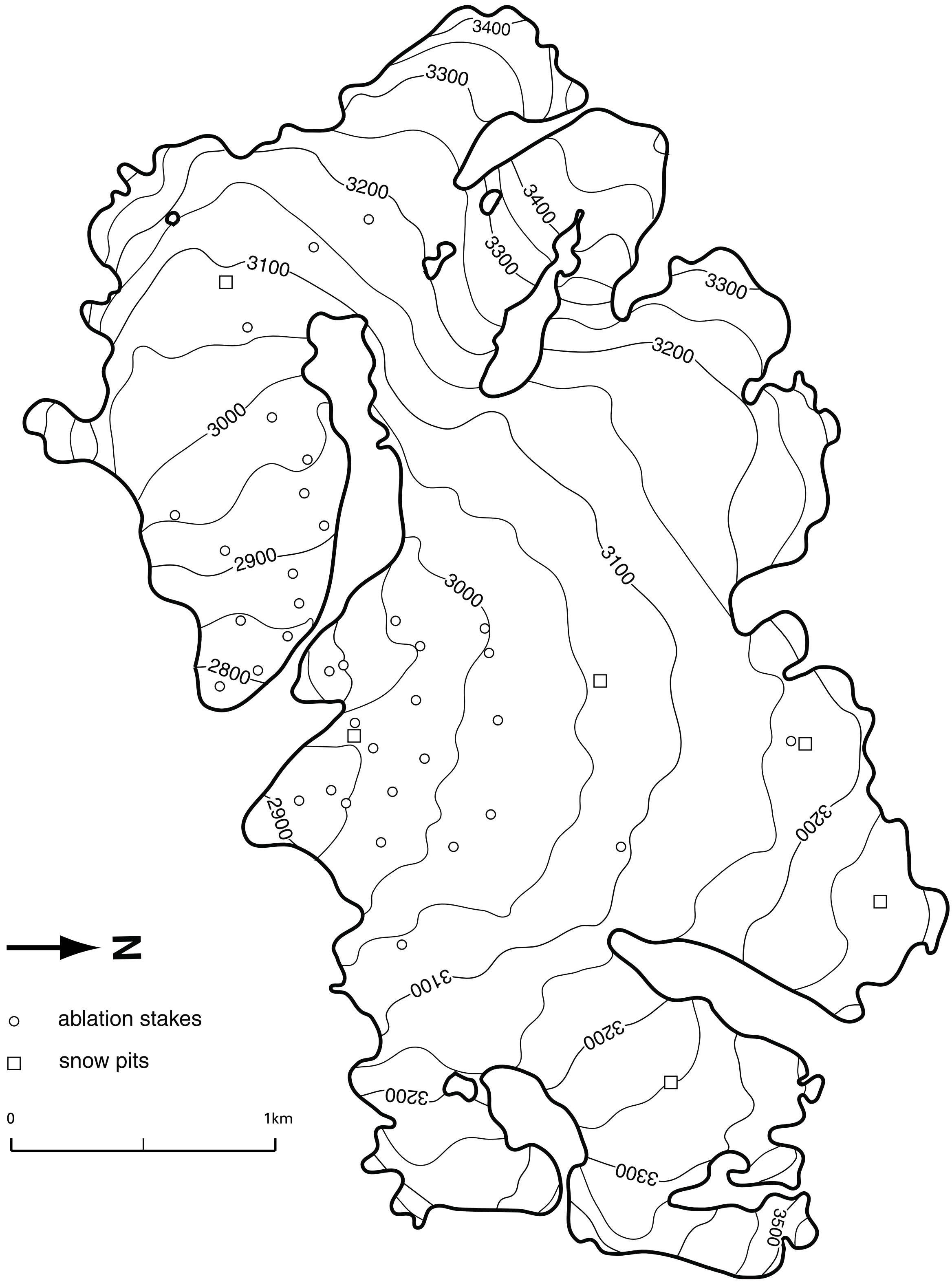
COORDINATES: 46.88 N / 10.82 W

Picture by Archive Commission for Glaciology, Bavarian Academy of Sciences, Munich on the 23rd of August 2003.

The rather flat temperate glacier is located in the southern part of the Oetztal Alps near the main Alpine ridge. The present surface area of 8.5 km^2 is unevenly distributed between 3628 and 2770 m a.s.l., with a mean elevation of 3145 m a.s.l. Mean annual air temperature at the equilibrium line (for balanced years at 3065 m a.s.l.) lies between -3.5 and -4.5 °C, based on records from the Vernagt gauging station at 2640 m a.s.l. and the Schwarzkögele climate station at 3050 m a.s.l. Mean annual precipitation for the Vernagt drainage basin (11.4 km^2) amounts to 1550 mm, 60% of which is, 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. There are 1:10’000 scale topographic maps based on photogrammetric surveys from 1889, 1969, 1979, 1982, 1990 and 1999.

The year 2001/02 brought a rather moderate mass loss (-266 mm w.e., AAR = 0.53). The year 2002/03, on the other hand, showed an extreme mass loss (-2113 mm w.e.) due to an ablation season that was characterised by 93 days with high melt in contrast to the average of 45 days over the last 20 years. For the first time since the beginning of observations in 1964, all winter accumulation of 2002/03 was completely melted (AAR=0). Annual runoff 2003 amounted to 3300 mm w.e. in contrast to 1200 mm w.e. for balanced years.

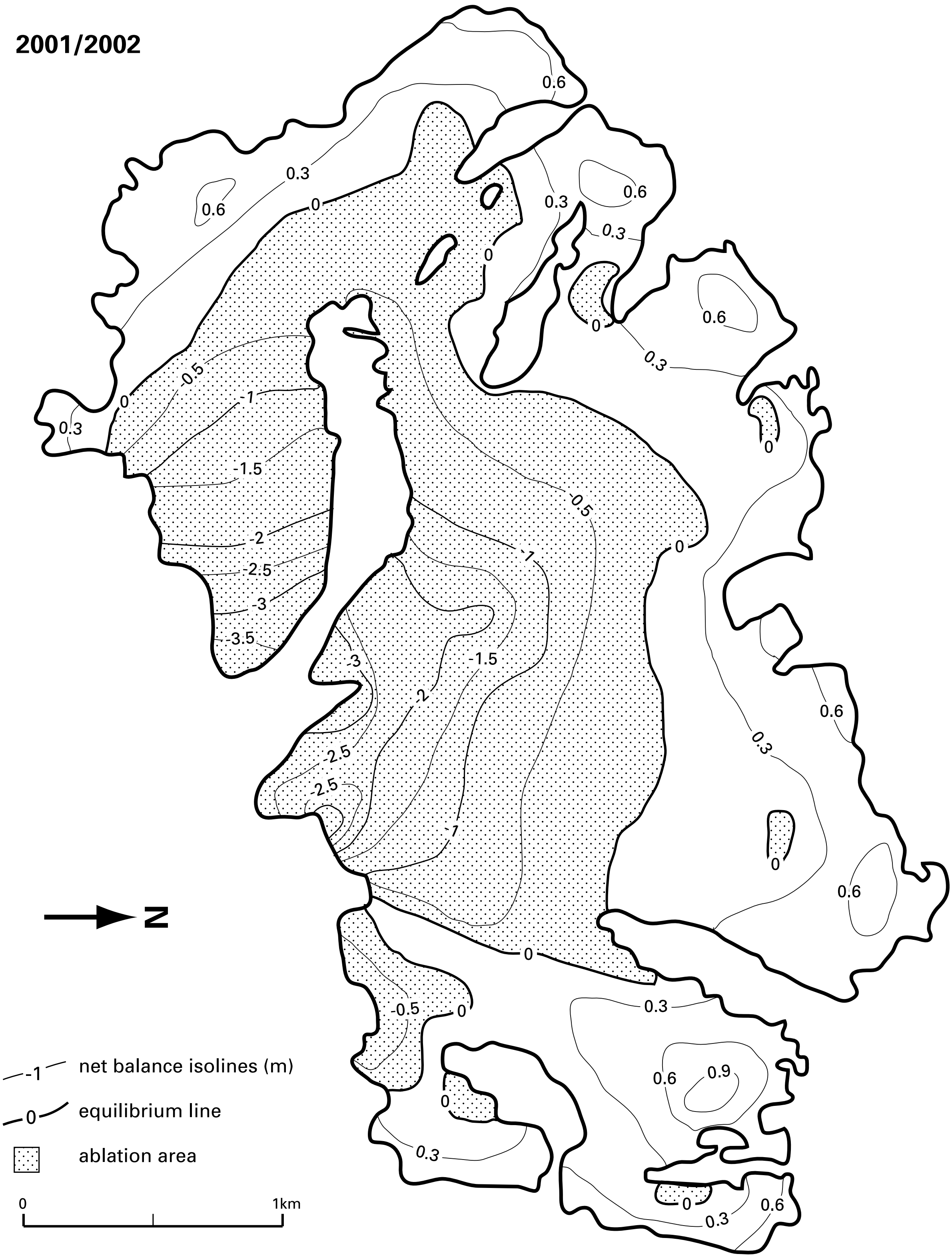
3.3.1 Topography and observational network



Vernagtferner (AUSTRIA)

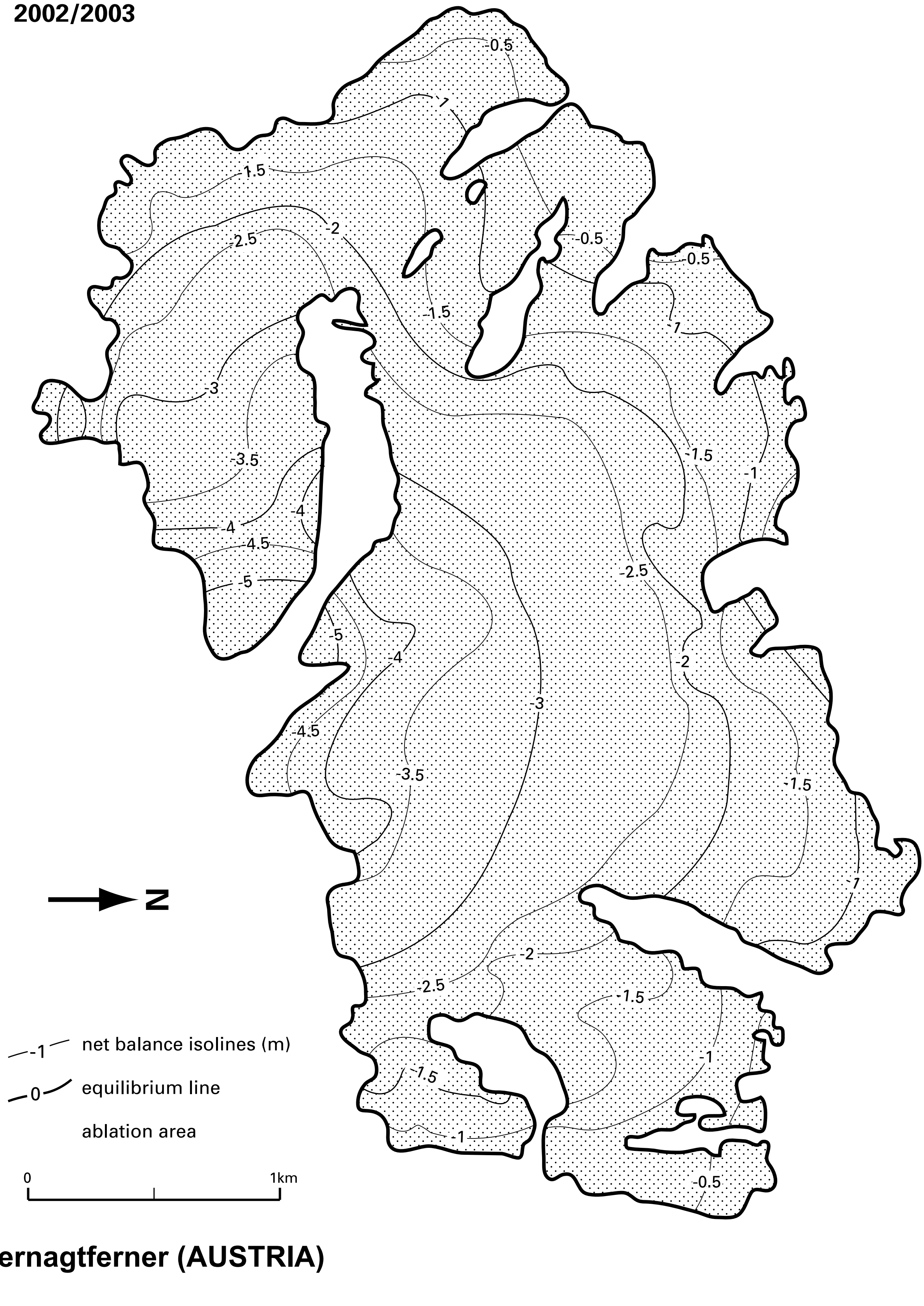
3.3.2 Net balance maps 2001/2002 and 2002/2003

2001/2002



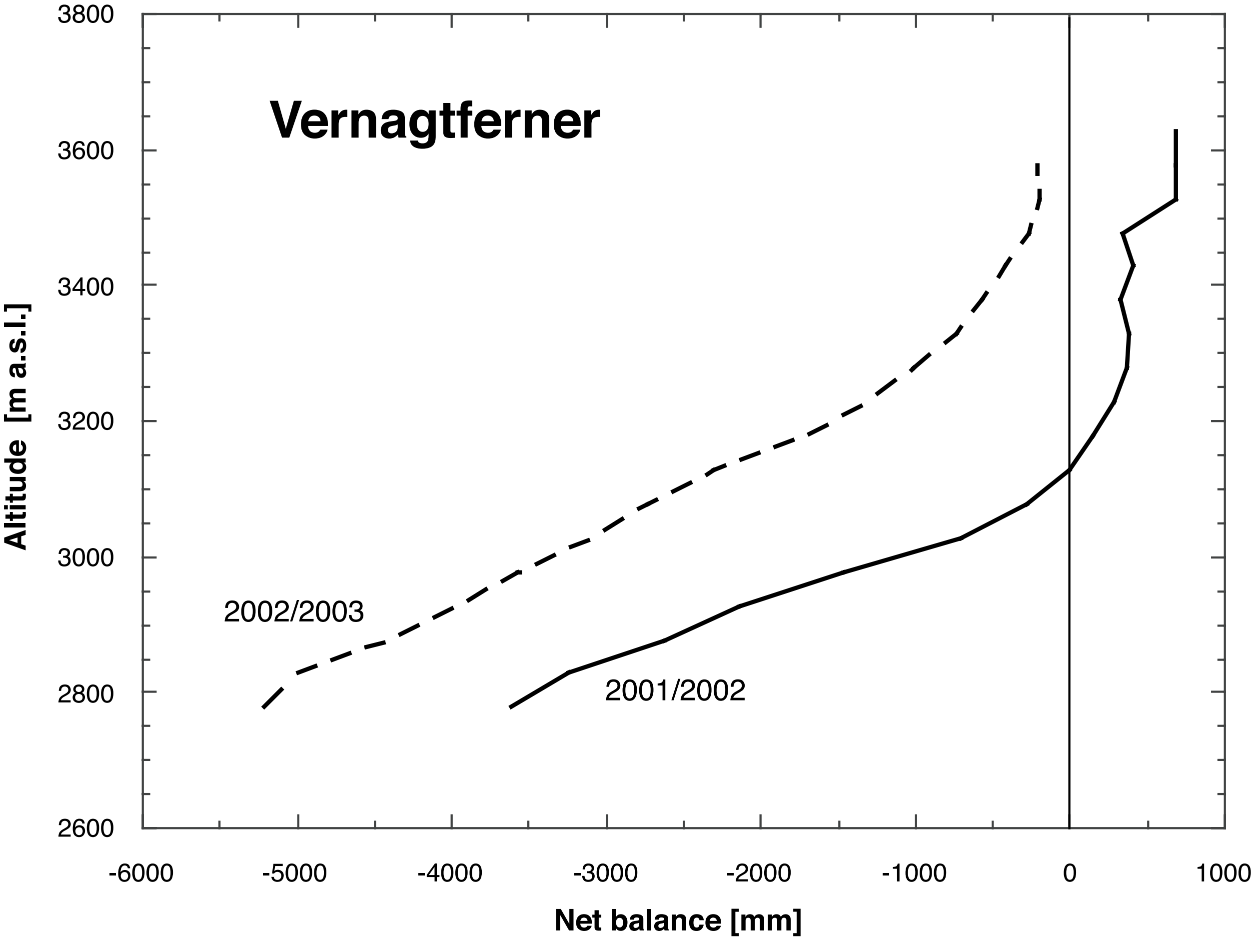
Vernagtferner (AUSTRIA)

2002/2003

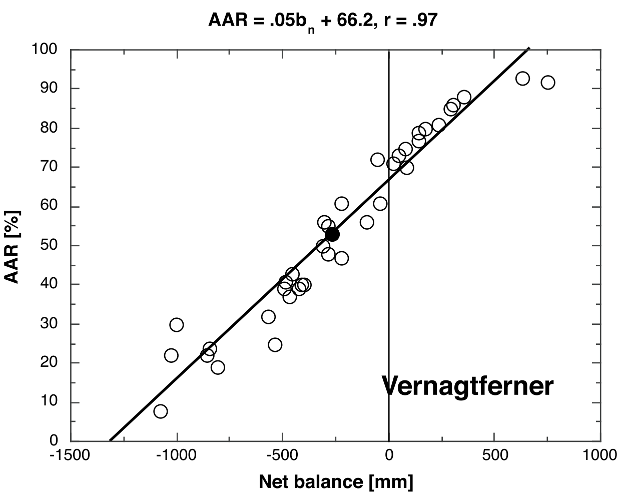


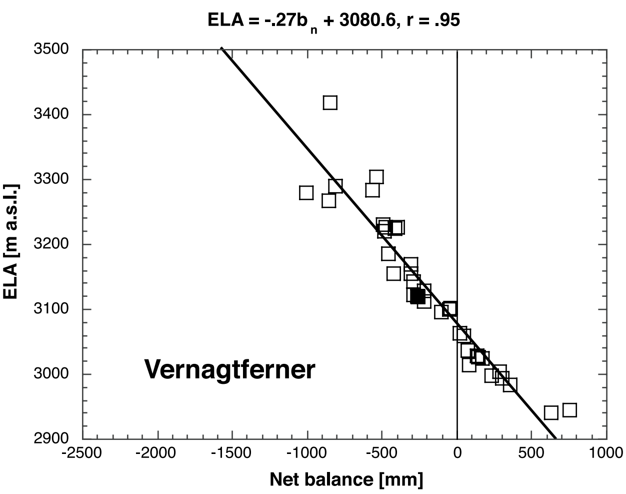
Vernagtferner (AUSTRIA)

3.3.3 Net balance versus altitude (2001/2002 and 2002/2003)



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)

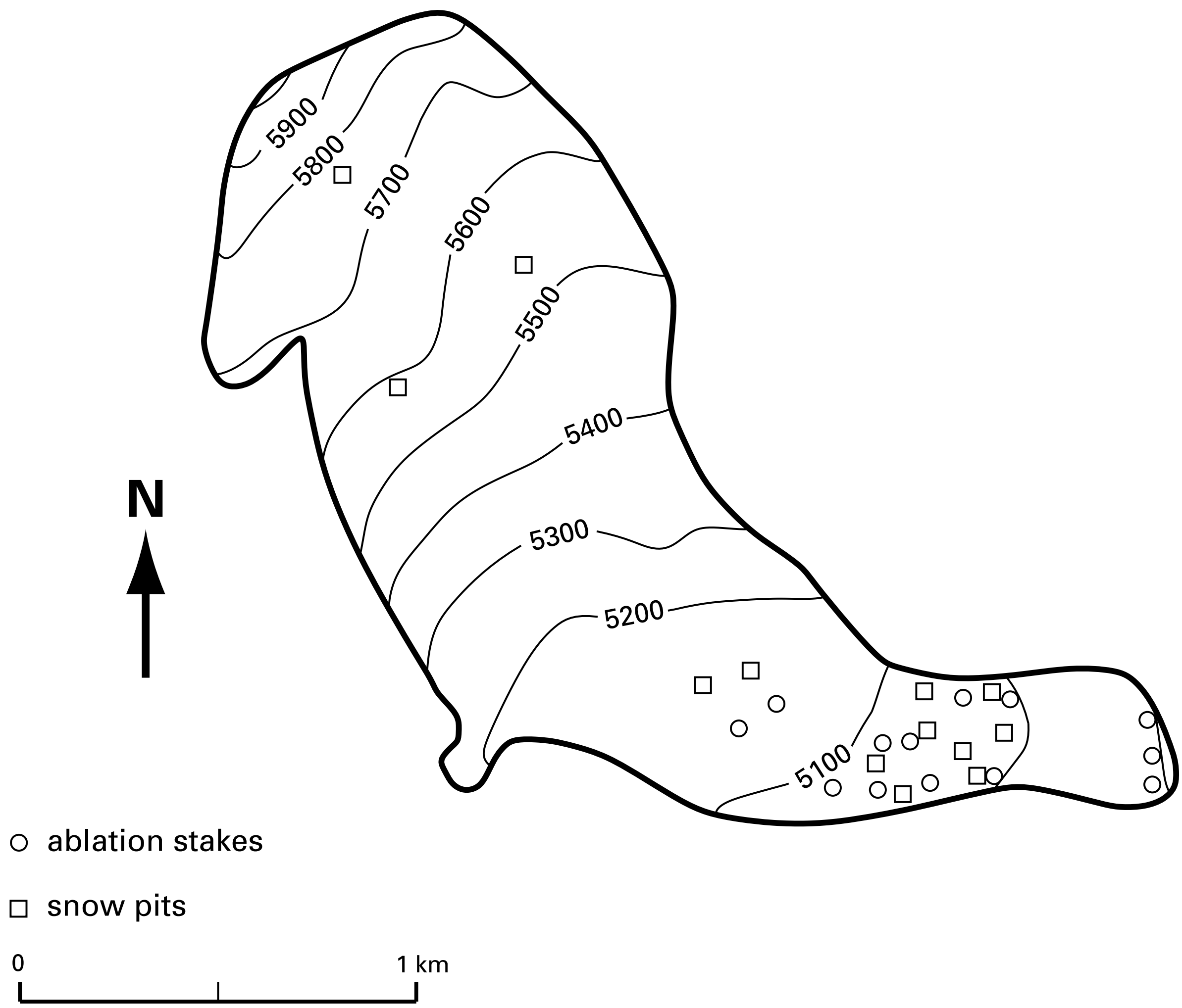
COORDINATES: 16.25 S / 68.17 W

Picture taken by B. Francou on the 23rd of May 2000.

