GLACIER MASS BALANCE BULLETIN

Bulletin No. 5 (1996–1997)

A contribution to the
Global Environment Monitoring System (GEMS)
and the
International Hydrological Programme (IHP)

Compiled by the World Glacier Monitoring Service

IAHS (ICSI) – UNEP – UNESCO
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Edited by

Wilfried Haeberli[1], Martin Hoelzle[1,2] and Regula Frauenfelder[1]

[1] Physical Geography
Department of Geography
University of Zurich

[2] Glaciology Section
Laboratory of Hydraulics, Hydrology and Glaciology
Swiss Federal Institute of Technology (ETH)
Zurich

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The cover page shows Peyto Glacier in Canada where detailed mass balance studies have been carried out since 1966. Photo taken by W.E.S. Hennoch (NHRI, 1966).

PREFACE

Since the establishment in 1894 of internationally coordinated long-term glacier observations, the goals of worldwide glacier monitoring have evolved and multiplied. Today, glacier signals are recognized as high-confidence temperature indicators and as valuable elements of early detection strategies in view of possible man-induced climate change (cf. the 1995 reports by the Intergovernmental Panel on Climate Change, IPCC, and The Global Climate System Review, December 1993–May 1996, WMO 856). As a consequence, efforts are being made at present to integrate worldwide glacier monitoring into global climate-related observing systems (cf. GCOS/GTOS Plan for Terrestrial Climate-related Observation; GCOS 32, version 2.0, WMO/TD–796, UNEP/DEIA/TR, 97–7).

Observed glacier fluctuations, indeed, contribute important information about ranges of natural variability and rates of change with respect to long-term energy fluxes at the earth's surface. Glacier fluctuations reconstructed for historical and holocene time periods from direct measurements, old paintings, written sources or moraines indicate that glacier extent in many mountain regions may have varied over the past centuries and millennia within a range defined by the extremes of the maximum Little Ice Age advance and today's reduced stage, respectively. As indicated by spectacular losses in glacier length, the general shrinkage of mountain glaciers during the 20th century is 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 characteristic rate of this change (a few decimeters ice depth per year) as deduced from glacier mass losses reflects an additional energy flux (a few W/m^2) which is broadly consistent with the estimated anthropogenic greenhouse forcing. The beginning of this rapid secular glacier retreat tendency was probably little affected by human activity. The observed evolution may, however, include an increasing part of anthropogenic influence: recent shrinking of glaciers for the first time now coincides with a man-induced climate forcing which could be responsible for a major part of the additional energy flux causing the observed melt rate. The situation appears to evolve at a high rate towards or even beyond the "warm" limit of natural holocene variability. In this situation, directly measured glacier mass balances belong to the key indicators for assessing possible trends of continuation or acceleration.

As a contribution to the Global Environment Monitoring System (GEMS) of the United Nations Environment Programme (UNEP) and to the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the World Glacier Monitoring Service (WGMS) of the 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 standardized glacier data. The following series of reports on the variations of glaciers in space and time were already 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)

- 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.Boesch)
- Glacier Mass Balance Bulletin No. 4, 1994–1995 (W. Haeberli, M. Hoelzle and S. Suter)

The present Glacier Mass Balance Bulletin (MBB) reporting the results for the balance years 1995/96 and 1996/97 is the fifth 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 be kept in mind also that this fast and somewhat preliminary reporting of mass balance measurements may require slight corrections and updates at a later time. Corrected and updated information can be found in the Fluctuations series.

The present Mass Balance Bulletin is available on the Internet homepage of the WGMS:

http://www.geo.unizh.ch/wgms/

In the future, mass balance values for selected glaciers will be made available on the WGMS homepage one year after the end of the measurement year.

Zurich, January 1999

Wilfried Haeberli
Director
World Glacier Monitoring Service

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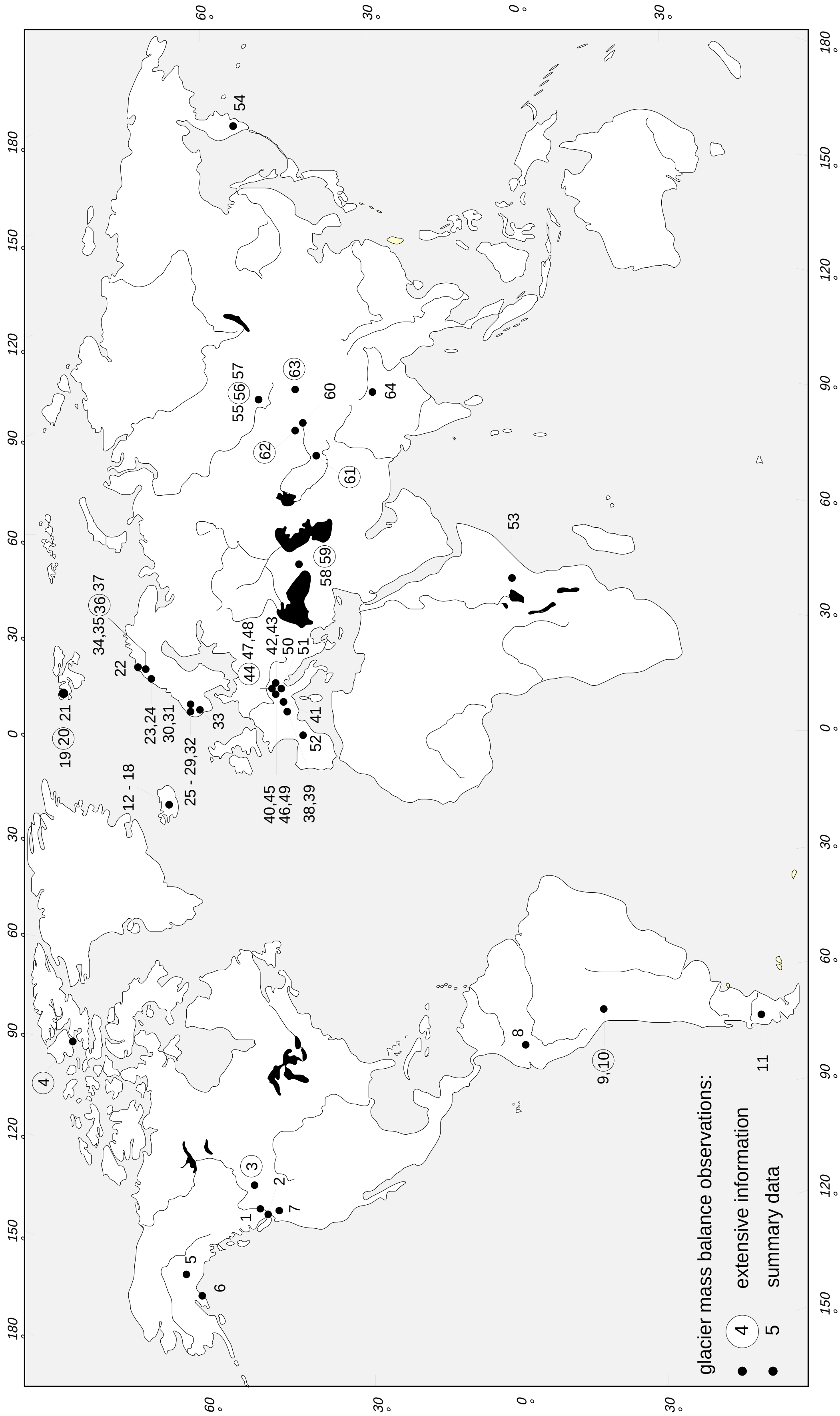
1. INTRODUCTION

Two main categories of data – summary information and extensive information – are being reported in the Glacier Mass Balance Bulletin. Summary information on specific balance, cumulative specific balance, accumulation area ratio and equilibrium line altitude is given for 64 glaciers. Such information provides a regional overview. In addition, extensive information such as balance maps, balance/altitude diagrams, relations between accumulation area ratios, equilibrium line altitudes and balance, as well as a short explanatory text with a photograph, are presented for 11 selected glaciers with existing long and complete series of direct glaciological measurements. These long time-series based on high density networks of stakes and firn pits are especially valuable for analyzing processes of mass and energy exchange at glacier/atmosphere interfaces and, hence, for interpreting climate/glacier relations.
The glaciers for which data are reported in the present bulletin are marked on the following world map (page 3).