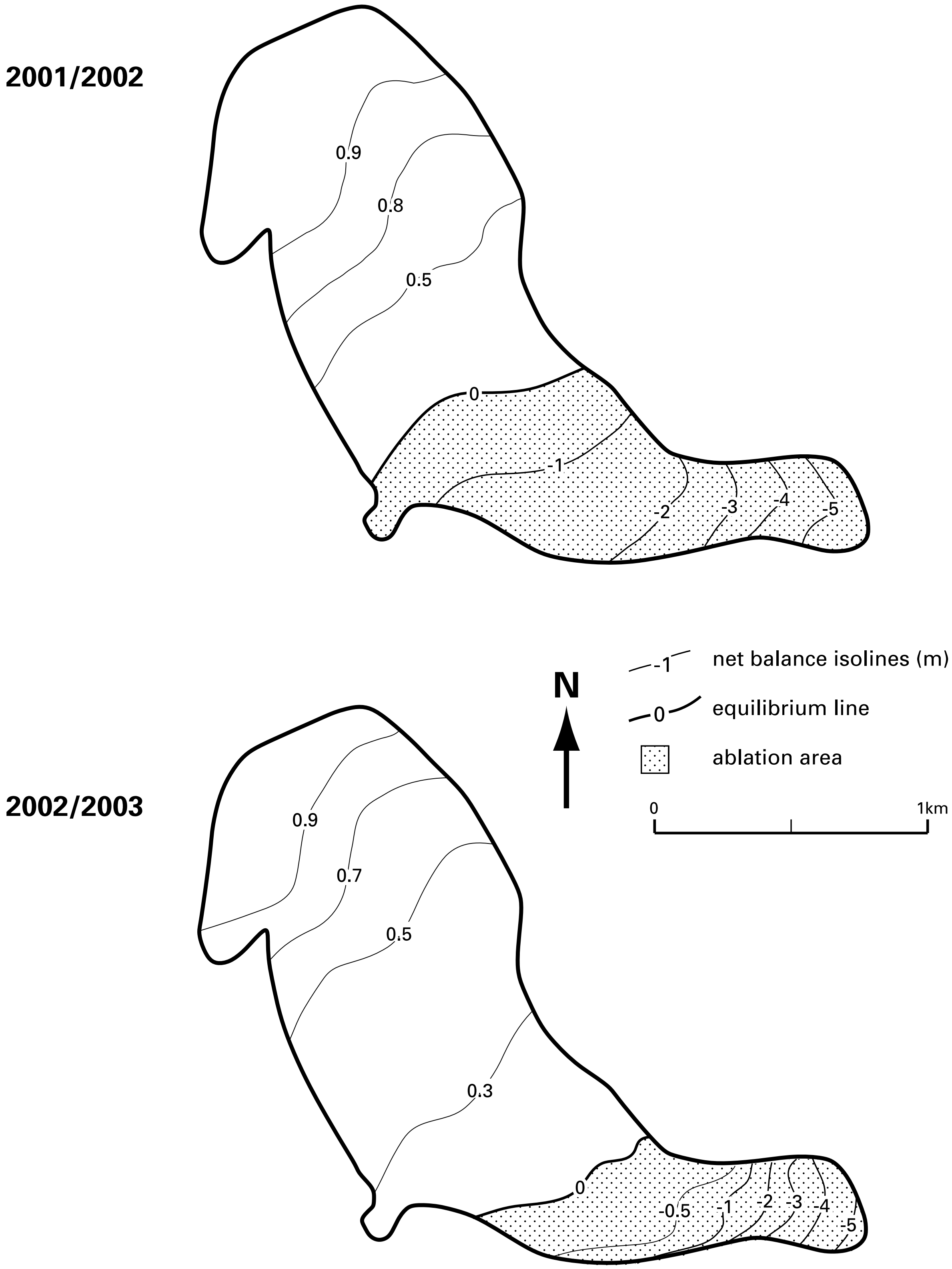
Zongo is a small valley-type glacier located north-east of La Paz, at the head of an important hydraulic power scheme that supplies the city. It is a 3 km long glacier, between 6000 and 4900 m a.s.l. and has a surface area of around 2.1 km^2. Exposure is to the south in the upper part and to the east at the lower tongue. Mean annual air temperature at the equilibrium line (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 in 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 90's and the first years of the following decade (2000–02) 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 temperature and wetter conditions thereby caused high albedo values to persist throughout the whole accumulation season. The year 2002/03 again re-established a moderately negative mass balance as a consequence of a correspondingly moderate positive anomaly in sea-surface temperatures, which developed in the equatorial Pacific early in 2002.

3.4.1 Topography and observational network

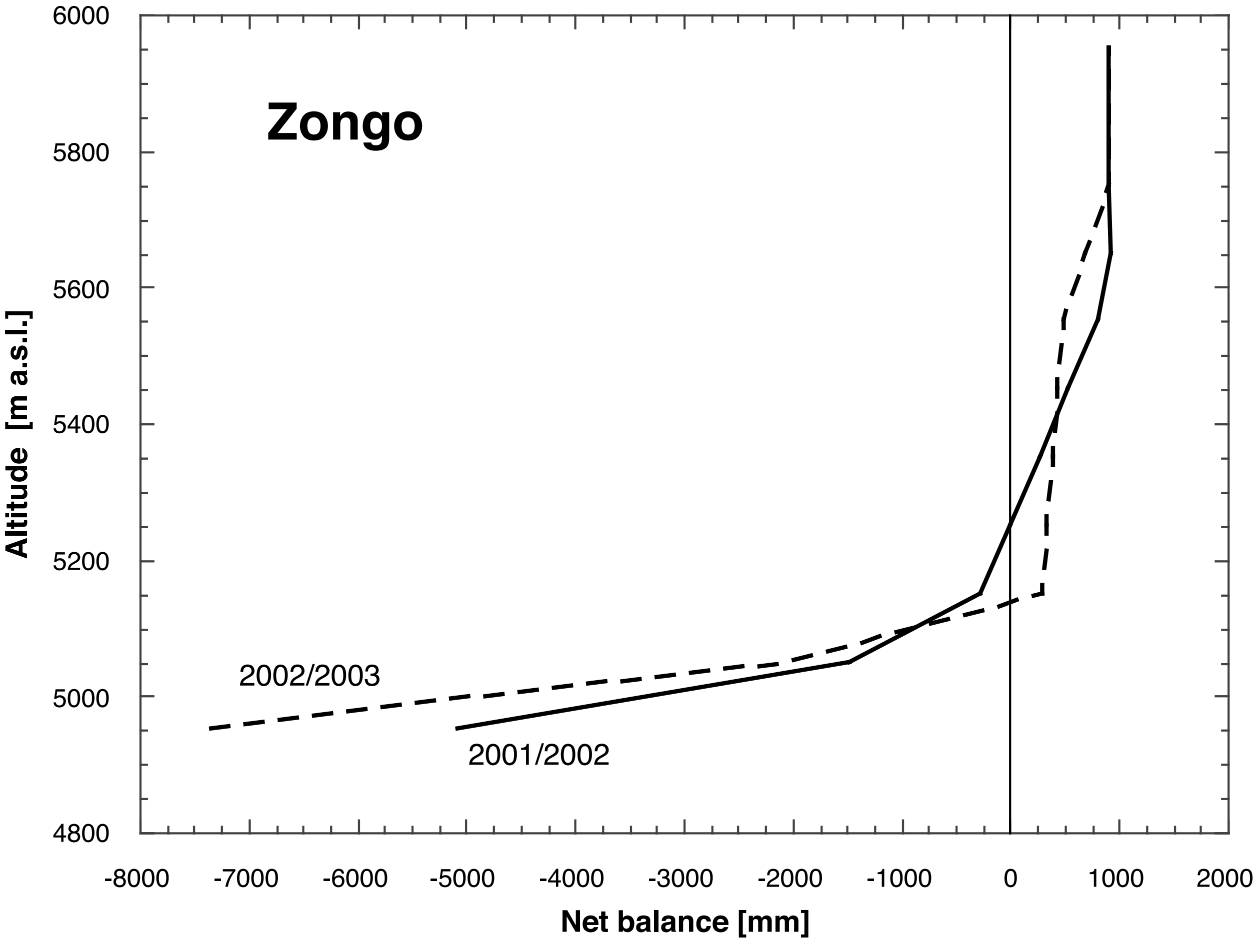


3.4.2 Net balance maps 2001/2002 and 2002/2003

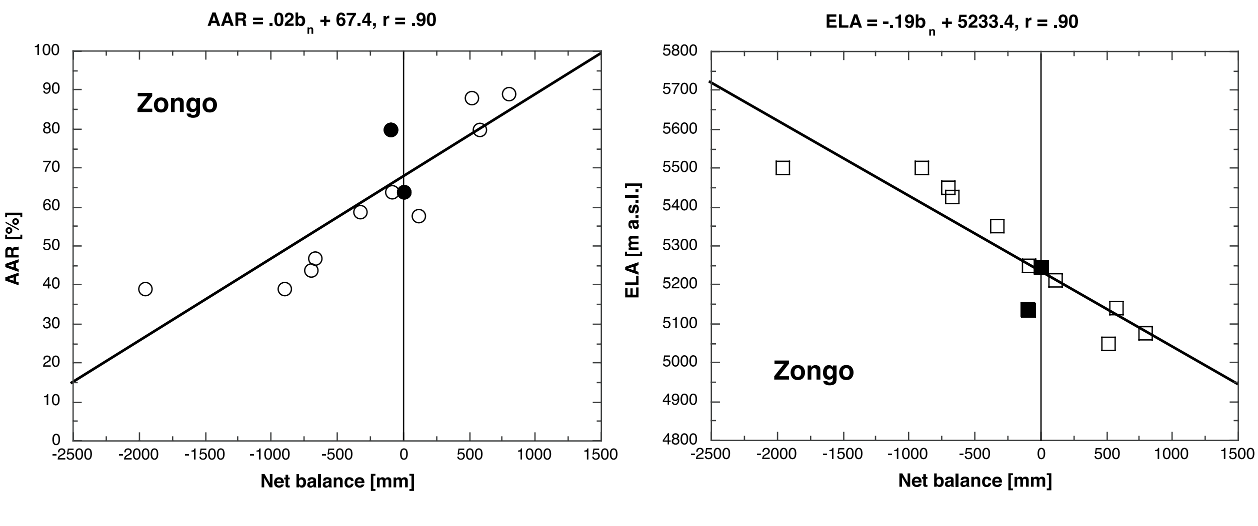


Zongo (BOLIVIA)

3.4.3 Net balance versus altitude (2001/2002 and 2002/2003)



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)

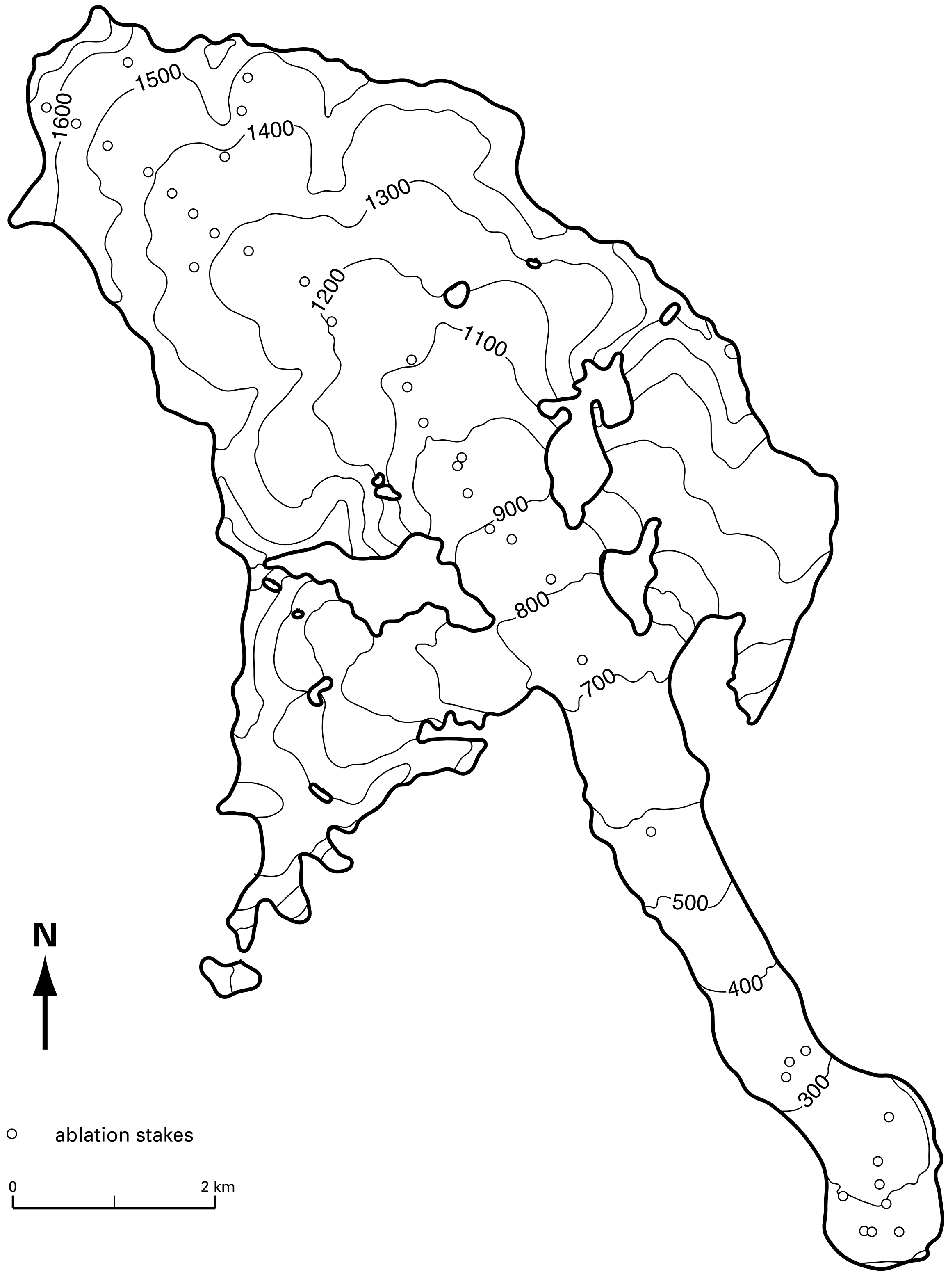
COORDINATES: 79.45 N / 90.67 W

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

White Glacier is a valley glacier occupying 38.7 km^2 in the Expedition Fiord area of Axel Heiberg Island, N.W.T. It extends in elevation from 1782 to 85 m a.s.l. and occupies 39.4 km^2, having shrunk by gradual retreat of its terminus from an extent of 40.2 km^2 in 1960. Based on a recent geodetic resurvey of the lower tongue the estimates of the mass balance have ben adjusted. Mean annual air temperature at sea level in the Expedition Fiord area averages about -20 °C and causes cold permafrost several hundred meters thick to exist in the periglacial areas. The glacier is predominantly cold but known to have a bed which is partly unfrozen, at least beneath the valley tongue. Annual precipitation at sea level is very low, about 100 mm, although annual accumulation at higher altitudes is greater. There is now evidence that the retreat of the terminus, previously about 5 m/a, is decelerating. The neighbouring Thompson Glacier, however, continues to advance. The terminuses of the two glaciers have been in contact since at least 1948, the time of the earliest photographs. Although the two terminuses remain distinguishable, the White Glacier has become a tributary of the Thompson Glacier.

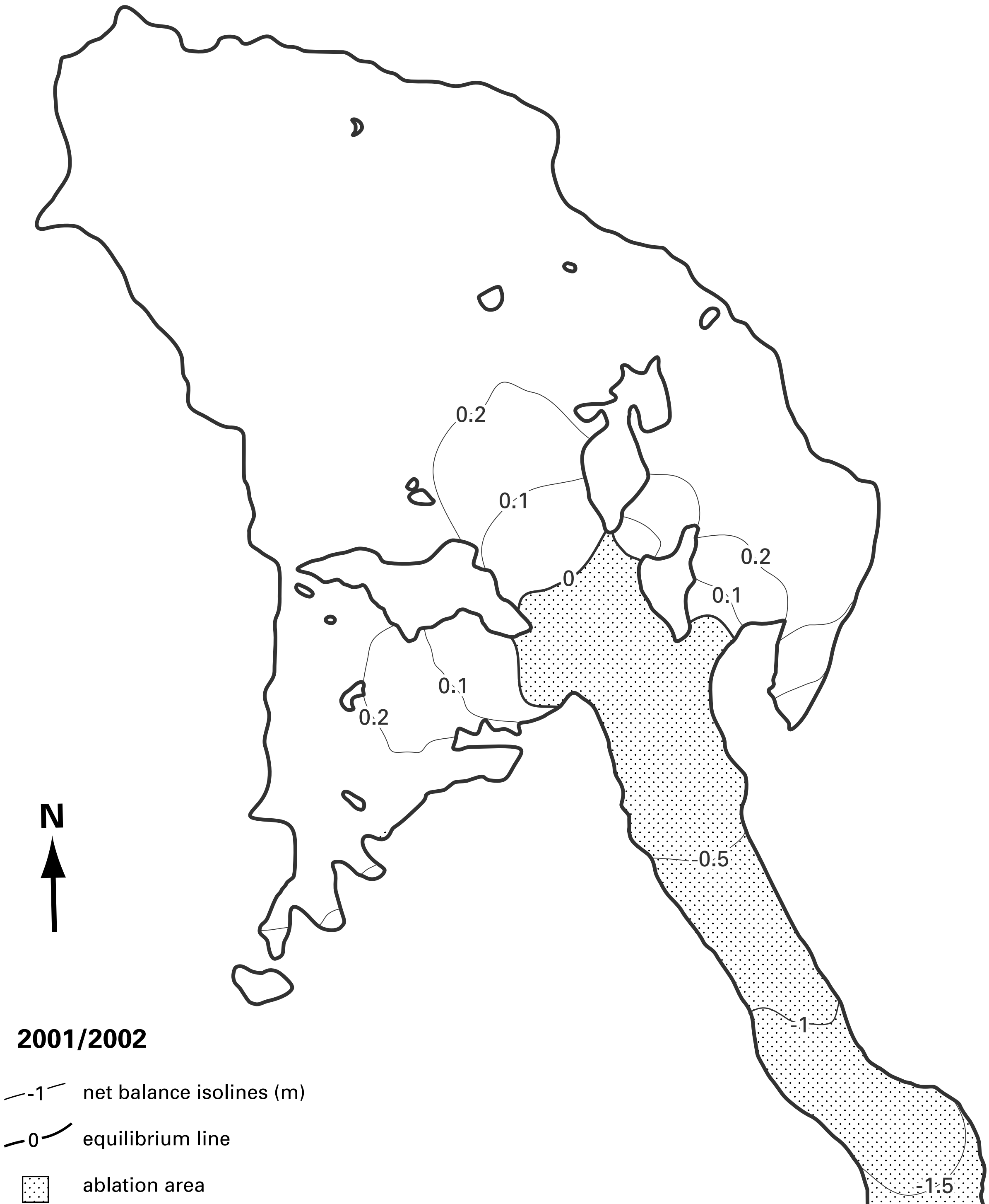
The balance years 2001/02 (32 mm w.e.) and 2002/03 (-106 mm w.e.) on White Glacier were close to normal. The newly updated average mass balance is -95 mm w.e. for 1960–91. The cumulative balance since 1959/60, with due allowance for three missing years, is -5800 mm w.e.

3.5.1 Topography and observational network

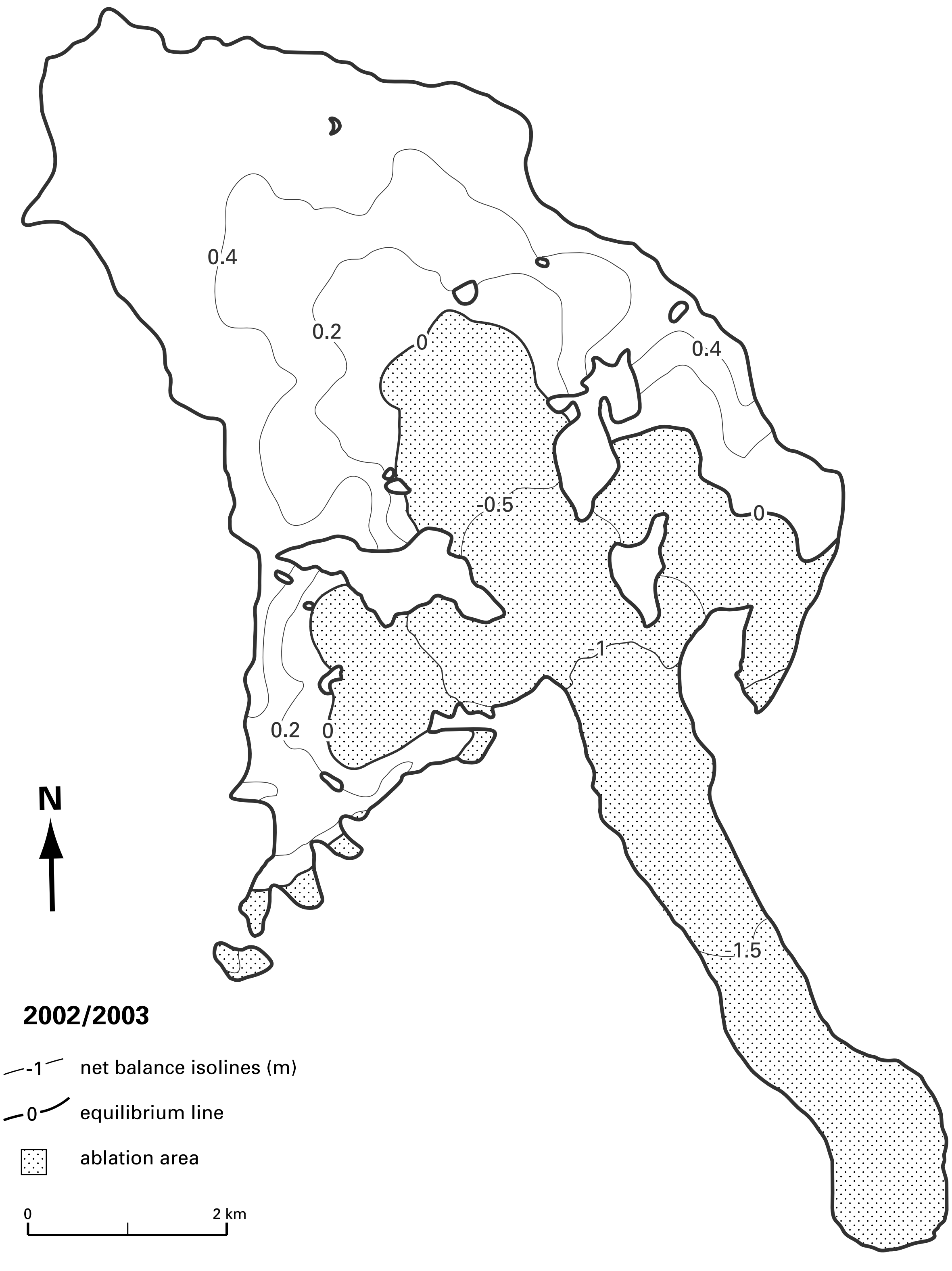


White (CANADA)

3.5.2 Net balance maps 2001/2002 and 2002/2003

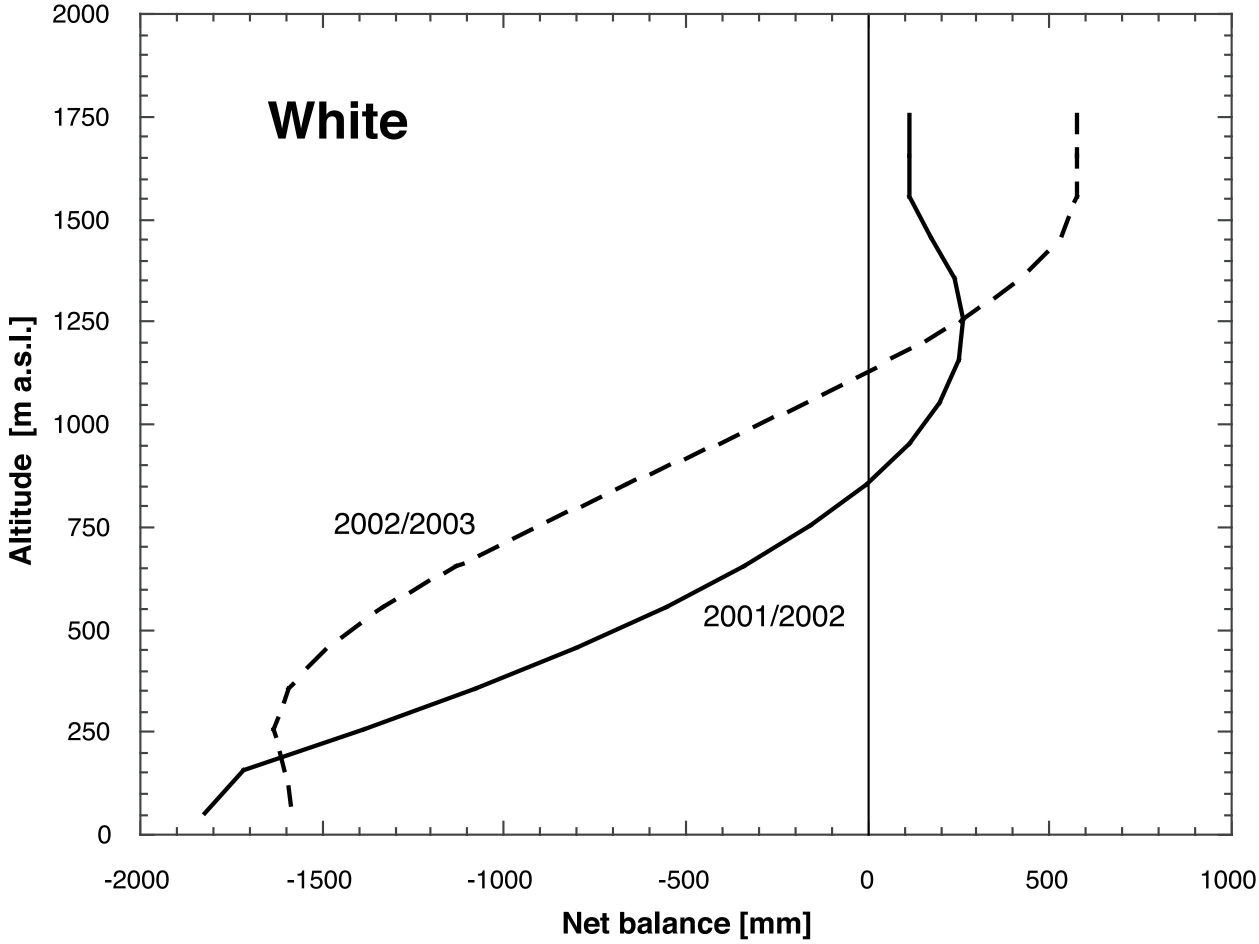


White (CANADA)

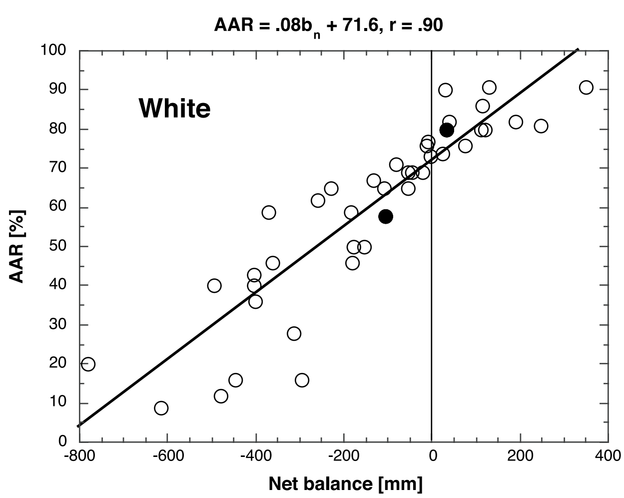


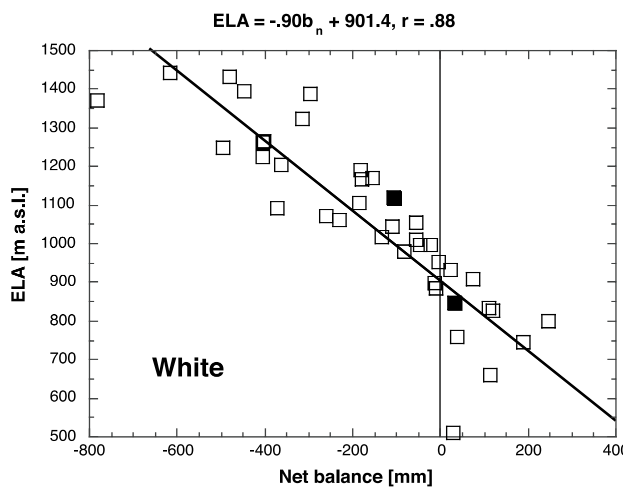
White (CANADA)

3.5.3 Net balance versus altitude (2001/2002 and 2002/2003)



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)

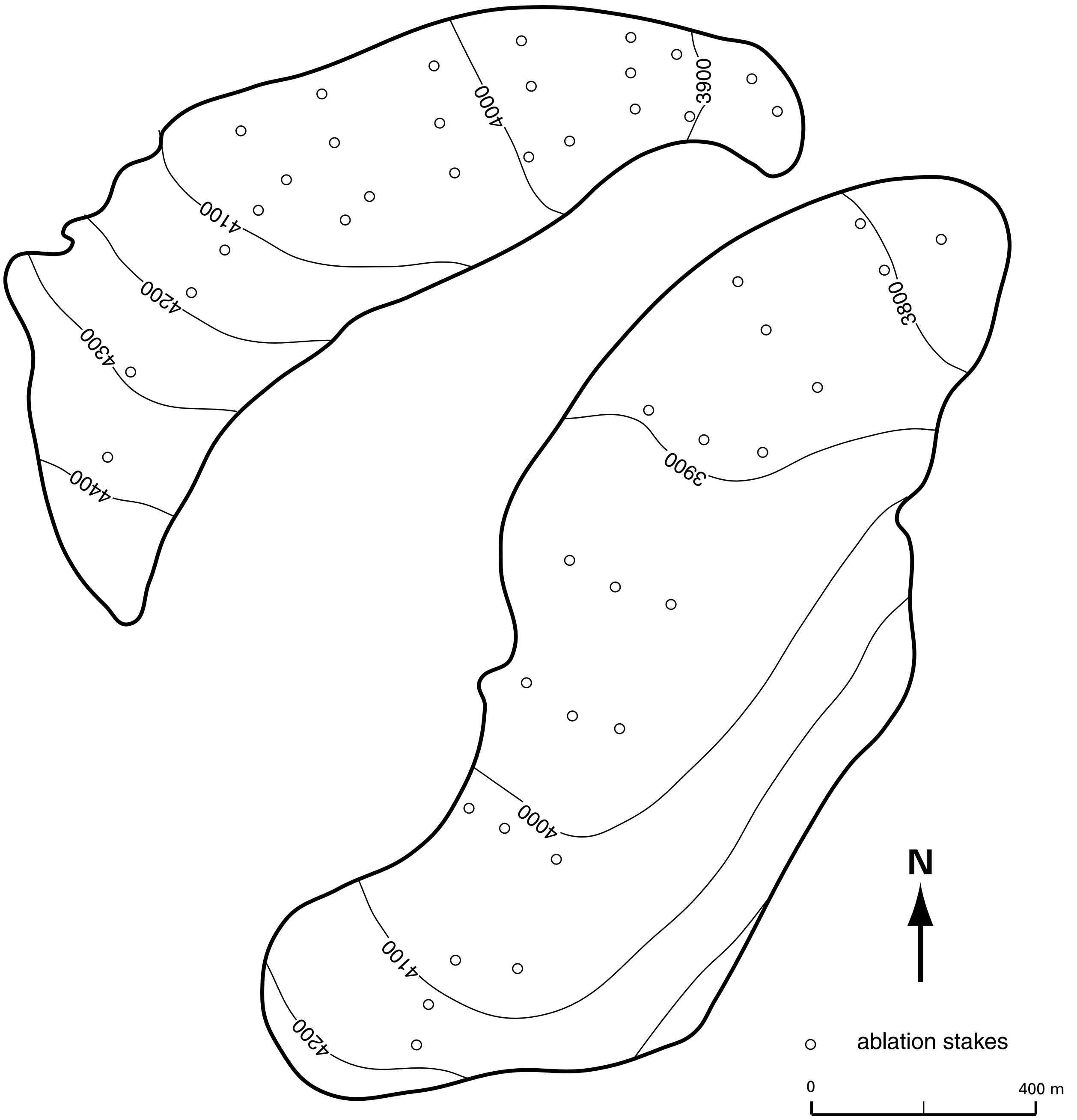
COORDINATES: 43.08 N / 86.82 E

Picture taken by Yang Huian in August 2001.

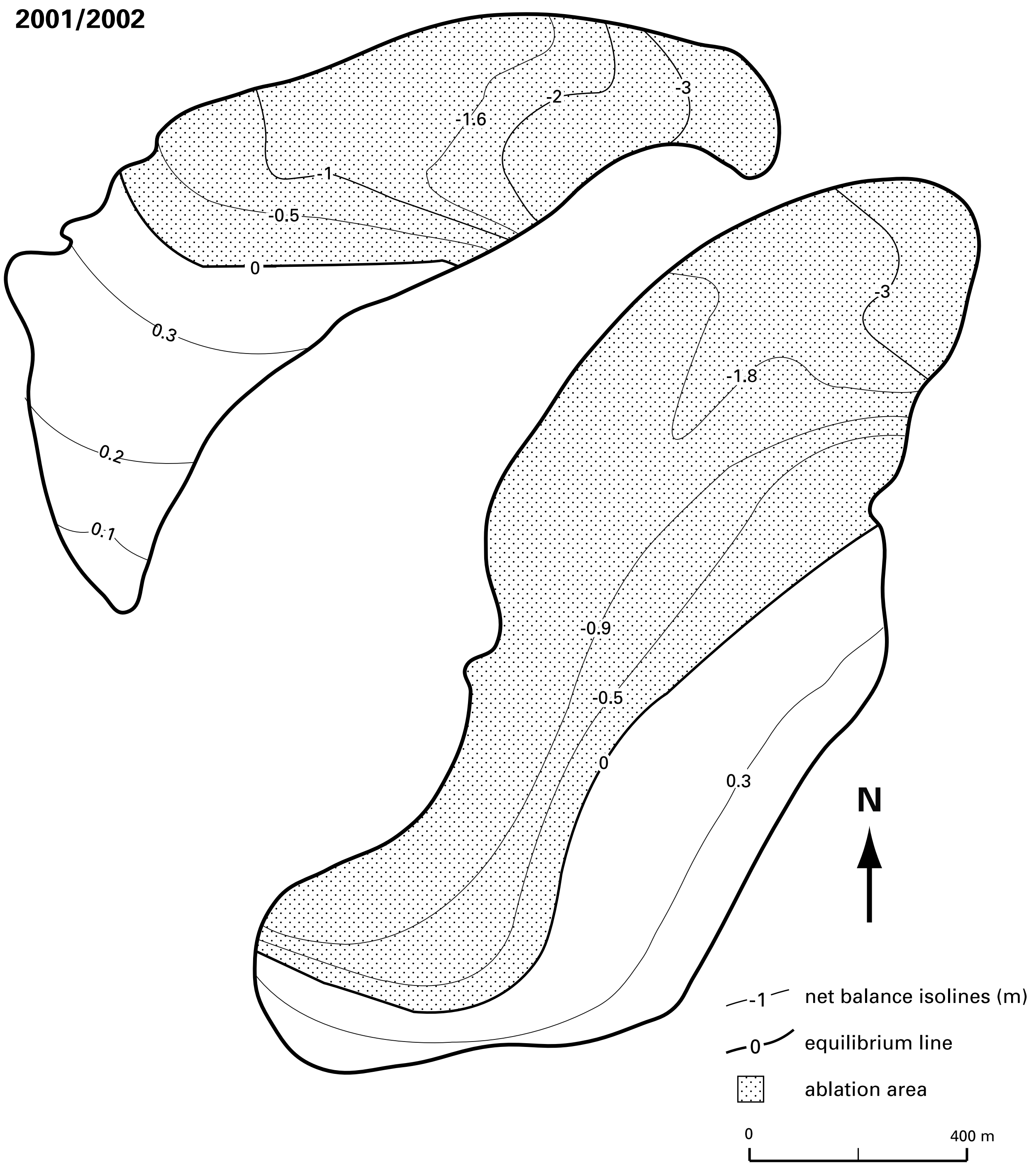
Due to continued glacier shrinkage, the two branches of the former glacier have become separated into two small glaciers but are still called the East and West branch of Glacier No. 1, respectively. The East branch has a total area of 1.1 km^2, the highest and lowest points are at 4267 m and 3742 m a.s.l. 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. The average annual precipitation is 400 to 500 mm at the nearby meteorological station located at 3539 m a.s.l. and 600 to 700 mm at the glacier. Mean annual air temperature at the equilibrium line (4096 m a.s.l. for years with a zero balance) is estimated at -8.0 to -9.0 °C. The predominantly cold glacier is surrounded by continuous permafrost but reaches melting temperatures over wide areas of the bed. Accumulation and ablation both primarily take place during the warm season and the formation of superimposed ice on this continental-type glacier is important. A 1:5’000 topographic map of the glacier and its forefield, dating from August 2001, is available for further analysis.

The mass balances (-871 mm w.e for the East branch, -767 mm w.e. for the West branch) of the year 2001/02 are the most negative values ever observed since the beginning of observation. The mass balance remained negative in 2002/03 (-387 mm w.e. for the East branch and -377 mm w.e. for the West branch). The calculated mean for the entire glacier was -834 mm w.e. in 2001/02 and -384 mm w.e. in 2002/03, respectively.

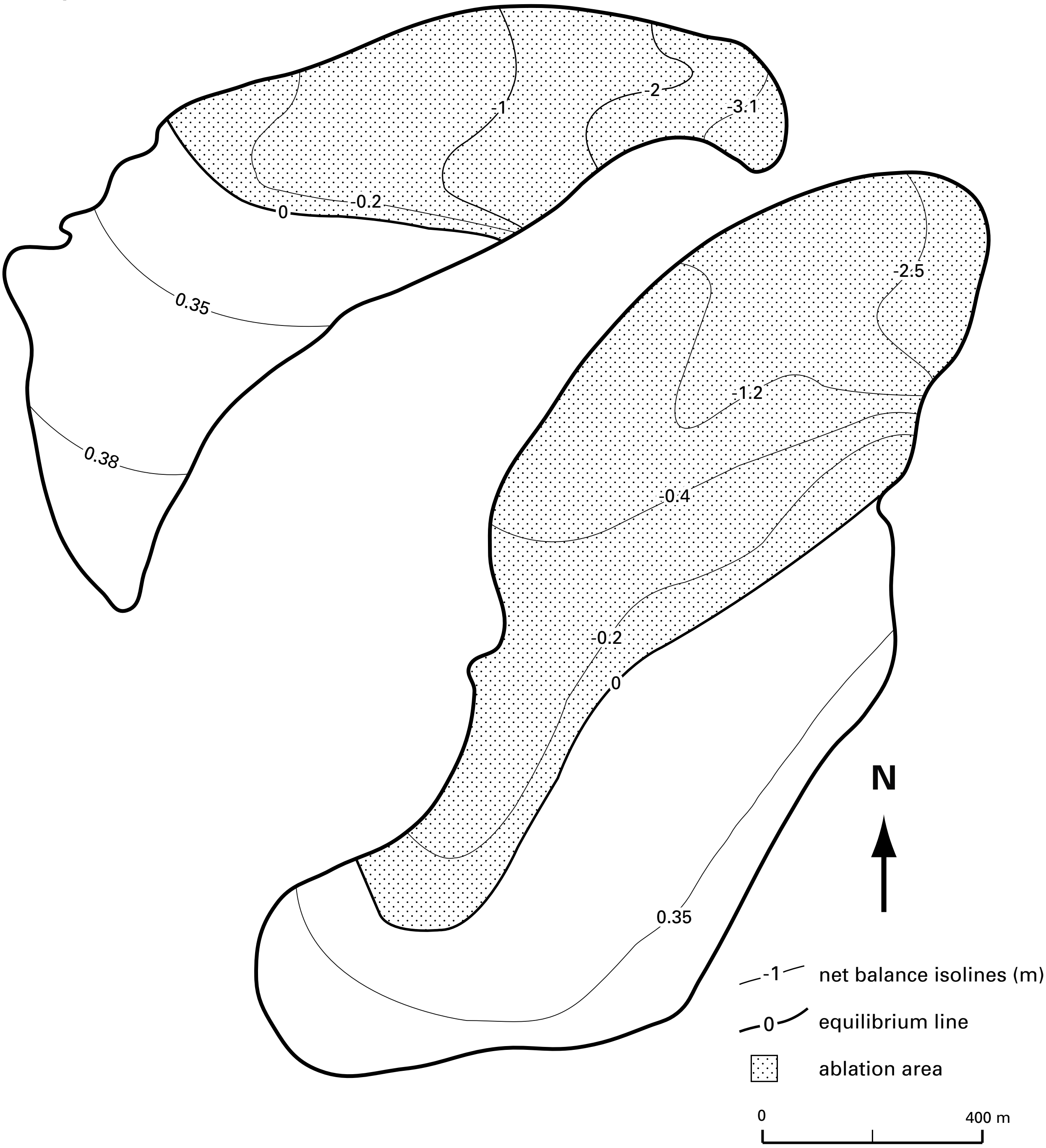
3.6.1 Topography and observational network



3.6.2 Net balance maps 2001/2002 and 2002/2003

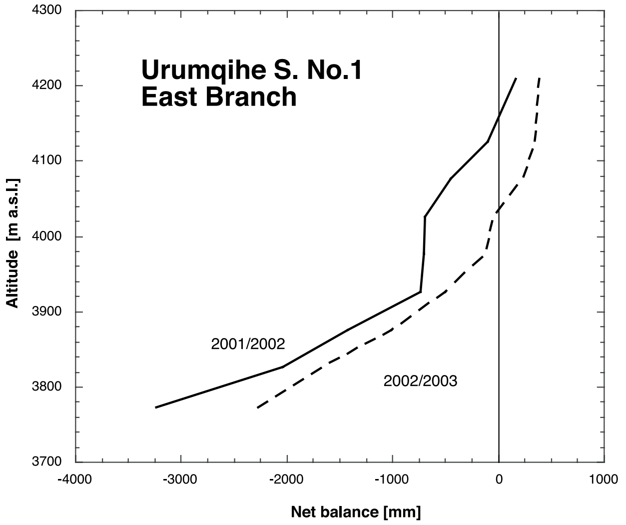


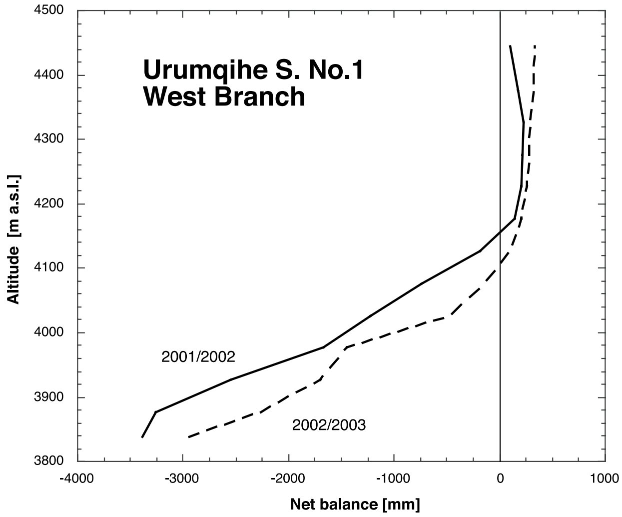
2002/2003



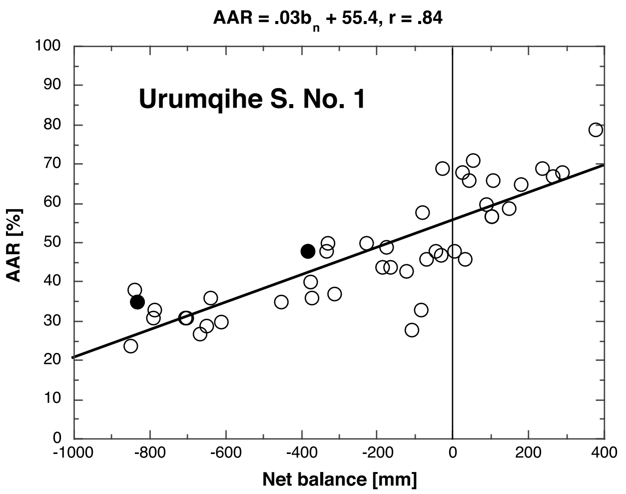
Urumqihe S. No. 1 (CHINA)

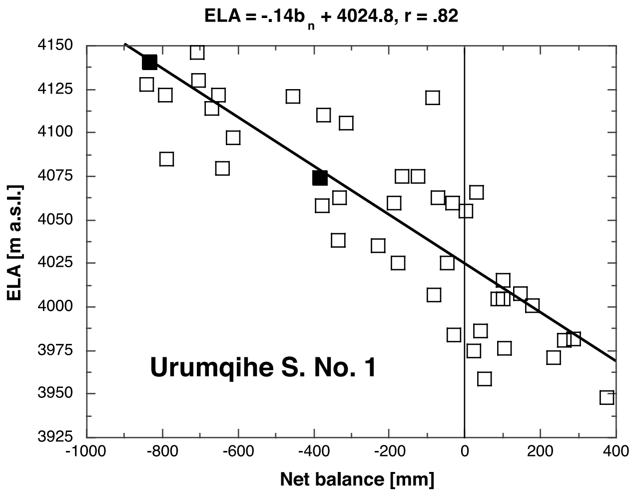
3.6.3 Net balance versus altitude (2001/2002 and 2002/2003)





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





3.7 FONTANA BIANCA (ITALY/CENTRAL ALPS)

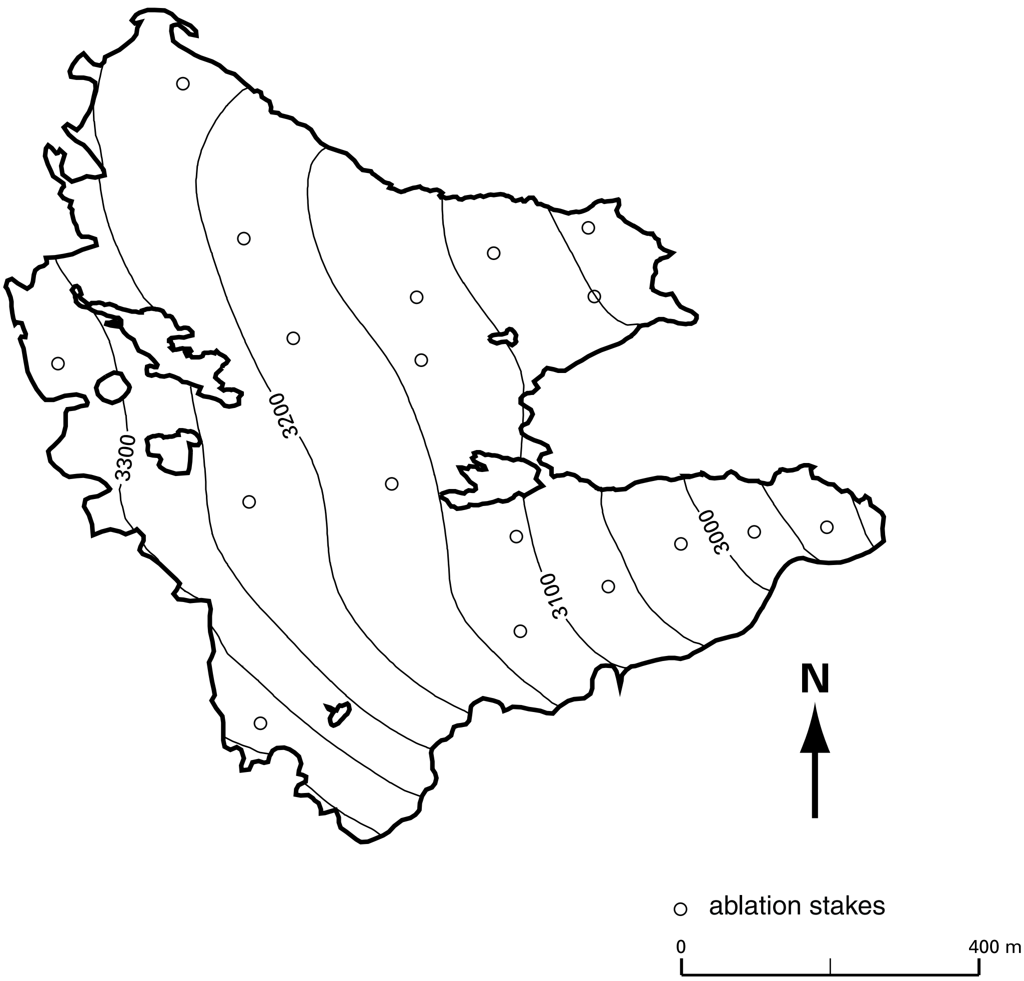
COORDINATES: 46.48 N / 10.77 E

Picture taken by F. Meissl in August 2003.