No.	Glacier Name	Country	Location	Coordinates	
1	Place	Canada	Coast Mtns.	50° 26’ N	122° 36’W
2	Helm	Canada	Coast Mtns.	49° 58’ N	123° 00’W
3	Peyto	Canada	Rocky Mountains	51° 41’ N	116° 32’W
4	White	Canada (High Arctic)	Axel Heiberg Island	79° 27’ N	90° 40’W
5	Gulkana	USA (Alaska)	Alaska Range	63° 15’ N	145° 28’W
6	Wolverine	USA (Alaska)	Kenai Mtns.	60° 24’ N	148° 54’W
7	South Cascade	USA	N Cascades Mtns.	48° 22’ N	121° 03’W
8	Antizana 15 alpha	Ecuador	E Cordillera	0° 29’ S	78° 09’W
9	Chacaltaya	Bolivia	Cordillera Real	16° 21’ S	68° 07’W
10	Zongo	Bolivia	Cordillera Real	16° 15’ S	68° 10’W
11	Glaciar de los Tres	Argentina	Patagonian Andes	49° 20’ S	73° 00’W
12	Hofsjökull North	Iceland	Central Iceland	64° 57’ N	18° 55’W
13	Hofsjökull Southwest	Iceland	Central Iceland	64° 43’ N	19° 03’W
14	Hofsjökull East	Iceland	Central Iceland	64° 40’ N	18° 35’W
15	Brúarjökull	Iceland	Central Iceland	64° 40’ N	16° 10’W
16	Dyngjujökull	Iceland	Central Iceland	64° 45’ N	17° 00’W
17	Eyjabakkajökull	Iceland	Central Iceland	64° 39’ N	15° 35’W
18	Thrándarjökull	Iceland	Central Iceland	64° 41’ N	14° 54’W
19	Austre Brøggerbreen	Norway (Svalbard)	N-Spitsbergen	78° 53’ N	11° 50’ E
20	Midtre Lovénbreen	Norway (Svalbard)	N-Spitsbergen	78° 53’ N	12° 04’ E
21	Kongsvegen	Norway (Svalbard)	N-Spitsbergen	78° 50’ N	12° 59’ E
22	Langfjordjøkelen	Norway	North Norway	70° 07’ N	21° 46’ E
23	Engabreen	Norway	North Norway	66° 39’ N	13° 51’ E
24	Okstindbreen	Norway	North Norway	66° 14’ N	14° 22’ E
25	Austdalsbreen	Norway	South Norway	61° 48’ N	7° 21’ E
26	Ålfotbreen	Norway	South Norway	61° 45’ N	5° 39’ E
27	Nigardsbreen	Norway	South Norway	61° 43’ N	7° 08’ E

No.	Glacier Name	Country	Location	Coordinates	
28	Gråsubreen	Norway	South Norway	61° 39’ N	8° 36’ E
29	Hansebreen	Norway	South Norway	61° 32’ N	5° 41’ E
30	Storbreen	Norway	South Norway	61° 34’ N	8° 08’ E
31	Hellstugubreen	Norway	South Norway	61° 34’ N	8° 26’ E
32	Jostefonn	Norway	South Norway	61° 25’ N	6° 35’ E
33	Hardangerjøkulen	Norway	South Norway	60° 32’ N	7° 22’ E
34	Riukojietna	Sweden	North Sweden	68° 05’ N	18° 05’ E
35	Mårmaglaciären	Sweden	North Sweden	68° 05’ N	18° 41’ E
36	Storglaciären	Sweden	North Sweden	67° 54’ N	18° 34’ E
37	Rabots glaciär	Sweden	North Sweden	67° 54’ N	18° 33’ E
38	Saint Sorlin	France	Alps	45° 11’ N	6° 10’ E
39	Sarennes	France	Alps	45° 07’ N	6° 10’ E
40	Silvretta	Switzerland	Alps	46° 51’ N	10° 05’ E
41	Gries	Switzerland	Alps	46° 26’ N	8° 20’ E
42	Sonnblickkees	Austria	Alps	47° 08’ N	12° 36’ E
43	Wurtenkees	Austria	Alps	47° 02’ N	13° 00’ E
44	Vernagtferner	Austria	Alps	46° 53’ N	10° 49’ E
45	Ochsentalergletscher	Austria	Alps	46° 51’ N	10° 06’ E
46	Vermuntgletscher	Austria	Alps	46° 51’ N	10° 08’ E
47	Kesselwandferner	Austria	Alps	46° 50’ N	10° 48’ E
48	Hintereisferner	Austria	Alps	46° 48’ N	10° 46’ E
49	Jamtalferner	Austria	Alps	46° 42’ N	10° 10’ E
50	Fontana Bianca	Italy	Alps	46° 29’ N	10° 46’ E
51	Careser	Italy	Alps	46° 27’ N	10° 42’ E
52	Maladeta	Spain	Pyrenees	42° 39’ N	0° 38’ E
53	Lewis	Kenya	Mount Kenya	0° 09’ S	37° 18’ E
54	Kozelskiy	Russia	Kamchatka	53° 14’ N	158° 49’ E
55	No. 125 (Vodopadniy)	Russia	Altai	50° 06’ N	87° 42’ E
56	Maliy Aktru	Russia	Altai	50° 05’ N	87° 45’ E
57	Leviy Aktru	Russia	Altai	50° 05’ N	87° 41’ E
58	Garabashi	Russia	Caucasus	43° 18’ N	42° 28’ E
59	Djankuat	Russia	Caucasus	43° 12’ N	42° 46’ E
60	Kara-Batkak (Karabatkak)	Kirghizstan	Tien Shan	42° 08’ N	78° 16’ E
61	Abramov	Kirghizstan	Pamir-Alai	39° 38’ N	71° 34’ E
62	Ts. Tuyuksuyskiy (Tuyuksu)	Kazakhstan	Tien Shan	43° 03’ N	77° 05’ E
63	Urumqihe S. No. 1	China	Tien Shan	43° 05’ N	86° 49’ E
64	AX010	Nepal	Himalayas	27° 42’ N	86° 34’ E