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 0.61 km^2, extends from 3370 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 gauging station (1900 m a.s.l.) mean annual air temperature is 3.1 °C and precipitation, on average, amounts to 970 mm per year. Because of continued mass loss and equilibrium line altitudes usually reaching above the highest point of the glacier, ice movement has reduced to near-zero. As a consequence, the remaining ice body starts to show first signs of disintegration with several fast growing rock islands.

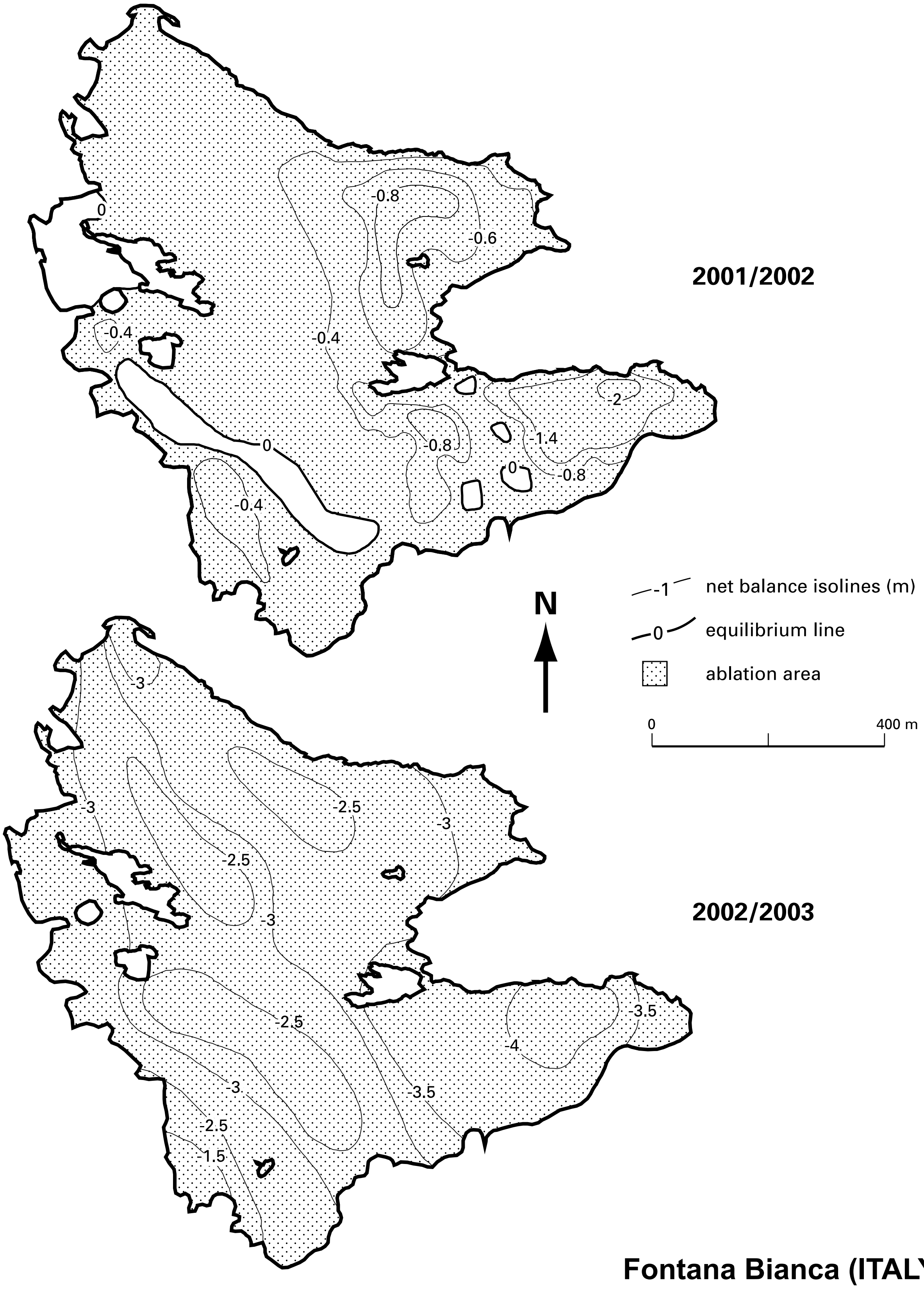
After the year 2000/01 with the first positive mass balance since 1991/92, the balance year 2001/02 brought a rather moderate net mass loss of -435 mm w.e. The equilibrium line altitude was at 3320 m a.s.l. In 2002/03, however, the most negative mass balance was recorded since measurements began in 1991. A mass loss of -2950 mm w.e. resulted from the unusually hot and dry conditions during the extreme summer of 2003. The cumulative mass balance since 1991 is -10724 mm w.e., i.e., not far from -1000 mm w.e. per year.

3.7.1 Topography and observational network

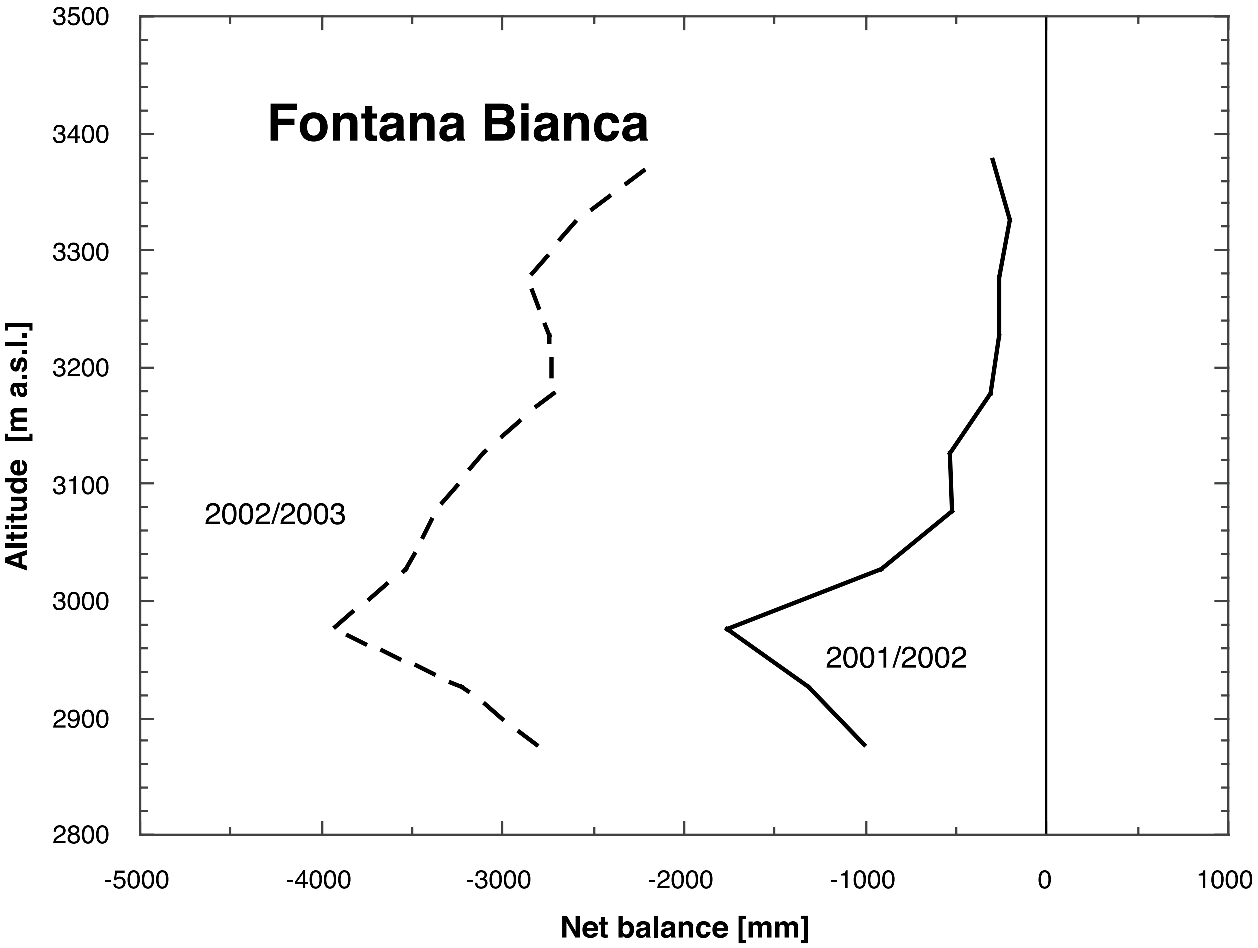


Fontana Bianca (ITALY)

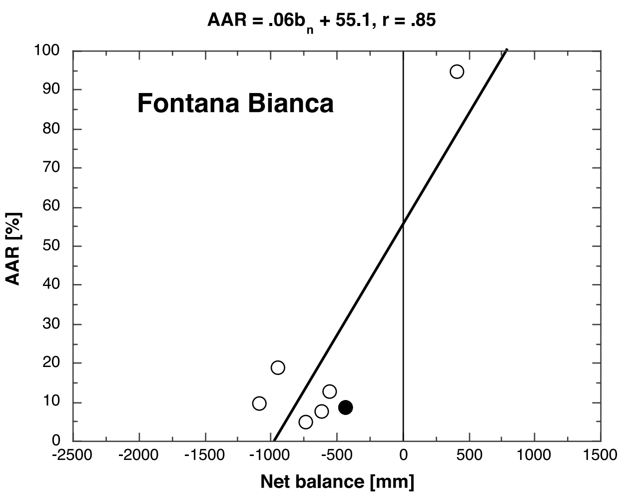
3.7.2 Net balance maps 2001/2002 and 2002/2003

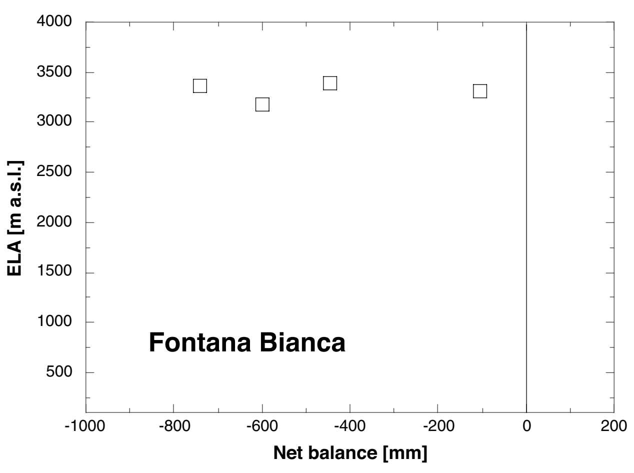


3.7.3 Net balance versus altitude (2001/2002 and 2002/2003)



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





3.8 TSENTRALNIY TUYUKSUYSKIY (KAZAKHSTAN/TIEN SHAN)

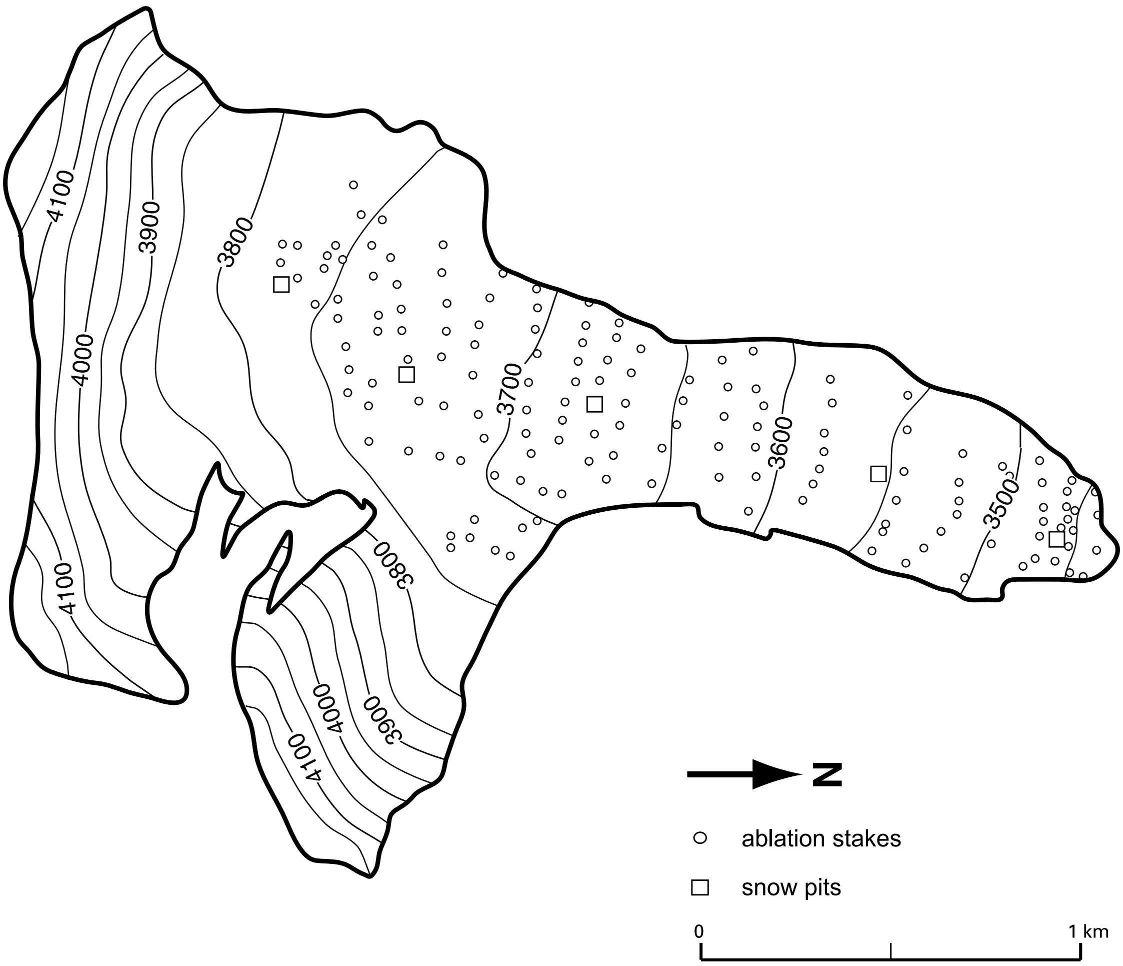
COORDINATES: 43.05 N / 77.08 E

Picture taken by V.P. Blagoveshchenskiy in September 2003.

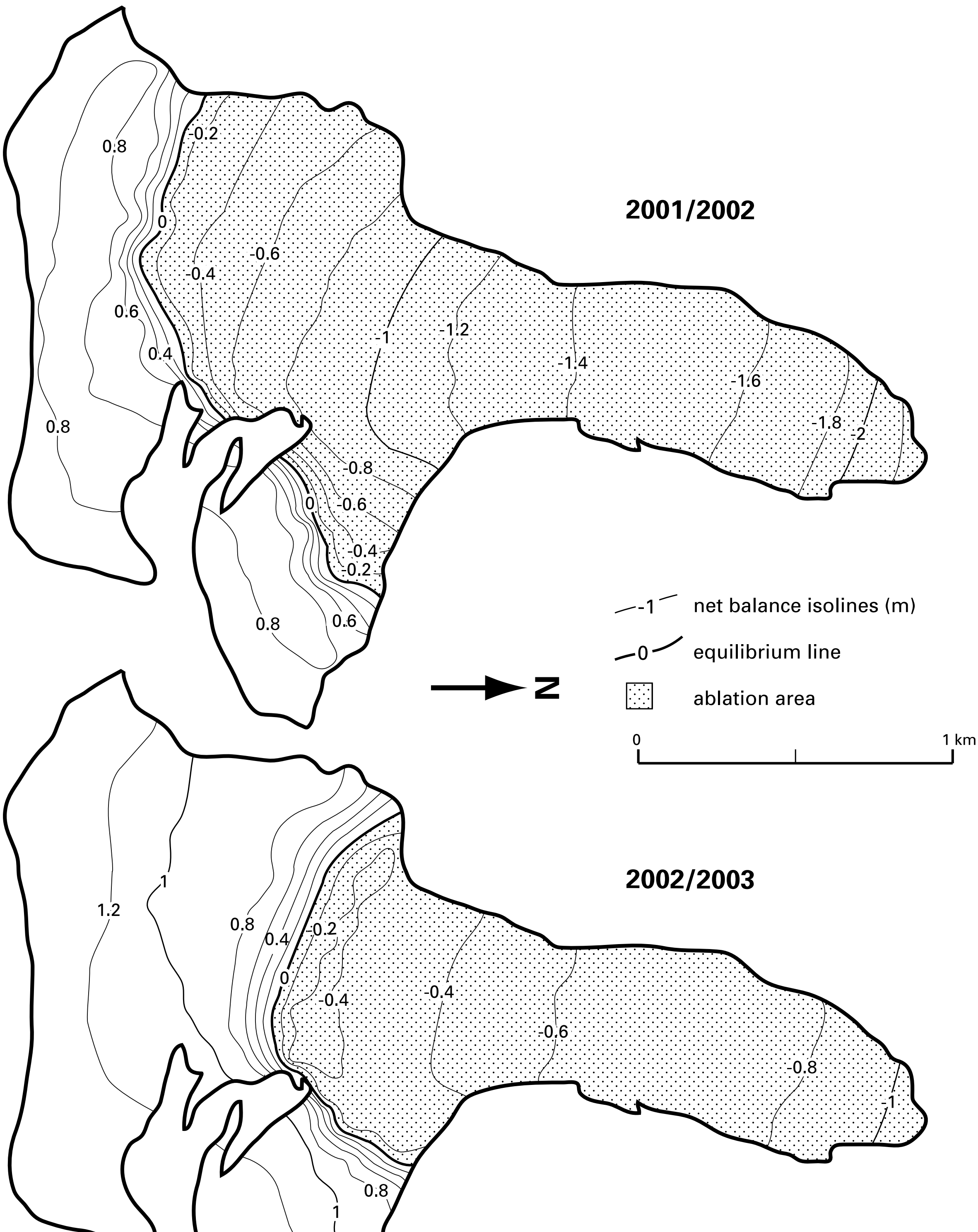
The valley type glacier in the Zailiyskiy Alatau Range of the Kazakh Tien Shan is also called the Tuyuksu Glacier. It extends from 4200 to 3425 m a.s.l. and has a surface area of 2.6 km^2 (including debris-covered ice) with the exposure being to the north. Annual mean air temperature at the equilibrium line of the glacier (around 3800 m a.s.l. for balanced conditions) is between -5.5 to -6.5 °C. The glacier is considered to be cold to polythermal and surrounded by continuous permafrost. Average annual precipitation as measured with a great number of precipitation gauges is about 1000 mm at the glacier. Characteristic features of the highly continental climatic conditions are stable winter anticyclones, low air temperature and a summer peak of precipitation (30% of the annual sum in 2001/02 and 64% in 2002/03).

The summer season of 2001/02 was 0.6 °C warmer than the average value for the period 1971/72–2002/03, while precipitation was 70% less than average. The summer temperature in 2002/03 was 1.5 °C lower than the average value, and precipitation was 150% higher then normal. As a result of these conditions, the glacier mass balance was -300 mm w.e. in 2001/02 and 360 mm w.e. in 2002/03. The positive balance of 2002/03 was the fourth case in the observational series for the last 32 years (1972, 1981, 1993, 2003).

3.8.1 Topography and observational network

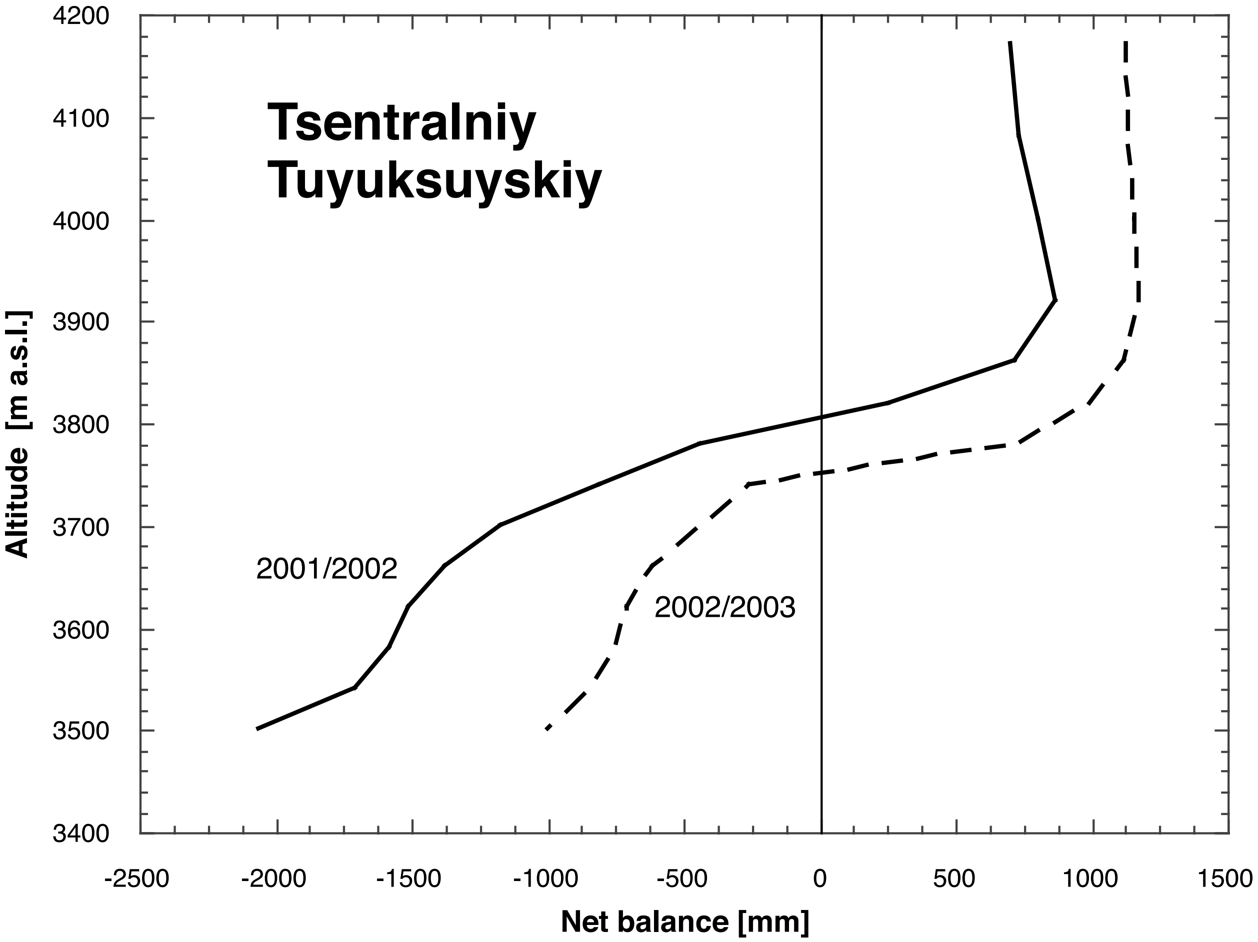


3.8.2 Net balance maps 2001/2002 and 2002/2003

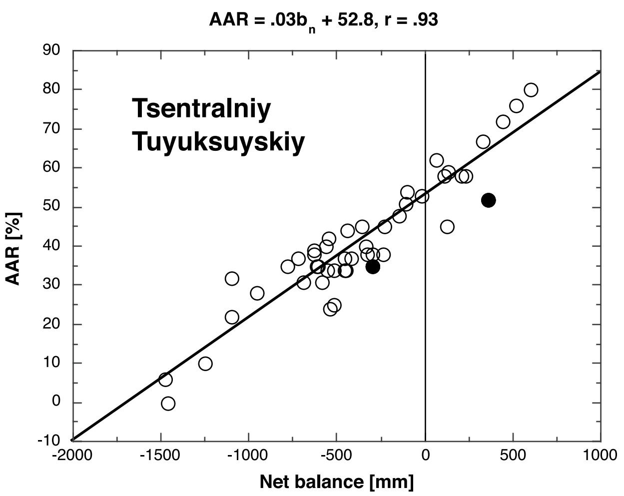


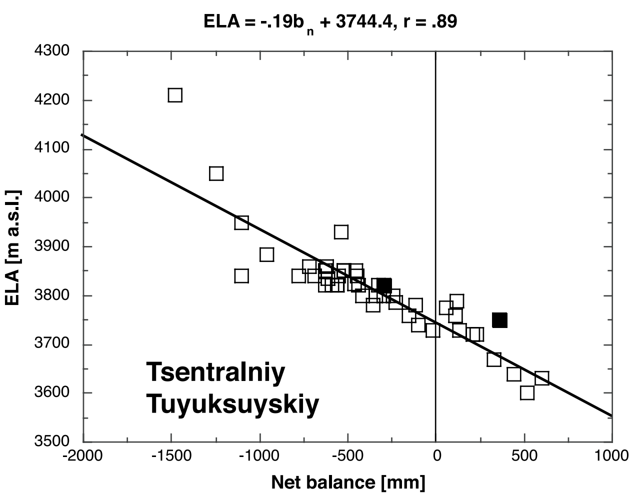
Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.8.3 Net balance versus altitude (2001/2002 and 2002/2003)



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





3.9 NIGARDSBREEN (NORWAY/WEST NORWAY)

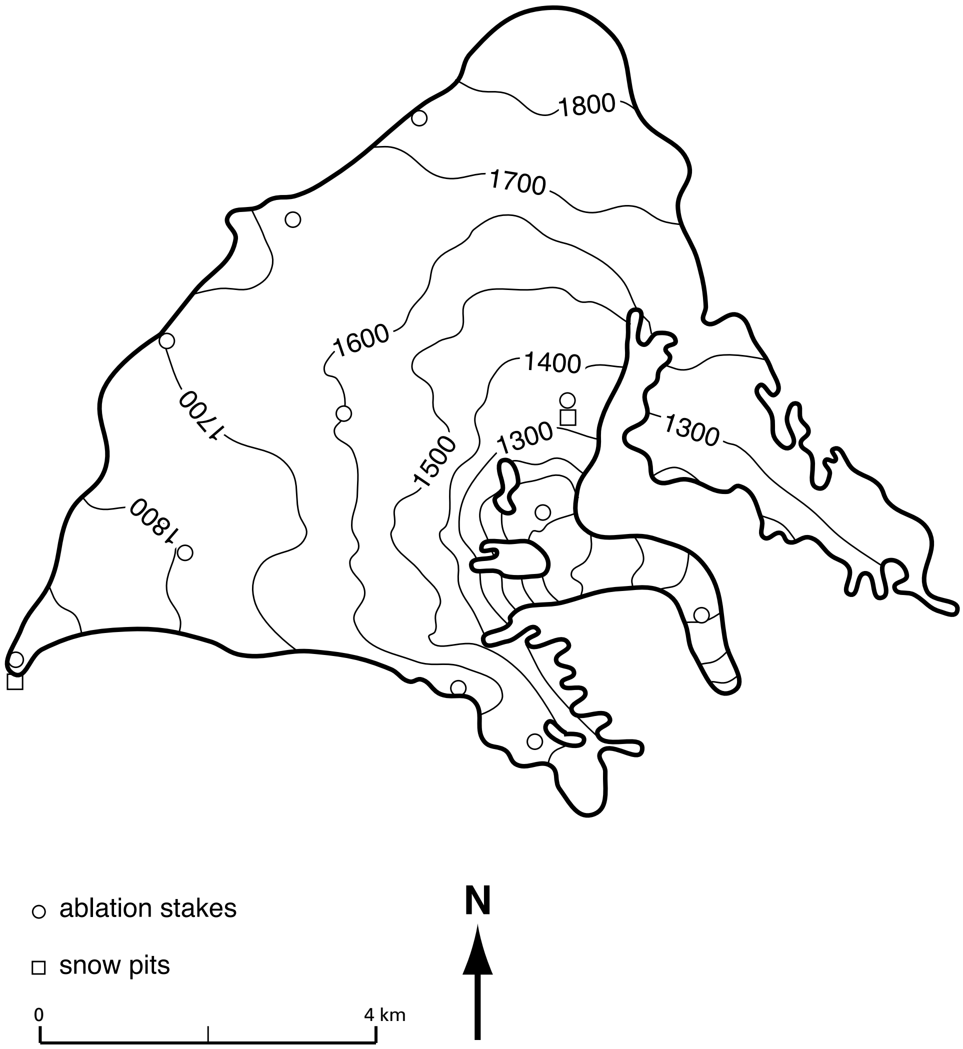
COORDINATES: 61.72 N / 07.13 E

Picture taken by B. Kjøllmoen on the 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.

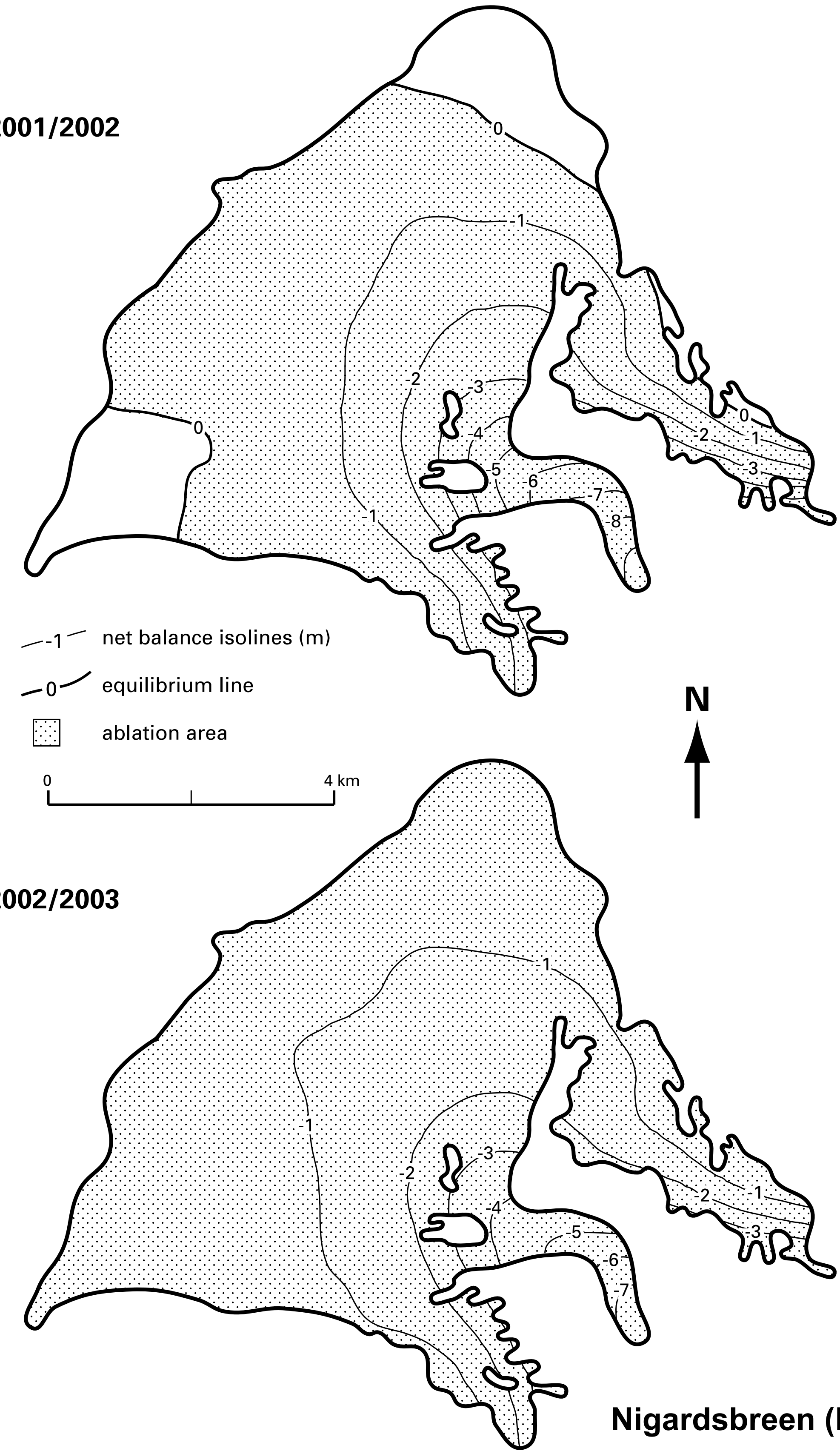
In 2001/02, the winter balance was 2410 mm w.e. (100% of the mean value for the total observation period) and the summer balance was -3300 mm w.e. (172% of the average 1962–2001 and the strongest loss measured since 1962). The resulting mass balance is -890 mm w.e. and the calculated equilibrium line altitude is about 1715 m a.s.l. In 2002/03, the winter balance was 1560 mm w.e. (65% of the average for the period 1962–2002) and the summer balance was -2720 mm w.e. (139% of the long-term mean). The resulting mass balance was -1160 mm w.e. The calculated equilibrium line altitude is above the glacier summit (>1960 m a.s.l.). Since 1962, the cumulative mass balance is now calculated as 17300 mm w.e., still close to 400 mm w.e. per year.

3.9.1 Topography and observational network



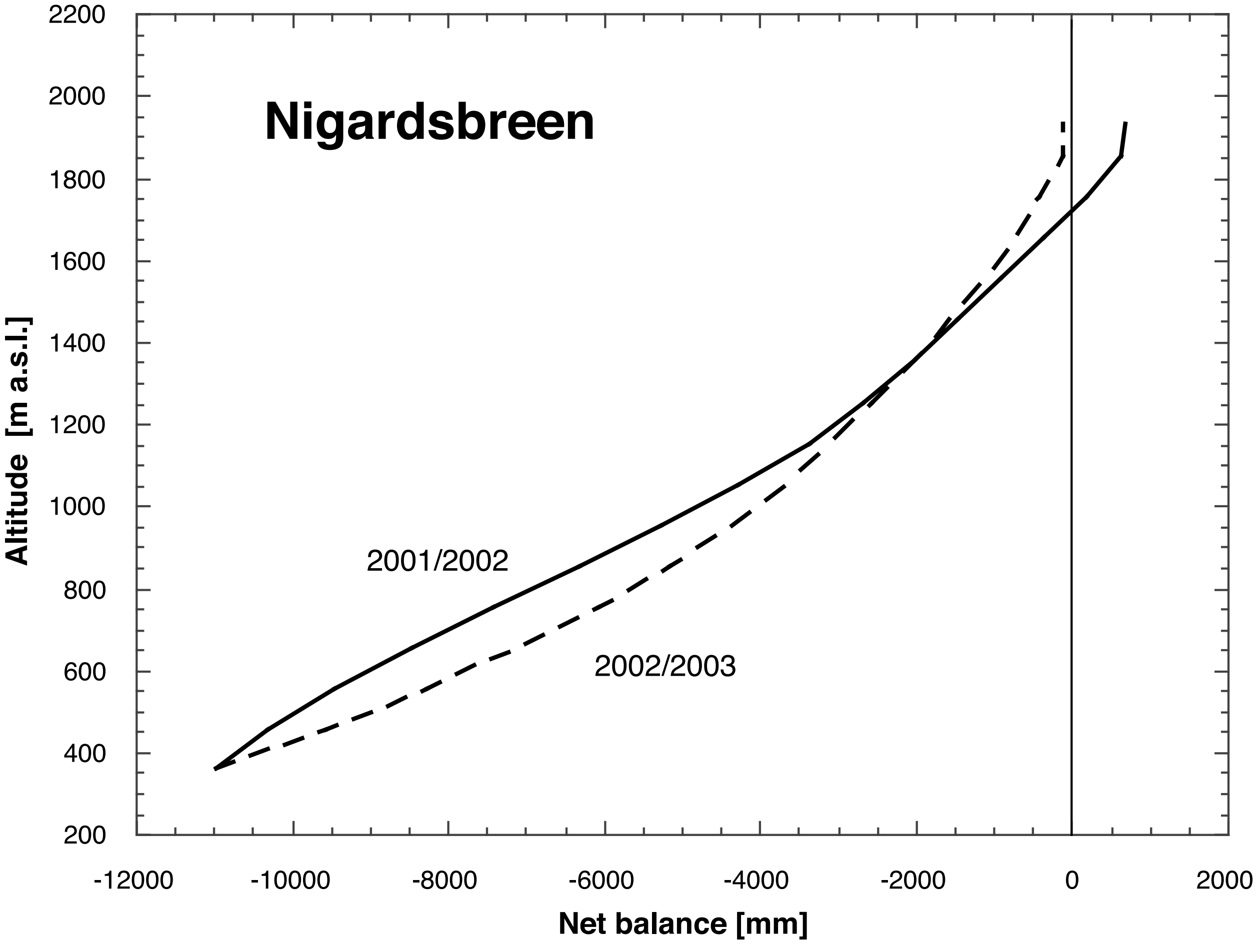
Nigardsbreen (NORWAY)

3.9.2 Net balance maps 2001/2002 and 2002/2003

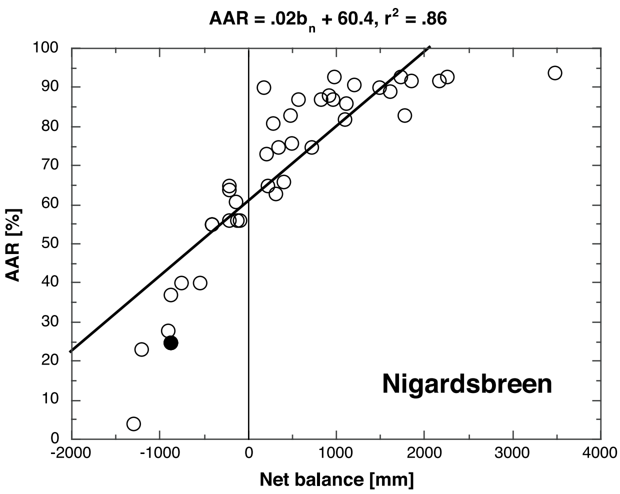


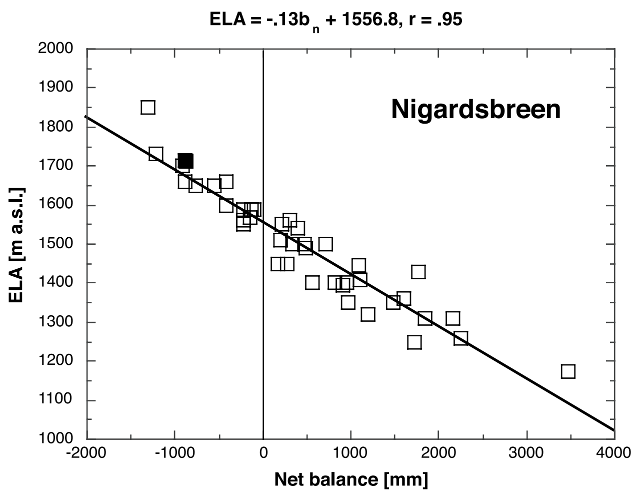
Nigardsbreen (NORWAY)

3.9.3 Net balance versus altitude (2001/2002 and 2002/2003)



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





3.10 WALDEMARBREEN (NORWAY/SPITSBERGEN)

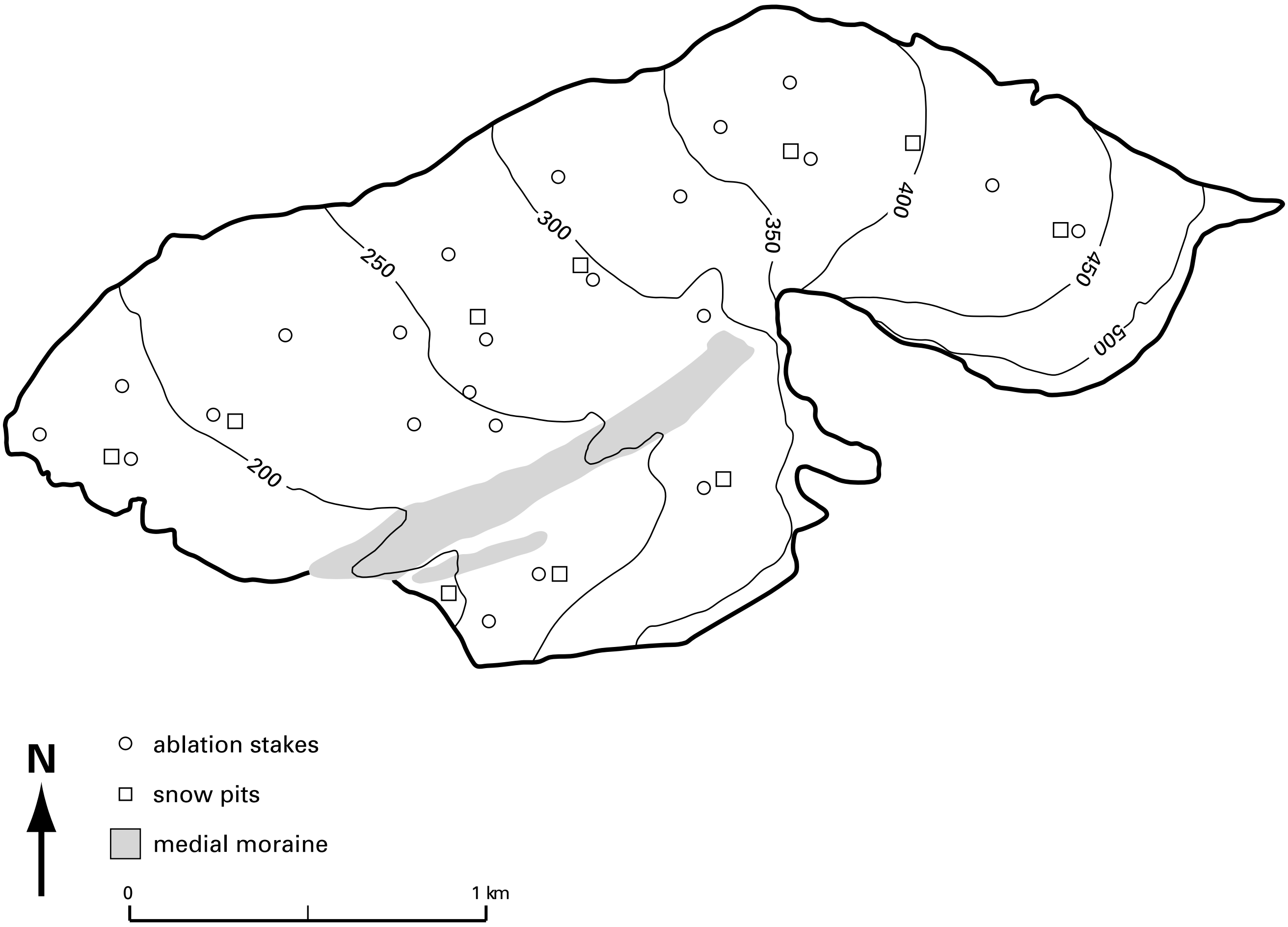
COORDINATES: 78.67 N / 12.00 E

Picture taken by I. Sobota in August 2003.

Waldemarbreen is located in the Oscar II Land, north-western Spitsbergen and flows down-valley to the Kaffiøyra plane. The glacier is composed of two parts separated by a 1600 m long medial moraine. It occupies an area of 2.68 km^2 and extends from 510 to 130 m a.s.l. with a general exposure to the west. Annual mean air temperature in this area is about -4 to -5 °C, the glacier is probably polythermal 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%. Detailed mass balance investigations have been conducted since 1995.