glacier mass balance observations:
4 extensive information
5 summary data

2. SUMMARY DATA

Specific net balance (b), equilibrium line altitude (ELA) and accumulation area ratio (AAR) of all glaciers from the balance years 1995/96 and 1996/97 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. Some of the observed glaciers can entirely become ablation or accumulation areas in extreme years. Corresponding AAR values of 0 or 100% as well as ELA values outside the altitude range of the observed glaciers were excluded in the calculation of AAR_0 and ELA_0 values. The corresponding graphs (AAR and ELA, respectively, versus specific net balance) are given in Chapter 3, but only for the glaciers with extensive information.

The graphs in the second part of this Chapter (2.2) present the development of cumulative specific net balance over the whole observation period for each glacier where two or more net balances were calculated.

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

Name		Country	b96 [mm]	b97 [mm]	ELA96 [m a.s.l.]	ELA97 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR96 [%]	AAR97 [%]	AAR_0 [%]
Helm	(1975)	Canada	+ 211	- 1073	1967	2035	2006	47	22	37
Peyto	(1966)	Canada	+ 129	- 818	2581	2722	2623	62	34	53
Place	(1965)	Canada	- 221	- 888	2055	2240	2083	54	24	49
White	(1960)	Canada	+ 38	- 56	759	1055	897	82	65	71
Gulkana	(1966)	USA	- 710	- 1760	1787	1871	1729	55	44	62
Wolverine	(1966)	USA	- 1190	- 2480	1245	1419	1155	54	15	62
South Cascade	(1953)	USA	+ 100	+ 630	1901	1857	1893	40	70	56
Antizana 15 alpha	(1995)	Equador	- 359	- 864	5100	5130	–	57	50	–
Chacaltaya	(1992)	Bolivia	- 1874	- 659	5454	5322	–	0	10	–
Zongo	(1992)	Bolivia	- 675	+ 797	5425	5075	5186	47	89	75
Glaciar de los Tres	(1996)	Argentina	+ 70	+ 650	1440	1410	–	66	27	–
Hofsjökull North	(1988)	Iceland	- 780	- 1050	1340	1400	1268	36	31	49
Hofsjökull Southwest	(1989)	Iceland	- 1230	- 1420	1370	1410	1263	24	18	41
Hofsjökull East	(1989)	Iceland	- 1170	- 1150	1360	1370	1179	31	30	53
Brúarjökull	(1993)	Iceland	- 220	–	1230	–	–	53	–	–
Dyngjujökull	(1992)	Iceland	- 390	–	1410	–	–	58	–	–
Eyjabakkajökull	(1991)	Iceland	- 850	–	1080	–	–	53	–	–
Thrándarjökull	(1991)	Iceland	- 450	–	1130	–	–	32	–	–
Köldukvislarjökull	(1994)	Iceland	- 630	–	1430	–	–	48	–	–
Austre Brøggerbreen	(1967)	Norway	- 170	- 710	310	490	274	49	7	56
Midtre Lovénbreen	(1968)	Norway	+ 20	- 430	305	390	295	58	36	60
Kongsvegen	(1987)	Norway	+ 390	+ 100	435	540	542	59	45	52
Engabreen	(1970)	Norway	+ 830	+ 1220	970	1010	1160	88	85	58
Okstindbreen	(1987)	Norway	- 300	- 1330	–	1301	57	–	63	
Austdalsbreen	(1988)	Norway	- 1070	- 530	1565	1450	1430	30	70	62