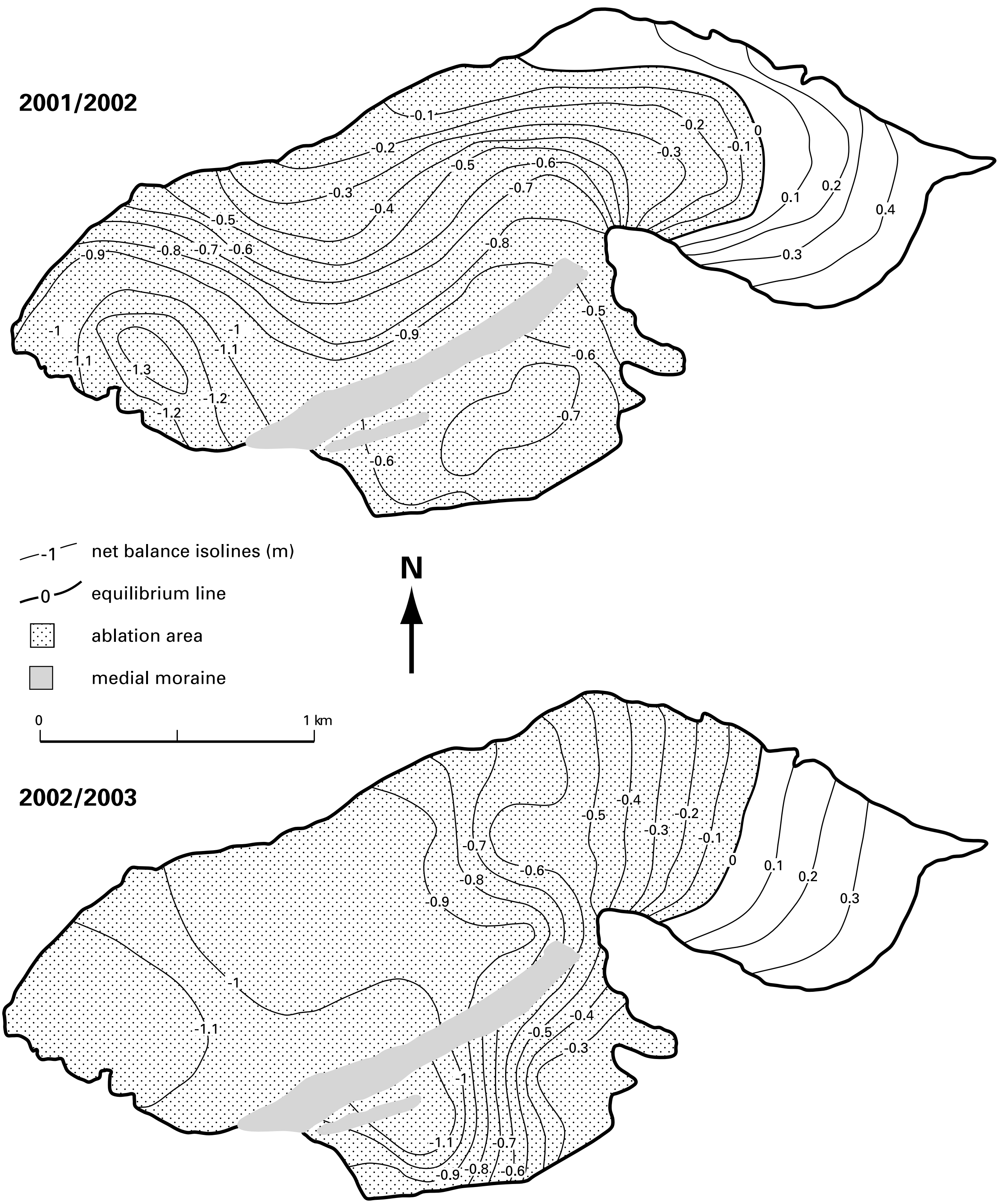
The balance in 2001/02 showed a net mass loss of -514 mm w.e. (winter accumulation 632 mm w.e., summer ablation -1146 mm w.e.) The ablation in 2002/03 was higher than normal (-1181 mm w.e.) and the accumulation was 454 mm w.e., resulting in a balance of -727 mm w.e. The mean value of the mass balance for the period 1995–2003 is -522 mm w.e.

3.10.1 Topography and observational network



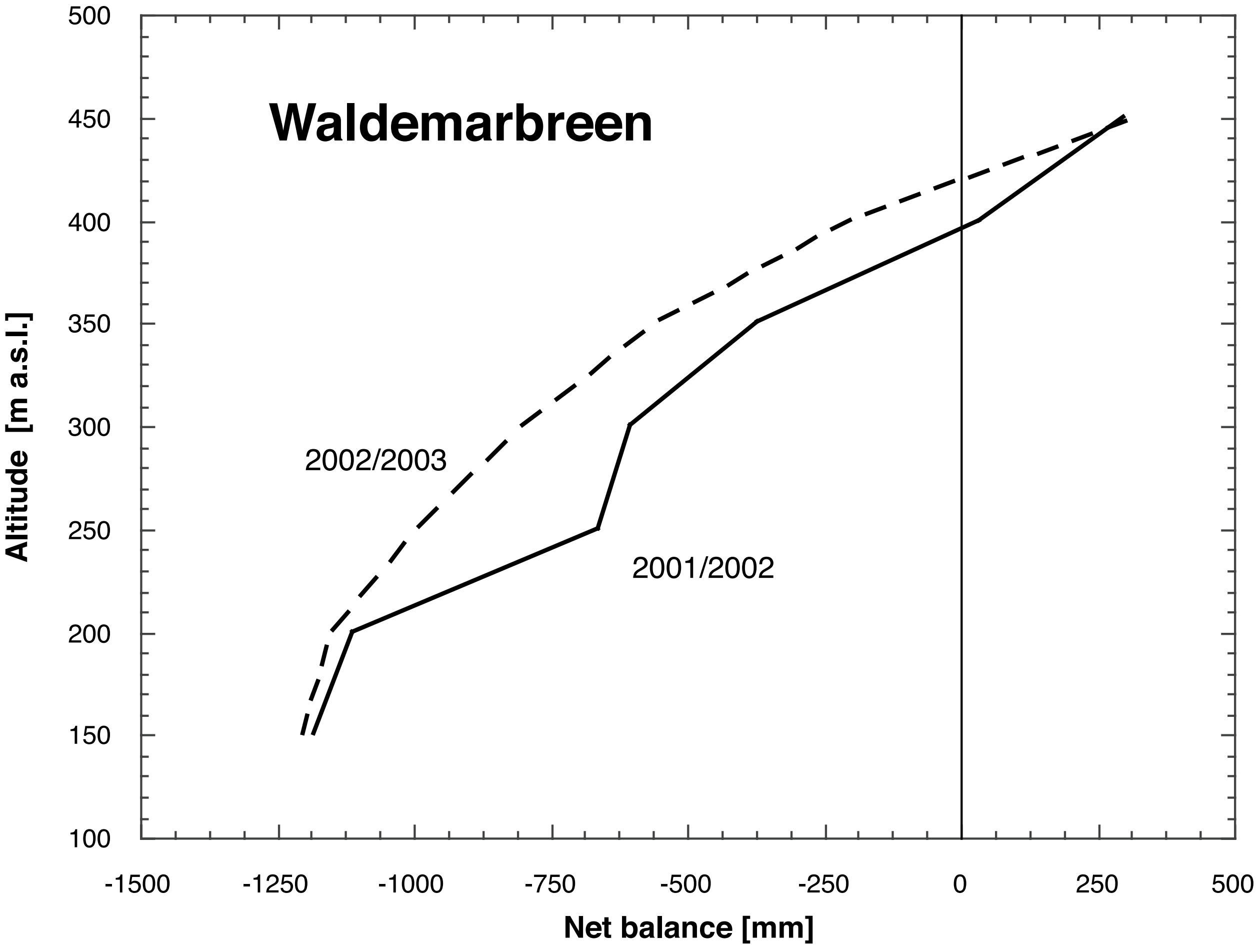
Waldemarbreen (NORWAY)

3.10.2 Net balance maps 2001/2002 and 2002/2003

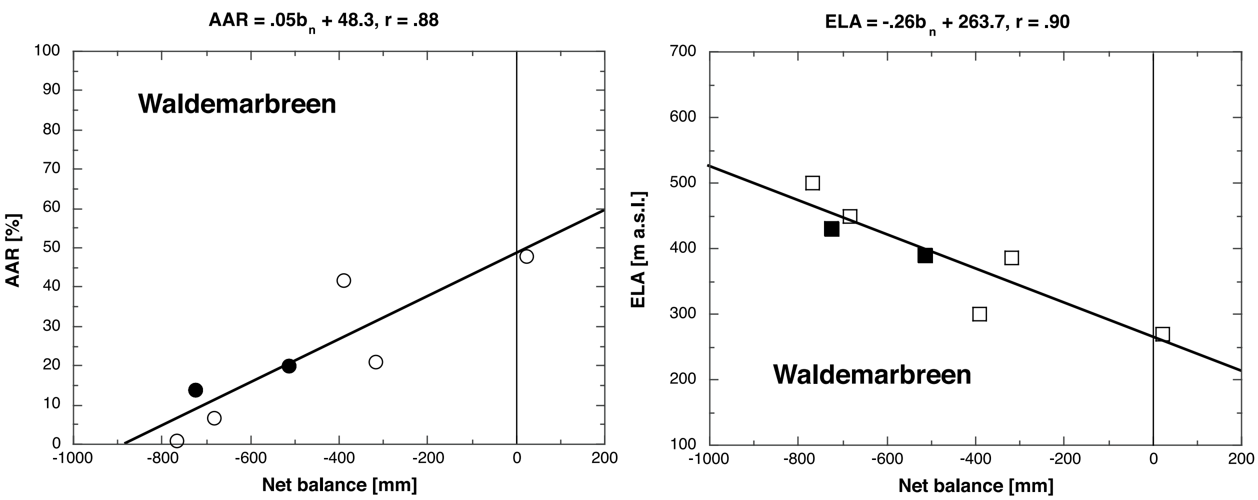


Waldemarbreen (NORWAY)

3.10.3 Net balance versus altitude (2001/2002 and 2002/2003)

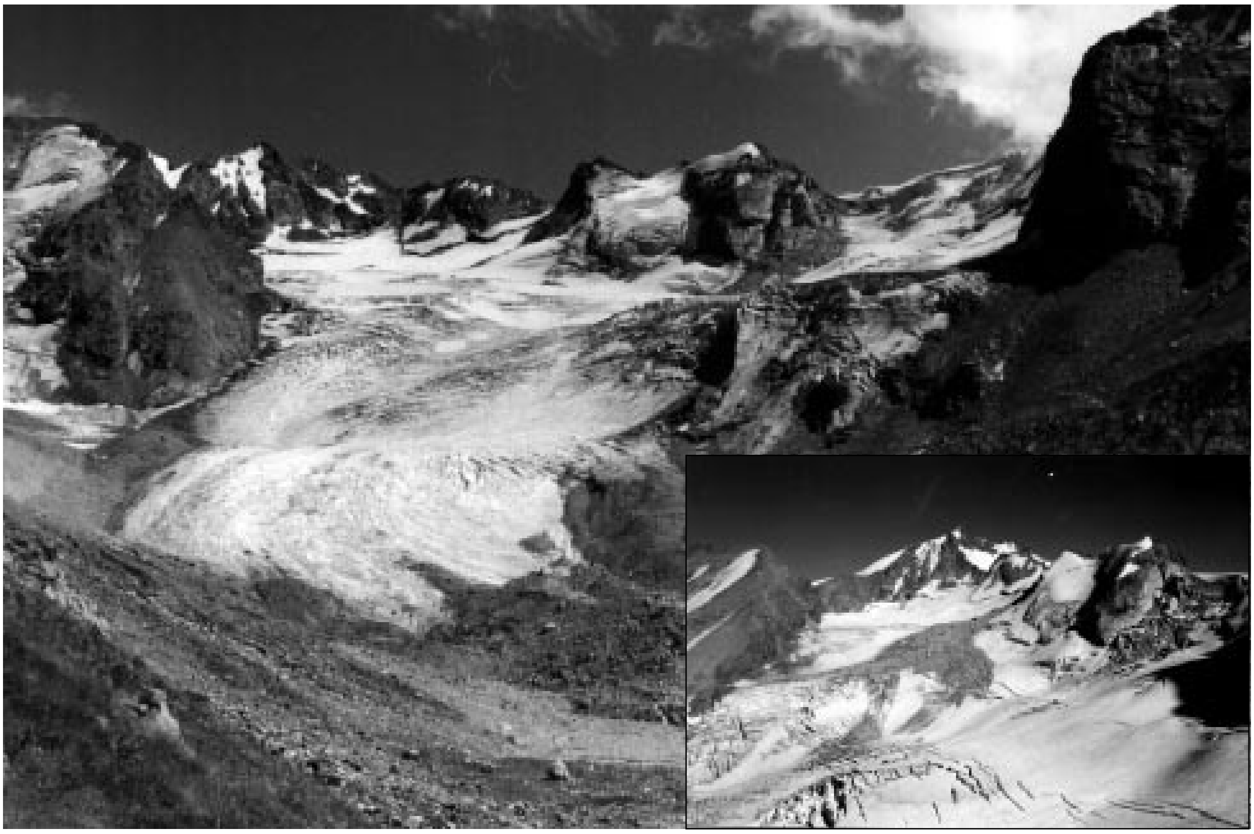


3.10.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period



3.11 DJANKUAT (RUSSIA/N CAUCASUS)

COORDINATES: 43.20 N / 42.77 E

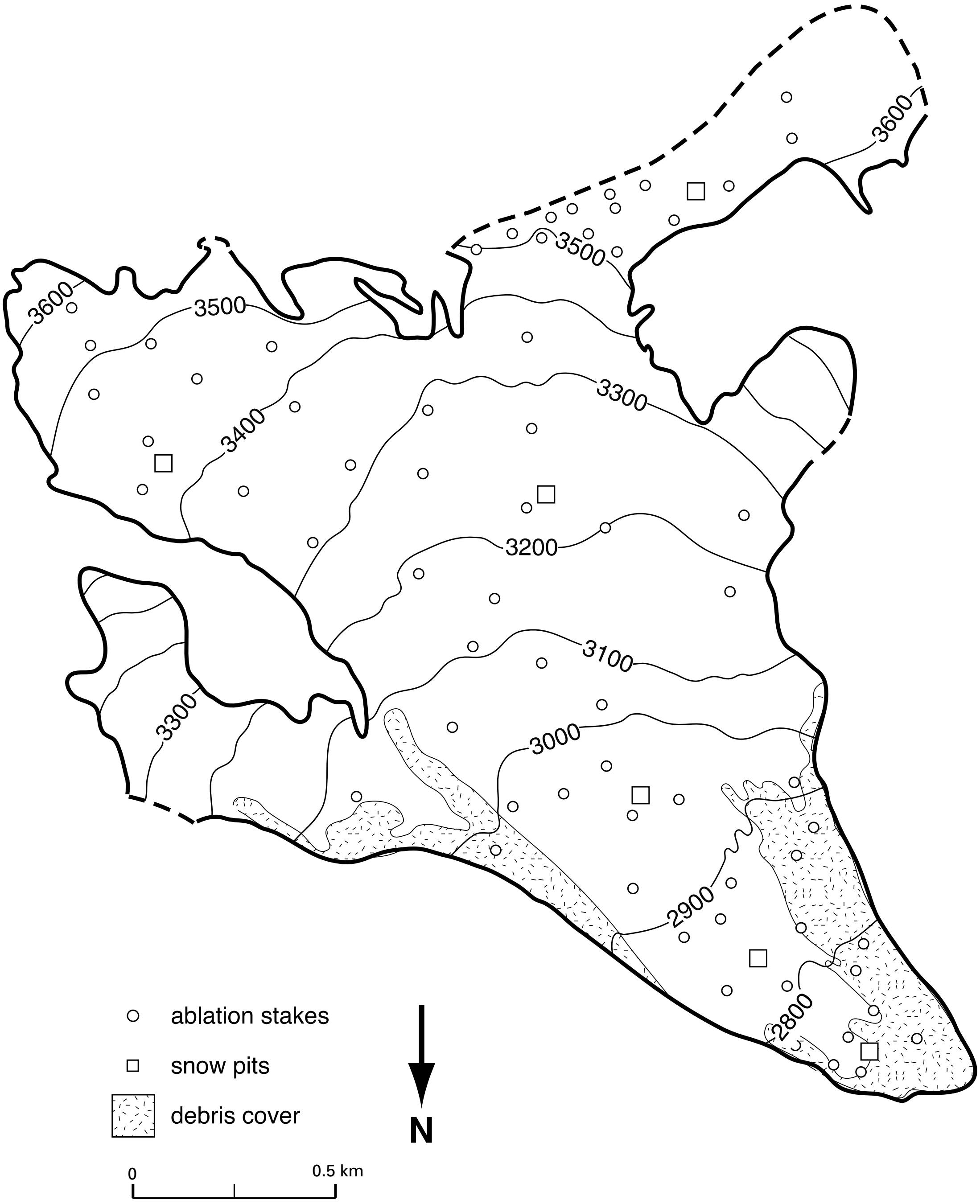


Picture taken by V. Popovnin in August 2001 and (inset) by A. Aleynikov in August 2003.

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 km² 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 1:10'000 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.

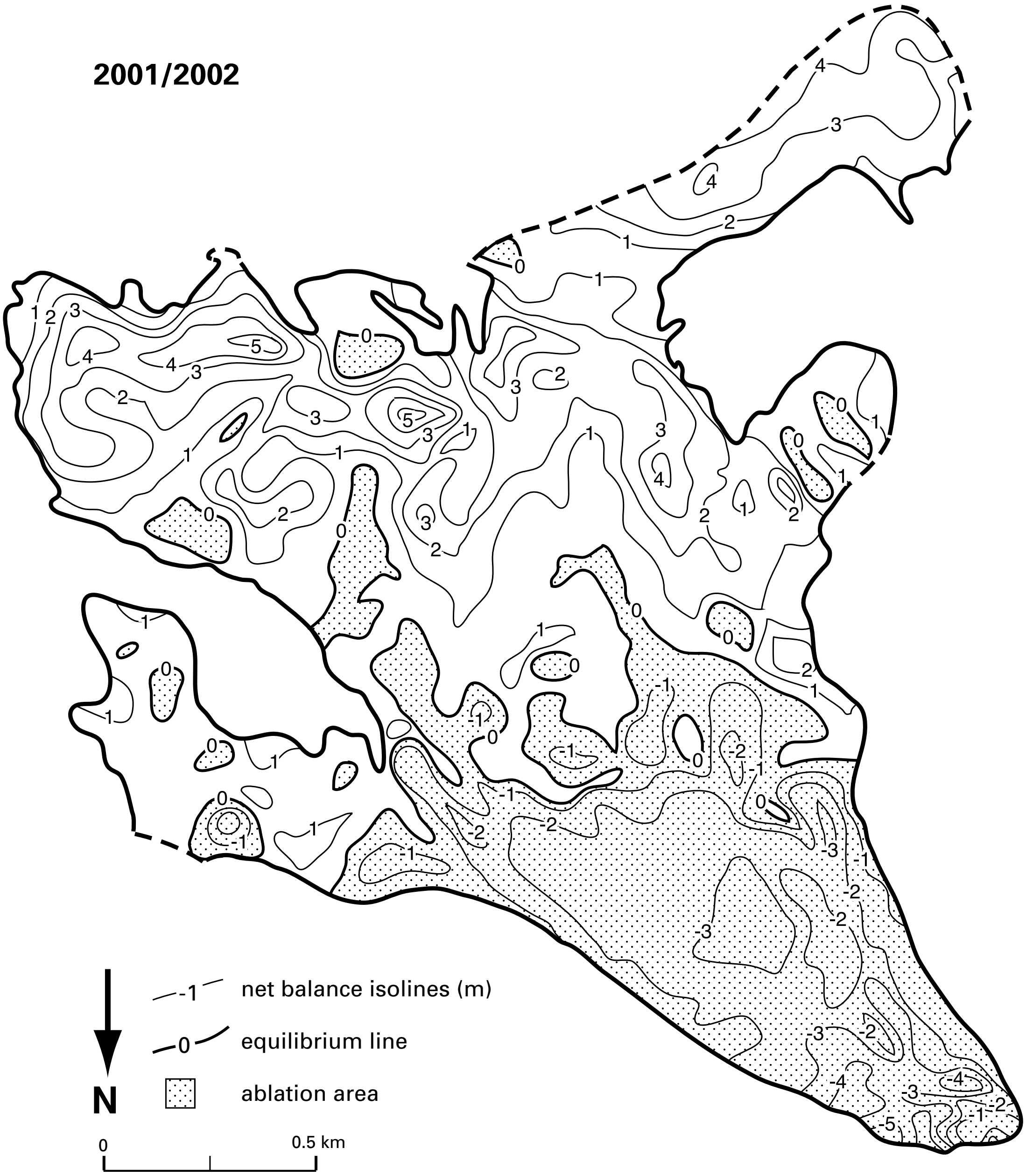
Both reported years were rather favourable for the glacier state, putting an end to the previous 4-year-long period of strong mass loss. The year 2001/02 was abundant in precipitation and cold, resulting in a 20% positive anomaly of accumulation and – together with reduced summer ablation – to a mass gain of 480 mm w.e. In 2002/03 anomalies of both balance constituents were of the same order of magnitude (ca. 8% positive for accumulation and negative for ablation), causing again a positive mass balance (280 mm). This value was partly influenced by a rock fall on the 1st of July, that crossed the main accumulation basin to the opposite margin and covered 0.13 km², or 4% of the glacier area, with a debris mantle around 0.7 m thick.

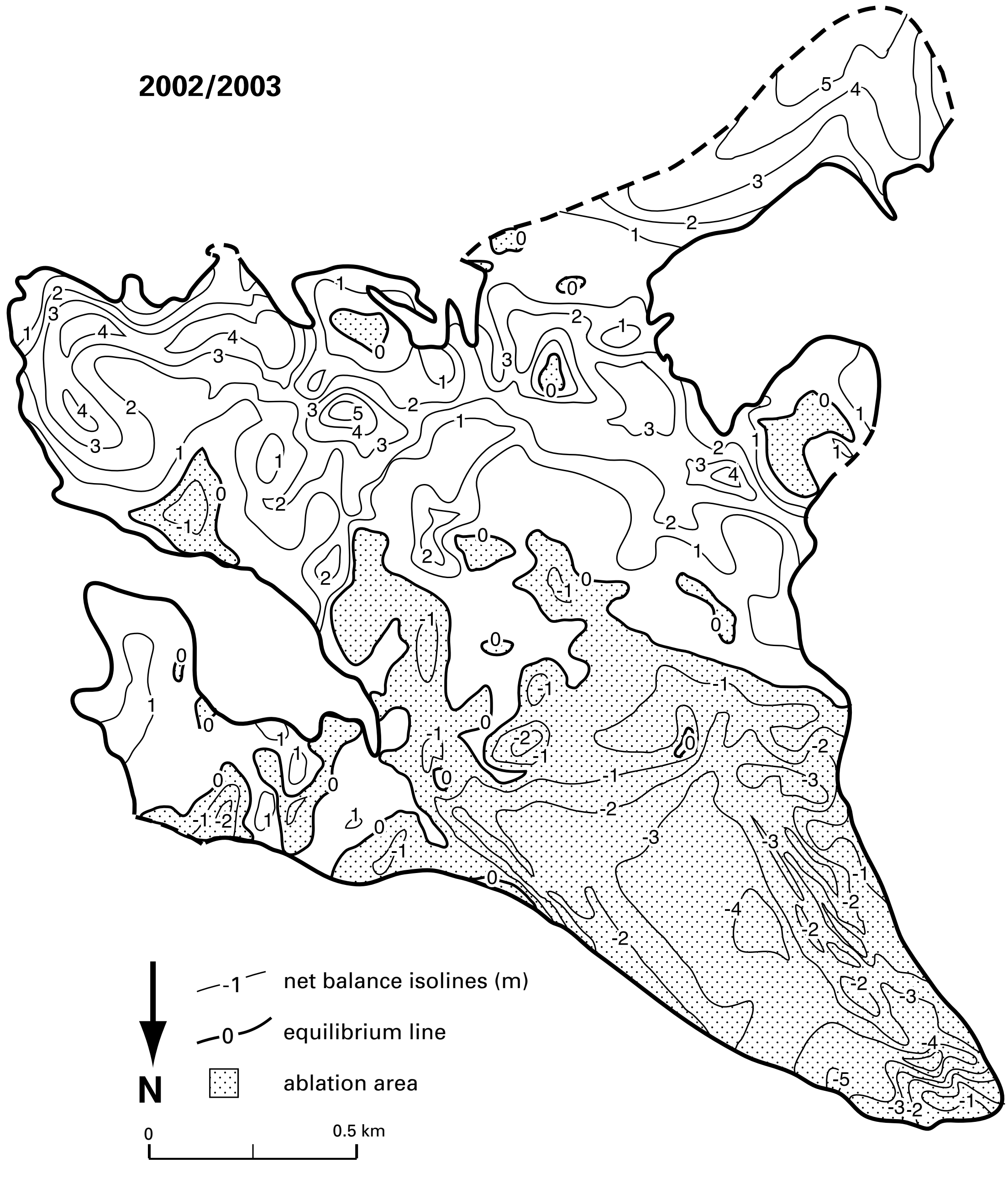
3.11.1 Topography and observational network



Djankuat (RUSSIA)

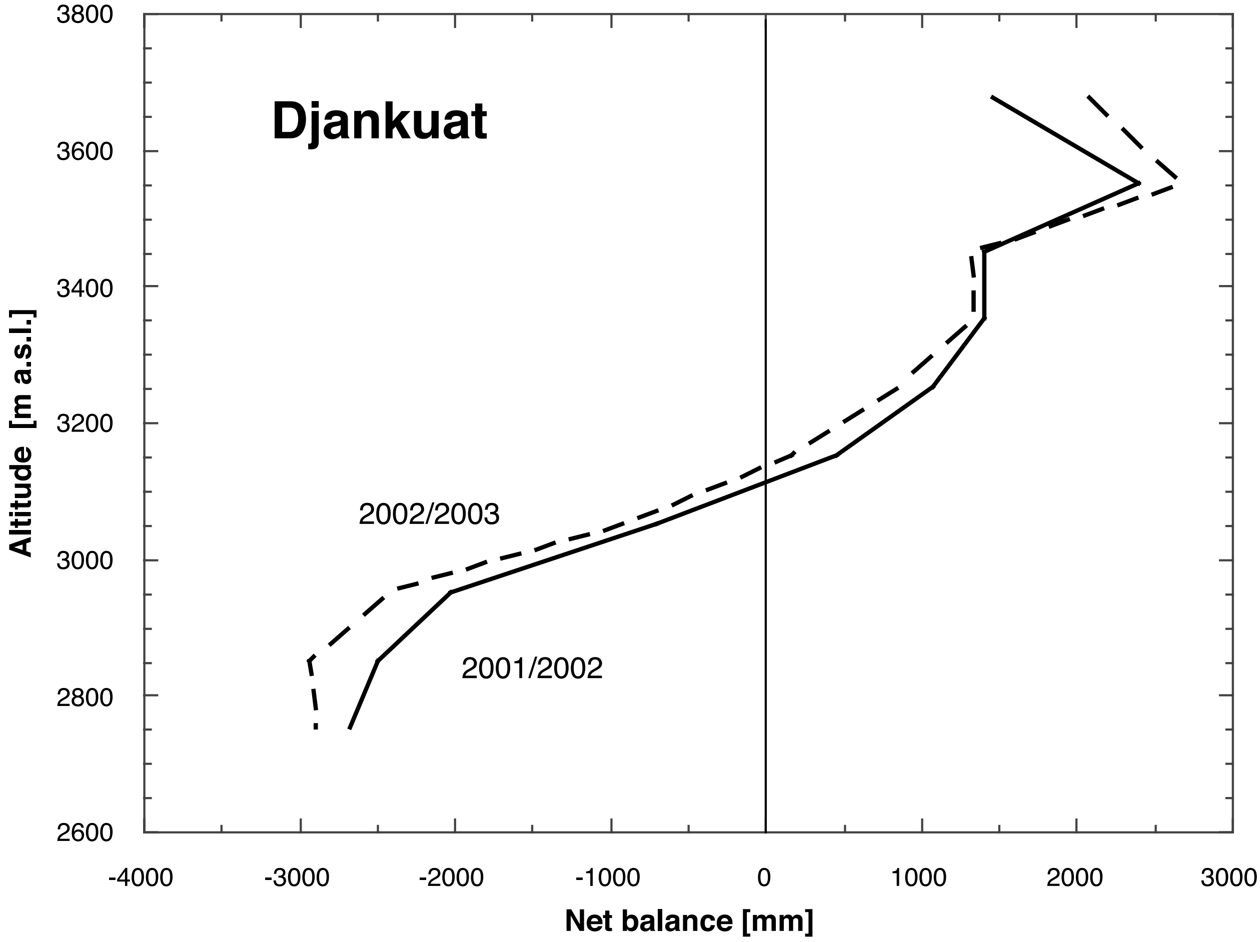
3.11.2 Net balance maps 2001/2002 and 2002/2003



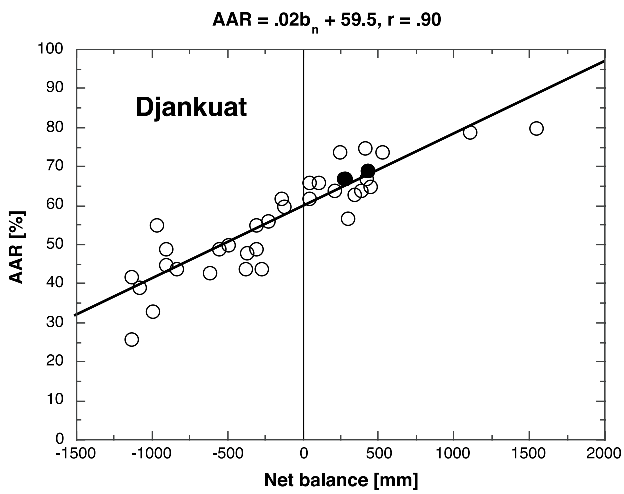


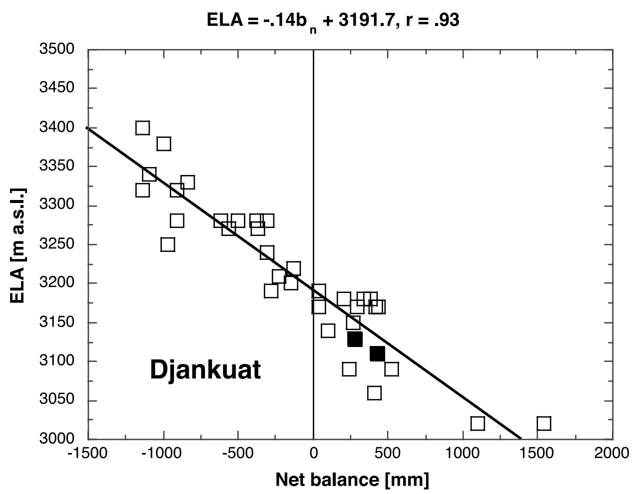
Djankuat (RUSSIA)

3.11.3 Net balance versus altitude (2001/2002 and 2002/2003)



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





3.12 MALIY AKTRU (RUSSIA/ALTAY)

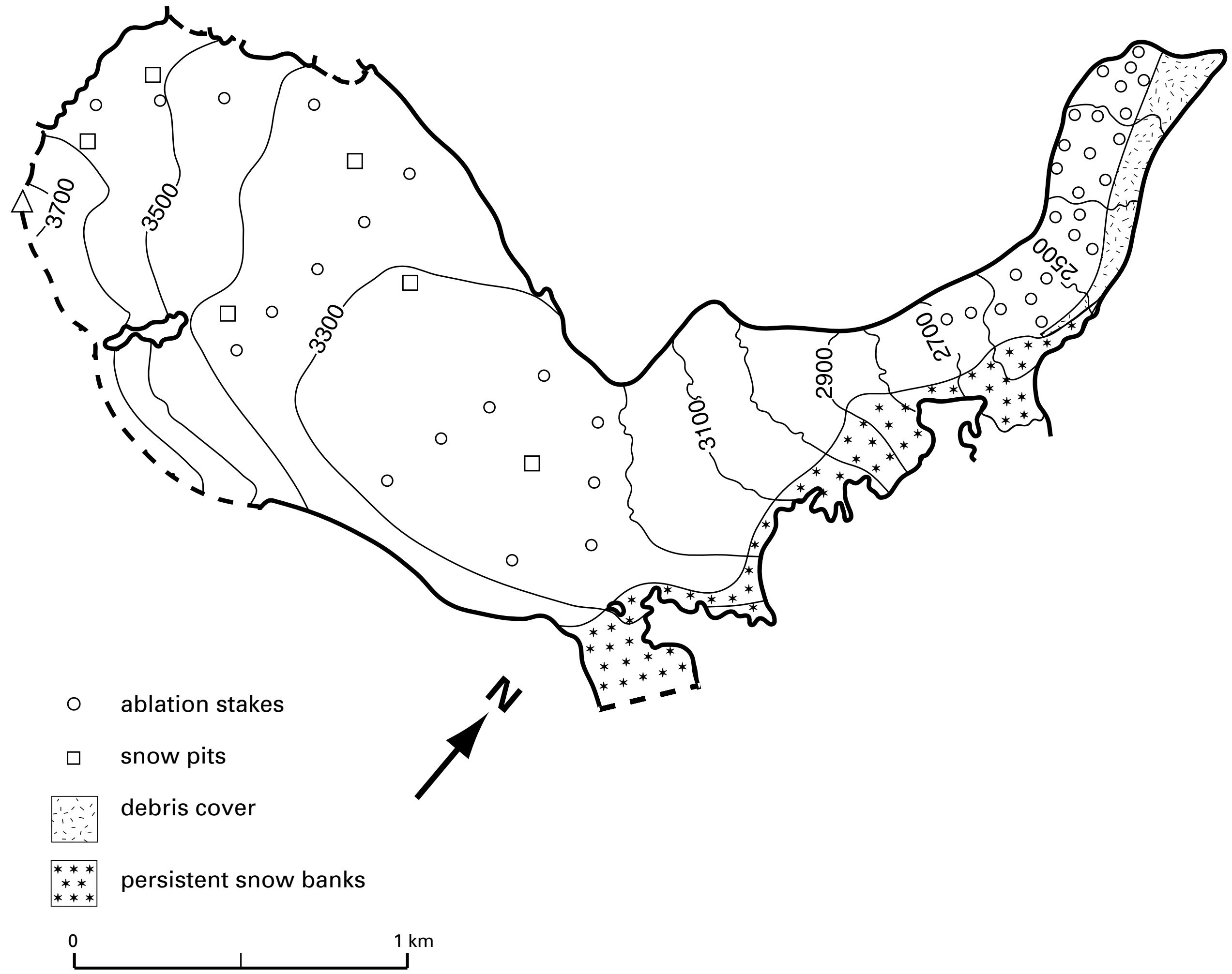
COORDINATES: 50.08 N / 87.75 E

Picture taken by Y.K. Narozhniy on the 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 (maximum 234 m) and its total volume is estimated to be 0.25 km^3. Annual mean 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.

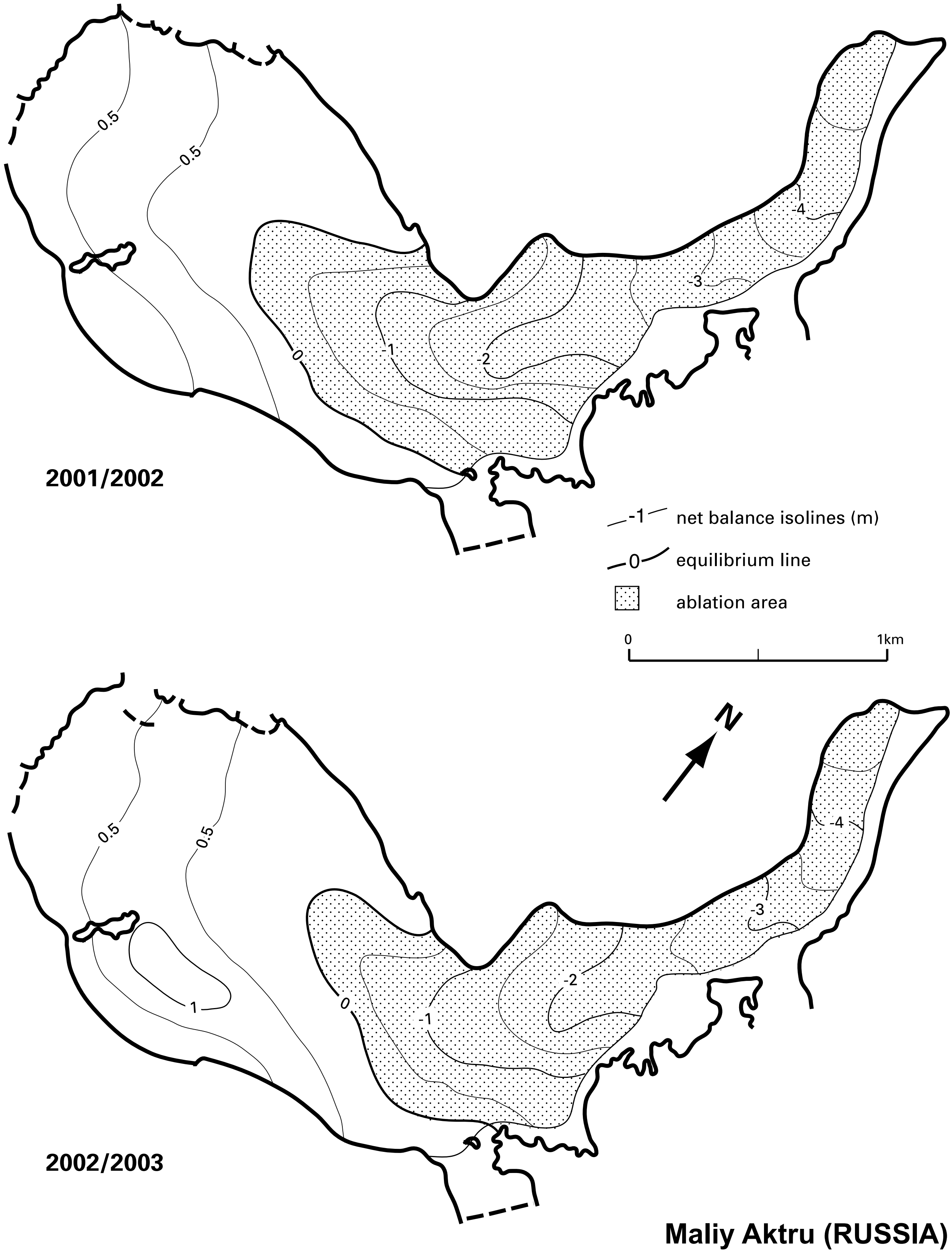
Glacioclimatological conditions in 2001/02 and 2002/03 were quite similar. In both years accumulation was close to its long-term average and ablation exceeded its mean value by 8-10%. As a result, the annual mass balance turned out to be negative and the glacier lost -410 mm w.e. and -370 mm w.e., correspondingly. The reported period, thereby, corroborates the contemporary trend towards intensive degradation of glaciers in the Altai.

3.12.1 Topography and observational network

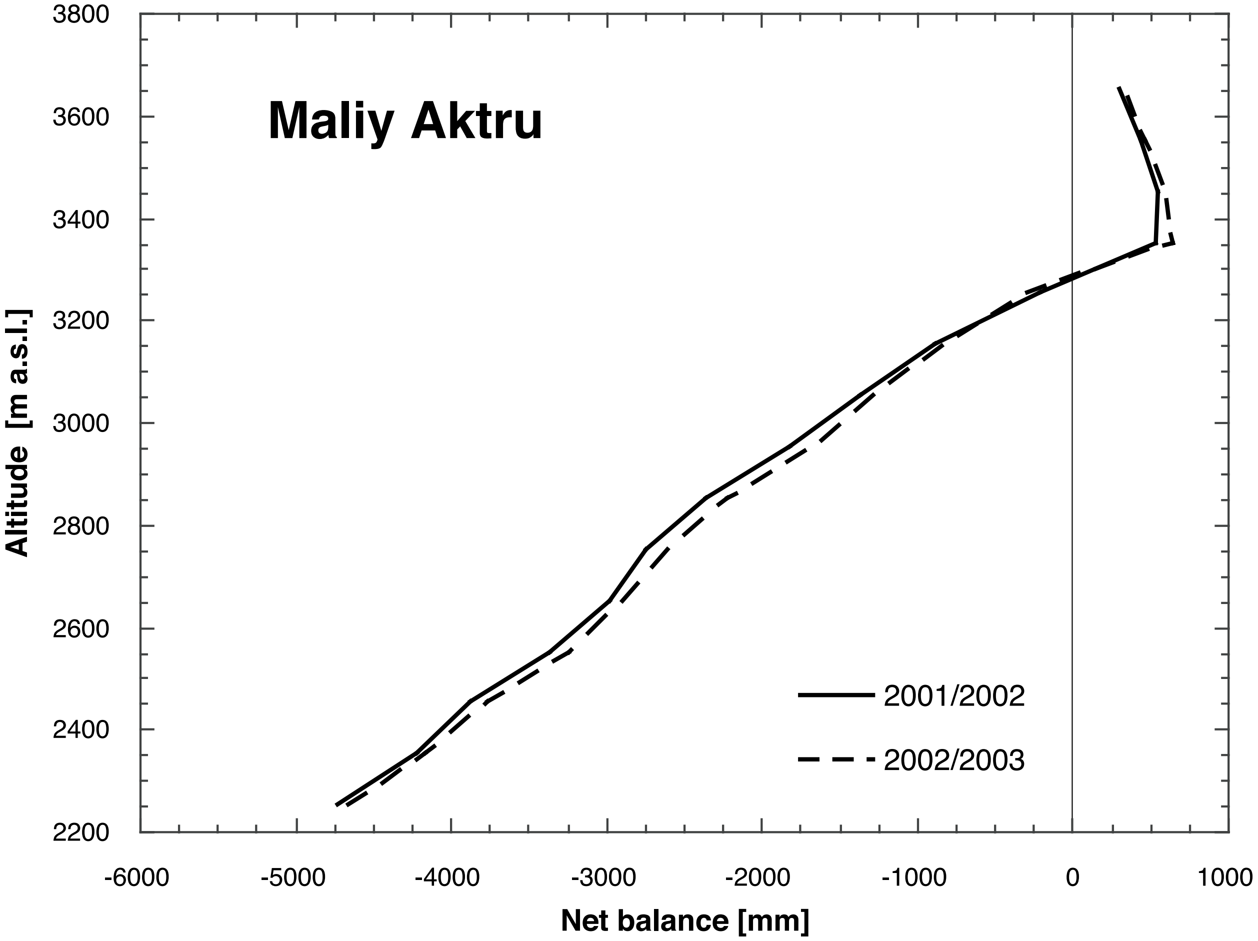


Maliy Aktru (RUSSIA)

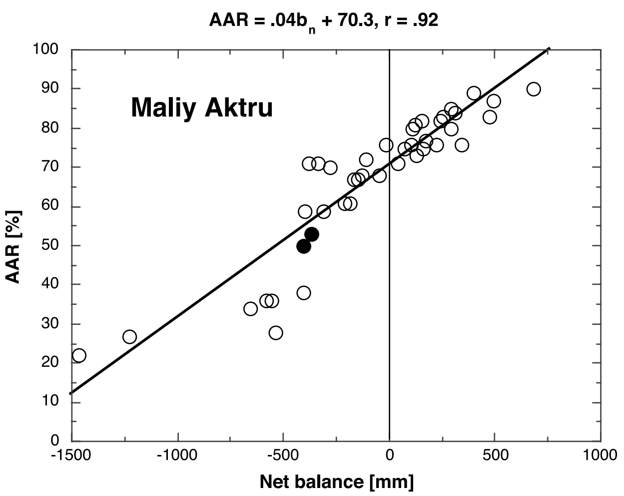
3.12.2 Net balance maps 2001/2002 and 2002/2003

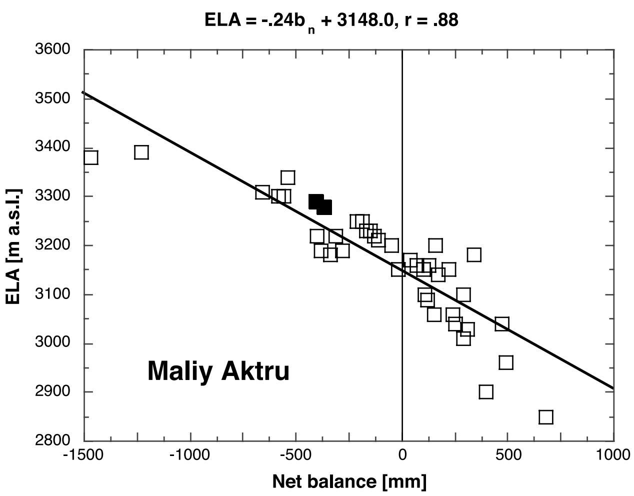


3.12.3 Net balance versus altitude (2001/2002 and 2002/2003)



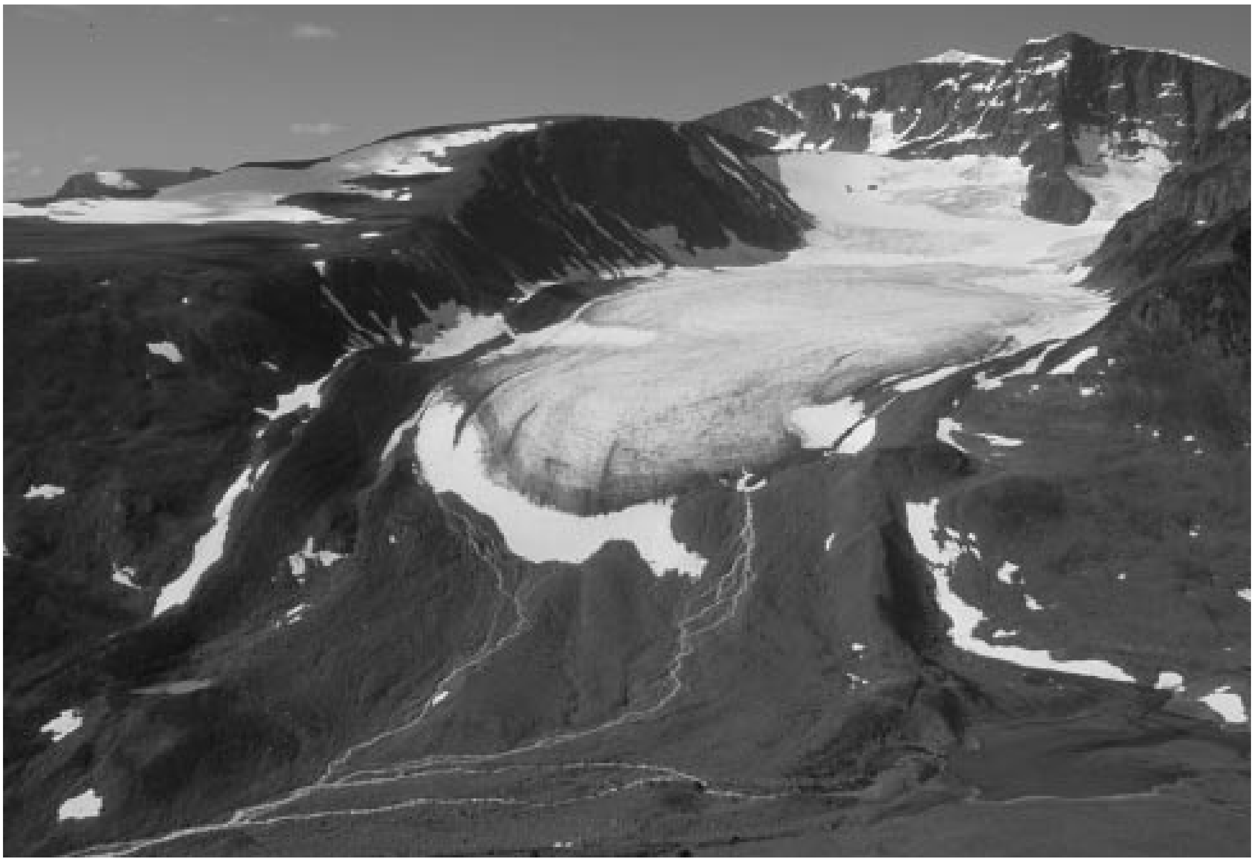
3.12.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