Ålfotbreen	(1963)	Norway	- 1880	+ 80	>1380[2)]	1200	1194	0	60	55
Nigardsbreen	(1962)	Norway	- 410	+ 470	1660	1500	1561	55	82	60
Gråsubreen	(1962)	Norway	- 450	- 1690	2205	>2290[2)]	2129	14	0	30
Storbreen	(1949)	Norway	- 1030	- 1030	1890	1875	1709	19	23	60
Hellstugubreen	(1962)	Norway	- 740	- 1650	1955	2200	1834	38	0	58
Hardangerjøkulen	(1963)	Norway	- 1110	- 470	>1860[2)]	1700	1668	0	74	65
Hansebreen	(1986)	Norway	- 2020	- 150	>1320[2)]	1160	–	0	50	–
Jostefonn	(1995)	Norway	- 1620	- 420	>1615[2)]	1400	–	0	63	–
Langfjordjøkelen	(1989)	Norway	- 20	- 690	680	820	709	77	58	66
Riukojietna	(1986)	Sweden	- 60	- 980	1346	1460	1348	59	0	57
Mårmaglaciären	(1990)	Sweden	- 380	- 200	1631	1634	1572	19	15	41
Storglaciären	(1946)	Sweden	- 360	- 630	1493	1498	1462	42	41	46
Rabots glaciär	(1982)	Sweden	- 470	- 140	1475	1485	1367	30	30	52
Saint Sorlin	(1959)	France	- 480	- 130	–	–	–	–	–	–
Sarennes	(1949)	France	0	- 500	–	–	–	–	–	–
Silvretta	(1960)	Switzerland	- 70	+ 540	2754	2650	2766	57	80	53
Gries	(1962)	Switzerland	- 230	- 270	2884	2893	2832	58	57	59
Sonnblickkees	(1959)	Austria	- 245	+ 314	2780	2780	2741	48	78	60
Wurtenkees	(1983)	Austria	- 638	- 154	2860	2880	2824	11	45	41
Vernagtferner	(1965)	Austria	- 413	- 487	3225	3220	3084	40	41	67

Name		Country	b96 [mm]	b97 [mm]	ELA96 [m a.s.l.]	ELA97 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR96 [%]	AAR97 [%]	AAR_0 [%]
Ochsentalergletscher	(1991)	Austria	- 270	+ 60	2880	2835	2843	59	66	64
Vermuntgletscher	(1991)	Austria	- 720	- 500	2970	2955	–	13	18	–
Kesselwandferner	(1953)	Austria	- 111	+ 11	3160	3120	3104	55	74	71
Hintereisferner	(1953)	Austria	- 827	- 591	3100	3050	2921	41	48	66
Jamtalferner	(1989)	Austria	- 550	- 217	2900	2800	2768	34	56	73
Caresèr	(1967)	Italy	- 1320	- 920	>3330[2]	3264	3094	0	3	48
Fontana Bianca	(1984)	Italy	- 440	- 620	>3440[2]	>3440[2]	–	0	8	–
Maladeta	(1992)	Spain	+ 207	+ 512	3049	3025	3056	41	50	38
Lewis[3])	(1979)	Kenya	- 490	–	4880	–	4796	23	–	57
Kozelskiy	(1973)	Russia	+ 600	+ 940	1200	1150	1452	68	70	52
No. 125 (Vodopadniy)	(1977)	Russia	- 120	- 170	3240	3250	3211	68	66	66
Maliy Aktru	(1962)	Russia	- 130	- 50	3220	3200	3143	68	68	70
Leviy Aktru	(1977)	Russia	- 170	- 150	3210	3220	3155	61	60	61
Garabashi	(1987)	Russia	- 30	+ 190	3840	3780	3803	55	66	60
Djankuat	(1968)	Russia	- 150	+ 270	3200	3150	3190	62	67	60
Kara-Batkak	(1957)	Kirghizstan	- 373	- 648	3900	4000	3860	51	42	55
Abramov	(1968)	Kirghizstan	- 350	- 1730	4163	4440	4150	48	13	59
Ts. Tuyuksuyskiy	(1957)	Kazakhstan	- 456	- 1467	3850	>4220[2]	3741	34	0	53
Urumqihe S. No. 1	(1959)	China	+ 42	- 853	3986	4160	4025	67	25	55
AX010	(1996)	Nepal	- 512	- 472	>5380[2]	5210	–	0	24	–