3.13 STORGLACIÄREN (SWEDEN/NORTHERN SWEDEN)

COORDINATES: 67.90 N / 18.57 E

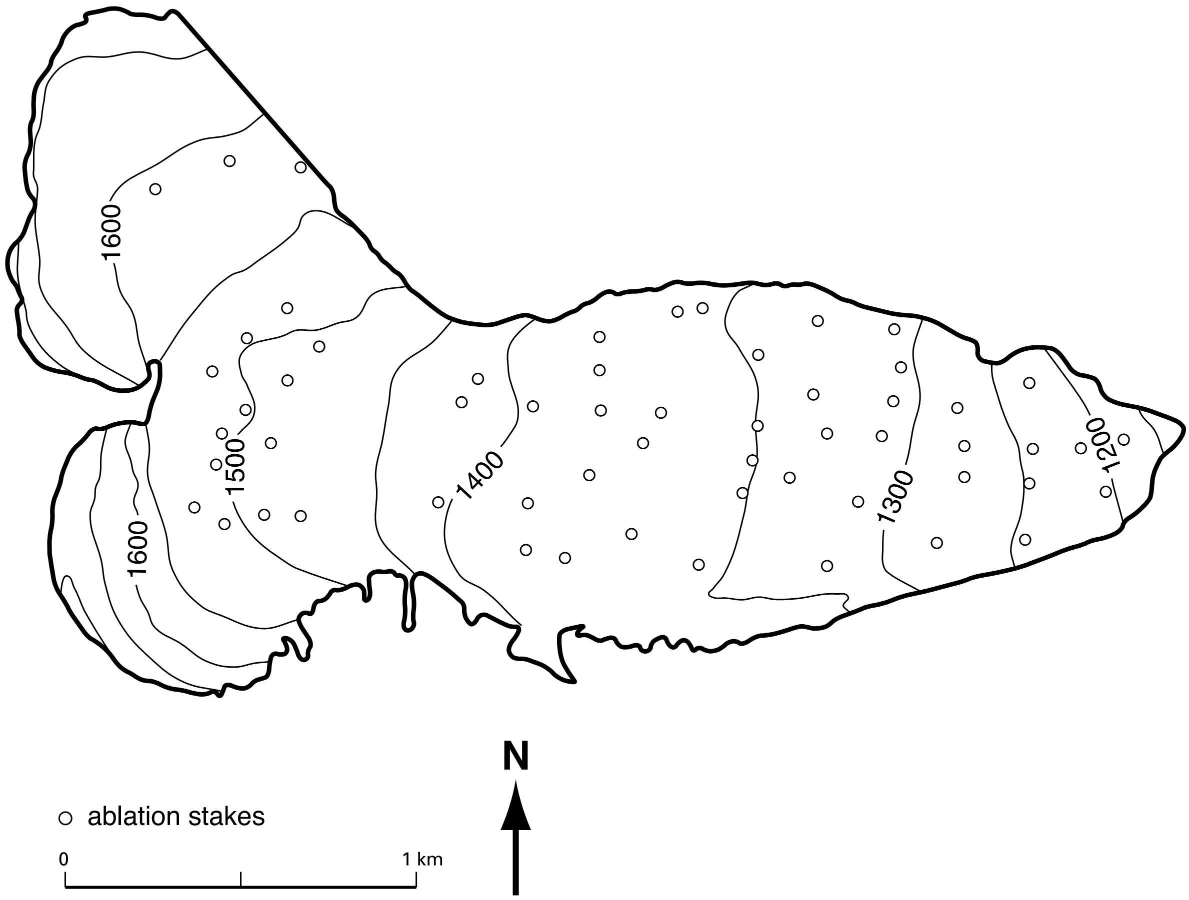


Picture taken by P. Holmlund on 4th of August 2004.

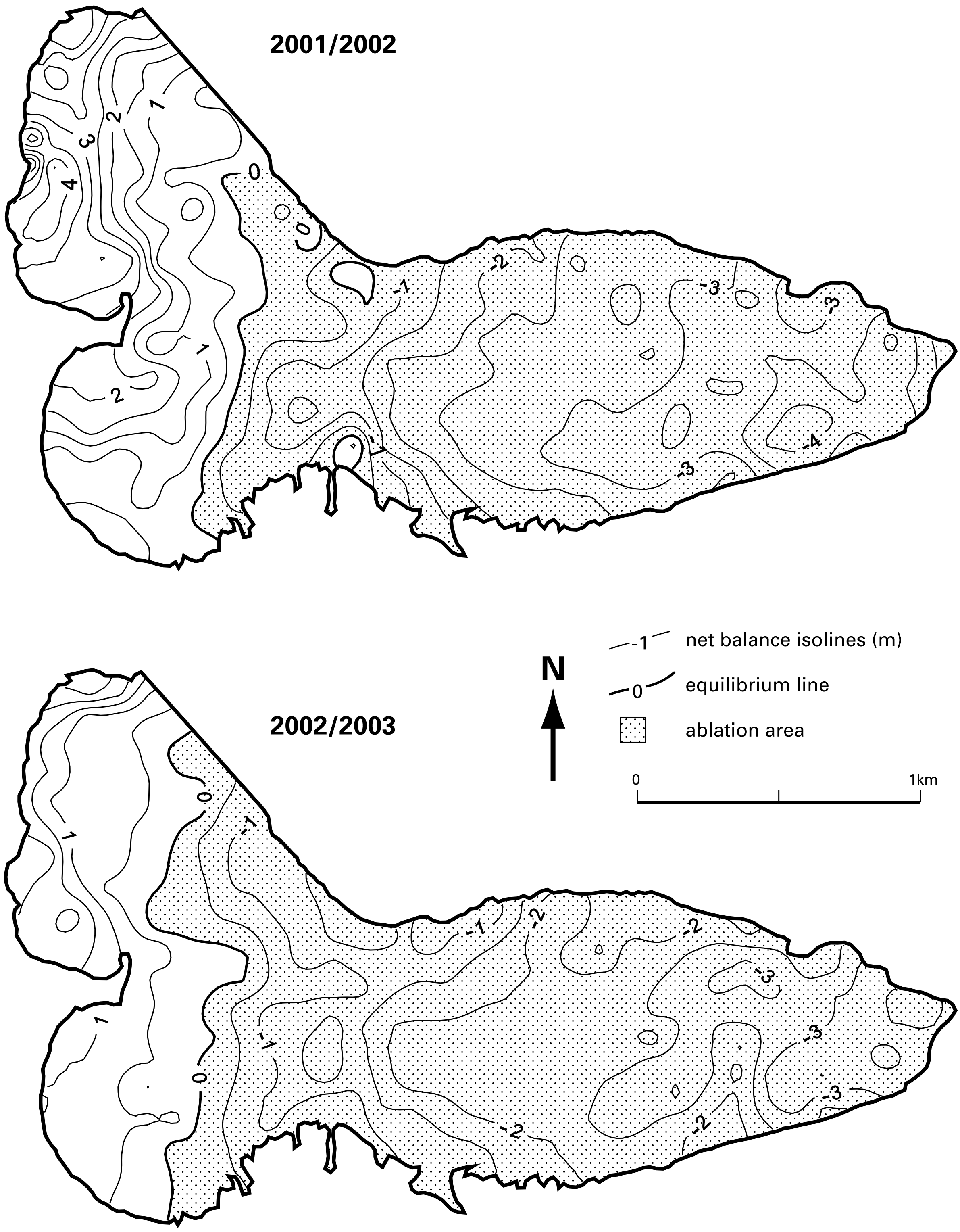
Storglaciären in the Kebnekaise Mountains of northern Sweden is a small valley-type glacier with a divided accumulation area and a smooth longitudinal profile. It is exposed to the east, maximum and minimum elevations are 1750 and 1130 m a.s.l., surface area is 3.12 km^2, and average thickness is 95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

The accumulation in 2001/02 (1750 mm) was normal but the ablation was one of the highest recorded (2580 mm), resulting in a net balance of -830 mm. The winter of 2002/03 was cold and dry and the following summer was long (5 months) and warm. The winter balance (1380 mm) was less than normal and the summer balance (-2480 mm) was again one of the highest recorded. The net balance of 2002/03 was -1040 mm.

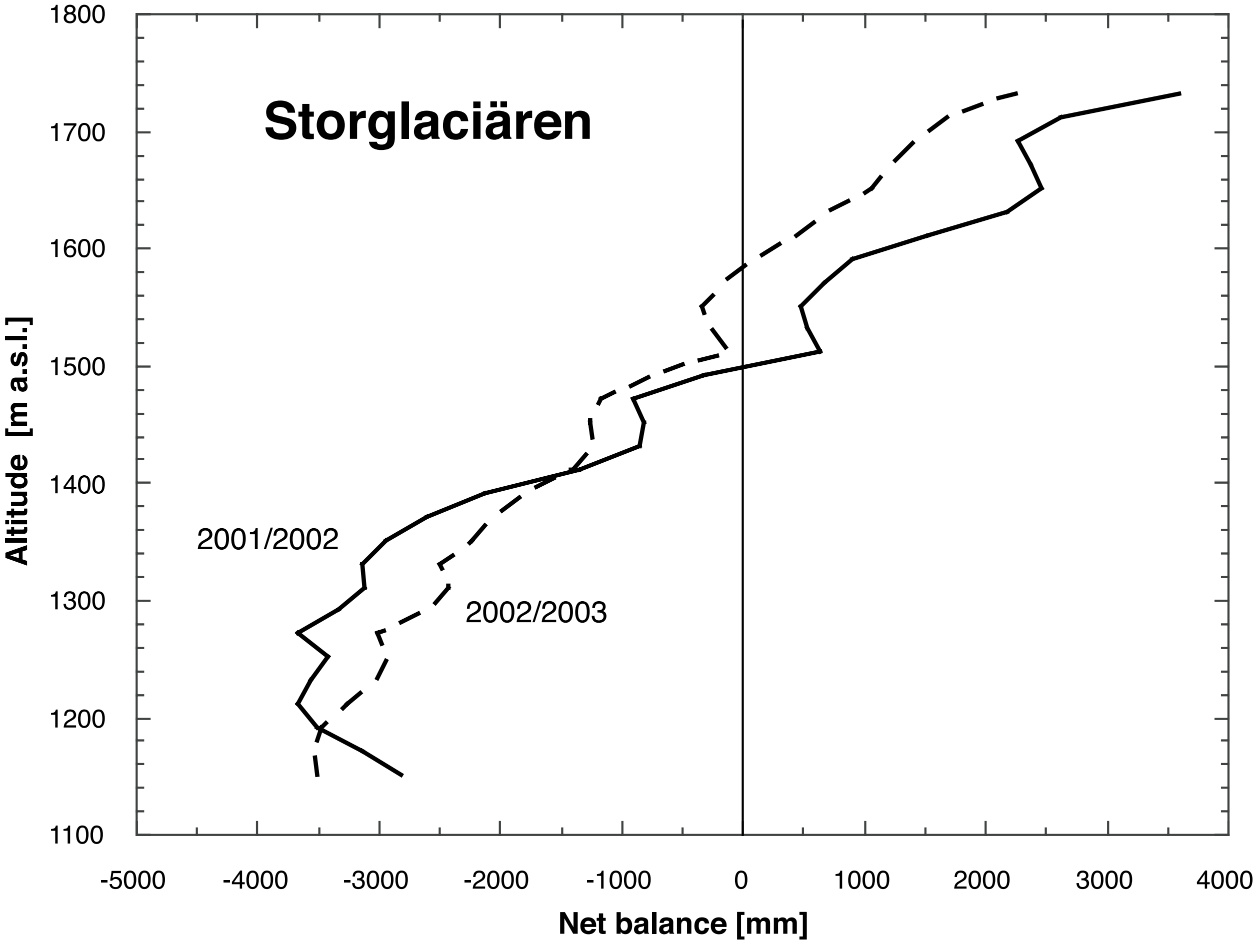
3.13.1 Topography and observational network



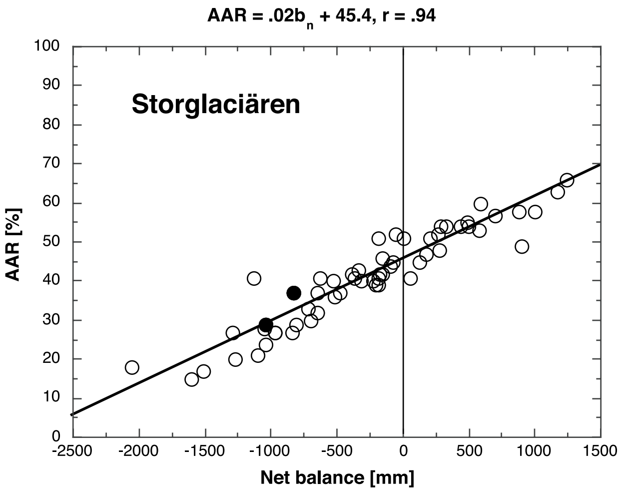
3.13.2 Net balance maps 2001/2002 and 2002/2003

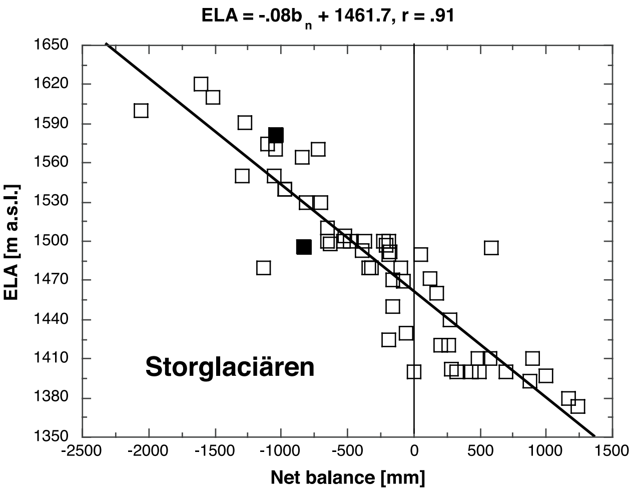


3.13.3 Net balance versus altitude (2001/2002 and 2002/2003)



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 1980–2003 are now available for 30 glaciers. Corresponding results of this sample from glaciers in North America, South America and Eurasia are summarised in Table 4.1 (all mm-values in water equivalent):

Table 4.1: Summarised mass balance data. The mean specific (annual) net balance of 30 glaciers averaged for the years 2000–2003 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	2000–2003
mean specific (annual) net balance:	- 286 mm	- 570 mm
standard deviation of means:	± 256 mm	± 518 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%

	2001/2002	2002/2003
mean specific (annual) net balance:	- 691 mm	- 1238 mm
standard deviation:	± 651 mm	± 1194 mm
minimum value:	- 2320 mm	- 3316 mm
maximum value:	+ 550 mm	+ 2060 mm
range:	2870 mm	5376 mm
positive balances:	13%	10%

Taking the two reported years together, the mean mass balance was -965 mm per year. This value is more than three times the average of 1980–1999 (-286 mm per year) and by far the most negative value reported so far for two-year averages. The proportion of glaciers with positive balances (13% in 2001/02, 10% in 2002/03) is roughly one third of the average observed during the two decades 1980–1999 (32%). During this period 15% of the mean specific annual net balances were positive. The mean mass balance during the years since the turn of the century (2000–2003: -570 mm) is twice that during 1980–1999 and the mean proportion of glaciers with positive balances is two thirds of the mean value during 1980–1999. Since then all annual mean values have been negative. The melt rate and loss in glacier thickness has been 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 reported period has been extreme and without precedence in the European Alps (cf. Schär and others, 2004), where new record mass losses exceeded earlier record values by at least another 50% (Frauenfelder et al., in press). This, together with strongly negative balance values in Scandinavia and western North America, created a new record of annual mass loss in almost a quarter of a century of documentation in the Glacier Mass Balance Bulletin. However, the mean of all glaciers included in this analysis is strongly influenced by the large proportion of Alpine and Scandinavian glaciers. A mean value is also calculated using only one single value (averaged) for each of the 9 mountain

*) Note that in earlier MBBs, means for decadal periods were calculated per glacier, here they are calculated per year of observation.

ranges concerned (Table 4.2). This second average is less negative and points to the strong regional weather anomaly in the summer of 2003, which is superimposed onto the general trend of glacier mass loss.

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

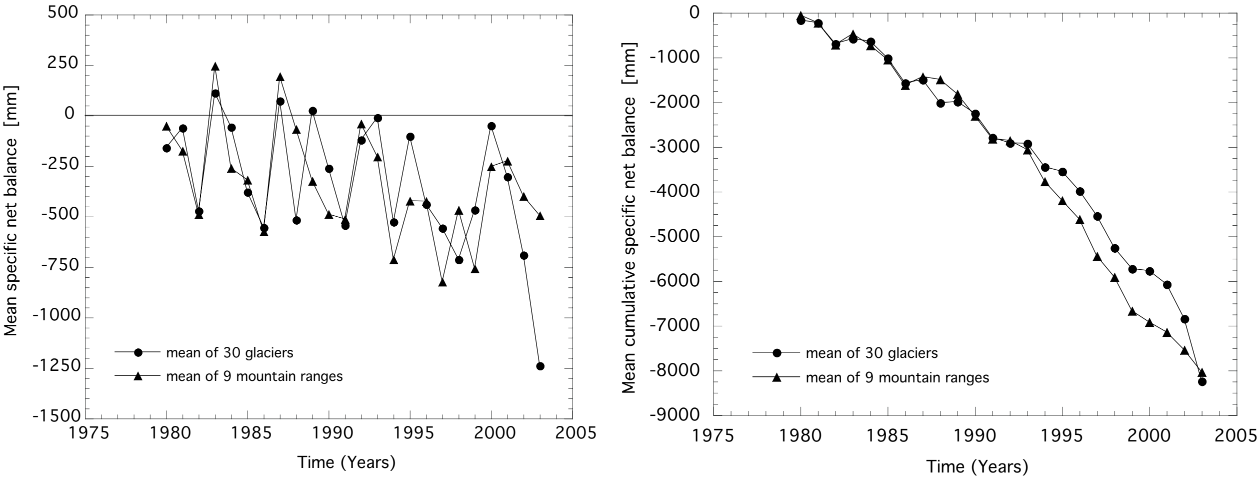


Figure 4.1: Mean specific net balance (left) and mean cumulative specific net balance (right) of 30 glaciers and 9 mountain ranges since 1980.

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 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 reducing 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.

Further analysis requires detailed consideration of aspects such as glacier sensitivity and 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 of 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

Table 4.2: Mass balance data for 9 mountain regions 1980–2003.

Year	Cascade Mtns.	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	-449	200	-380	-581	-318
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	2430	-505	-1215	-626	333	520	-626	-67
1989	-875	-1440	-1260	-345	1911	-886	117	40	-177	-324
1990	-834	-1555	-1530	-585	1196	-1074	107	340	-454	-488
1991	-595	-260	-1050	115	80	-1204	-480	-310	-903	-512
1992	-1400	-210	1740	-120	1161	-1161	-127	-130	-109	-40
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	8	60	40	-408	-422
1996	-61	-950	-1180	-75	-643	-414	-140	-150	-207	-424
1997	-129	-2120	-2880	-570	-470	-223	-123	270	-1160	-823
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	987	-647	-230	-1140	-222	-252
2001	-1165	-120	1810	-405	-750	122	-190	-620	-701	-224
2002	214	-875	80	-550	-1145	-825	-357	430	-567	-399
2003	-1548	-180	2060	-845	-1395	-2453	-363	280	-12	-495
Mean	-870	-379	-190	-389	78	-660	-98	-81	-424	-335

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

influenced by maritime-type glaciers such as 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. 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. Time series of balance and length measurements are now close to the estimated dynamic response times of individual glaciers and make it possible to derive long-term average mass balances from cumulative length changes of the network glaciers. Systematic analysis of corresponding data (Hoelzle et al., 2003) shows that the reported mass balance series are indeed representative for large areas and decadal time periods. Surface lowering, thickness loss and the resulting reduction in driving stress and flow may, however, increasingly replace processes of tongue retreat by processes of downwasting coupled with enhanced feedbacks from albedo and balance/altitude effects. Such developments can be studied by dynamically fitting mass balance histories to present-day geometries and historical length change measurements of long-observed glaciers using time-dependent flow models (Oerlemans, 2001). Application of such models leaves no doubt that many of the presently observed mass balance glaciers could vanish within a few decades. Observational concepts for such dramatic developments have been developed (Haeberli 2004) within the framework of the Global Terrestrial Observing System (GTOS) of global climate-related observational programmes (GCOS). They follow a tiered strategy leading from detailed process studies (detailed mass balance, climate and flow measurements) via regional measurements of mass balance (basic results from index stakes and repeated mapping, laser altimetry on large glaciers), determination of glacier length changes (samples which are representative for variable glacier geometry and individual mountain ranges) to periodically repeated glacier inventories compiled by means of satellite imagery and geoinformatics.

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References

Haeberli, W. (2004): Glaciers and ice caps: historical background and strategies of world-wide monitoring. In: Bamber, J.L. and Payne A.J. (eds): Mass Balance of the Cryosphere. Cambridge University Press, Cambridge: 559–578.

Hoelzle, M., Haeberli, W., Dischl, M., and Peschke, W. (2003): Secular glacier mass balances derived from cumulative glacier length changes. Global and Planetary Change 36: 295–306.

Oerlemans, J. (2001): Glaciers and climatic change. Balkema, pp. 148, Rotterdam.

Schaer, C., Vidale, P.L., Lüthi, D., Frei, C., Häberli, C., Liniger, M. and Appenzeller, C. (2004): The role of increasing temperature variability in European summer heat waves. Nature 427: 332–336.

Frauenfelder, R., Zemp, M., Haeberli, W. and Hoelzle, M. (2005): Worldwide glacier mass balance measurements: trends and first results of an extraordinary year in Central Europe. Ice and Climate News: 9-10 (http://clic.npolar.no/newsletters/archive/ice_climate_2005_08_no_06.pdf).

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