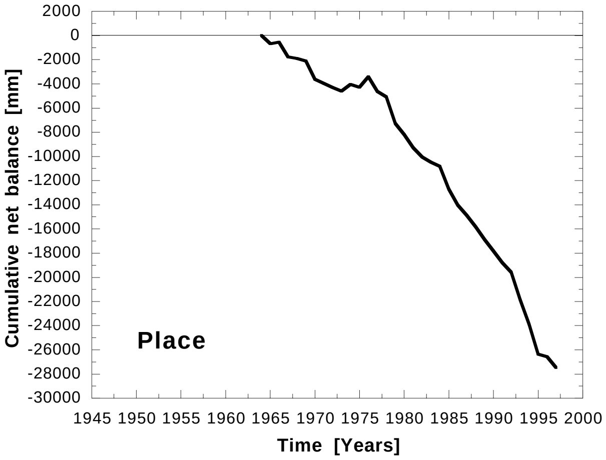
[1]) Numbers in brackets behind the glacier names indicate the beginning of continuous mass balance records.

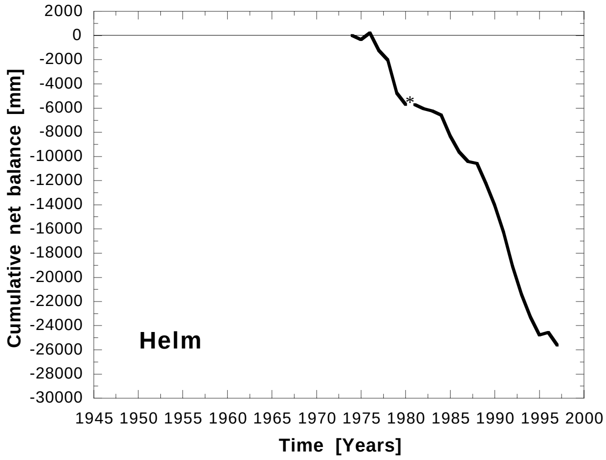
[2]) Above glacier maximum elevation.

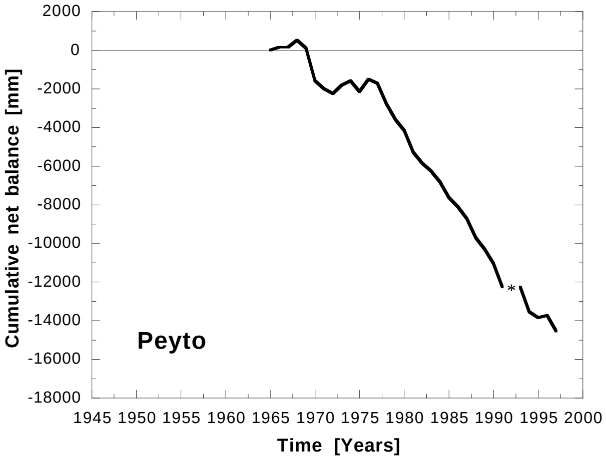
[3]) Note that the balance year here starts in March of the year indicated.

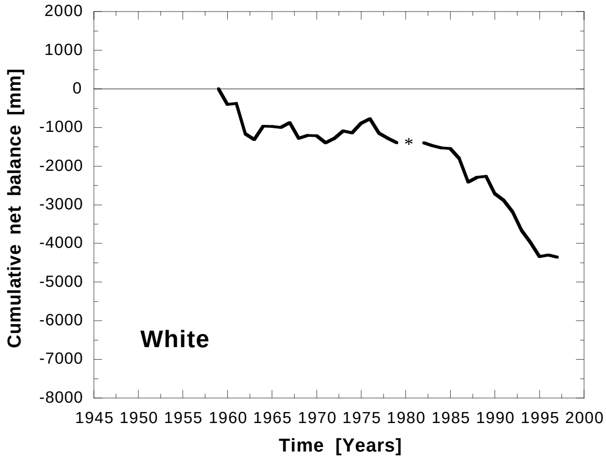
2.2 CUMULATIVE SPECIFIC NET BALANCES

CANADA



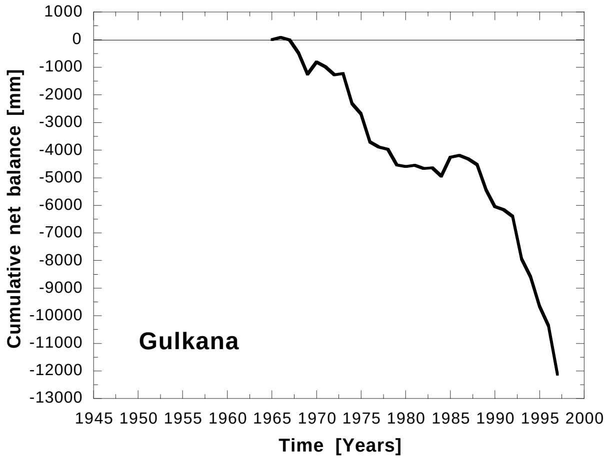


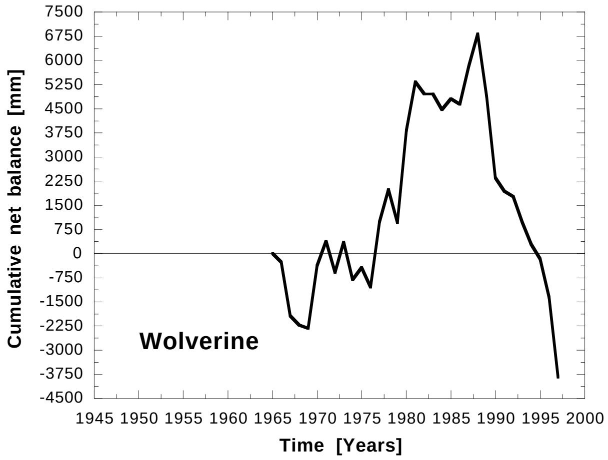


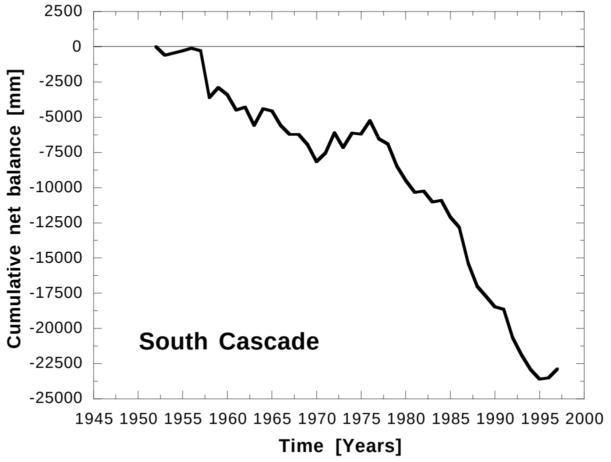


*) missing values in mass balance series

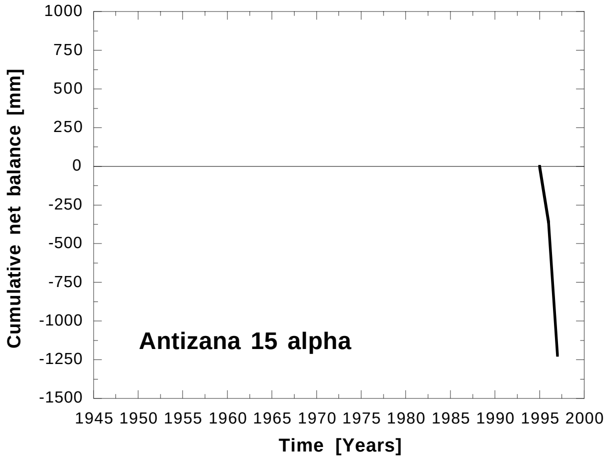
USA


Gulkana
Cumulative net balance [mm]
Time [Years]

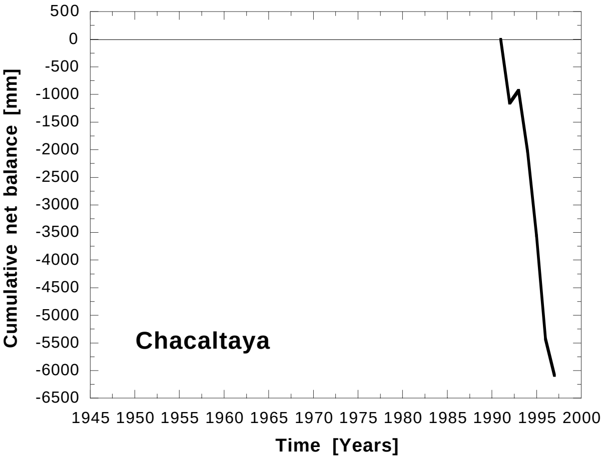

Wolverine
Cumulative net balance [mm]
Time [Years]

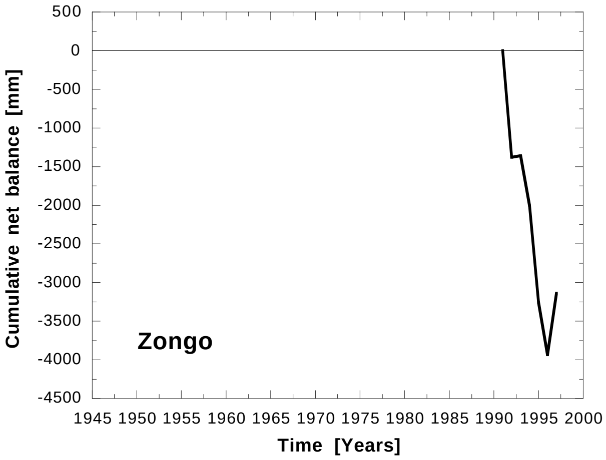

South Cascade
Cumulative net balance [mm]
Time [Years]

EQUADOR

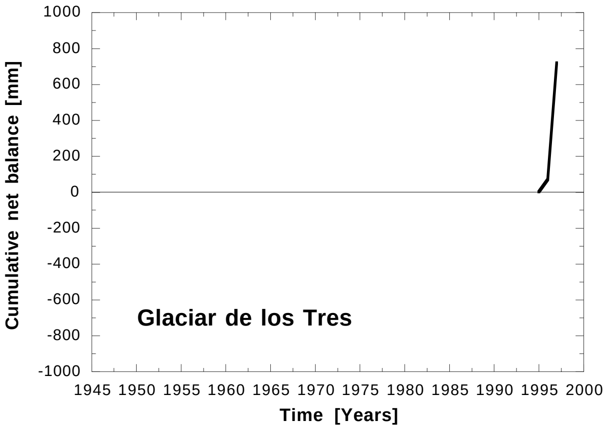

Antizana 15 alpha
Cumulative net balance [mm]
Time [Years]

BOLIVIA

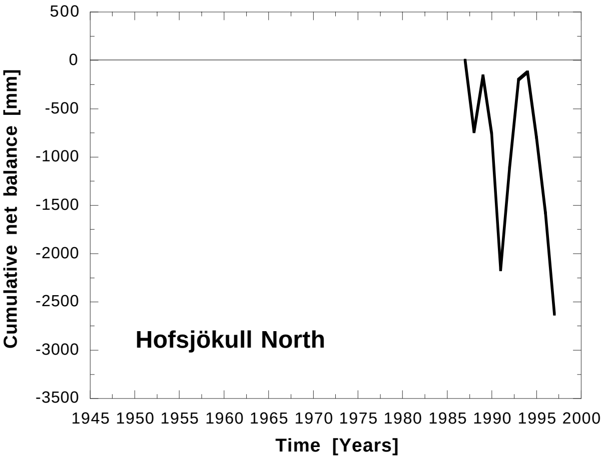


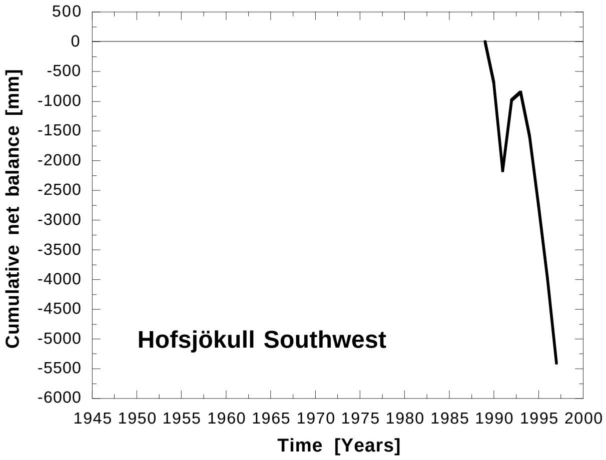


ARGENTINA

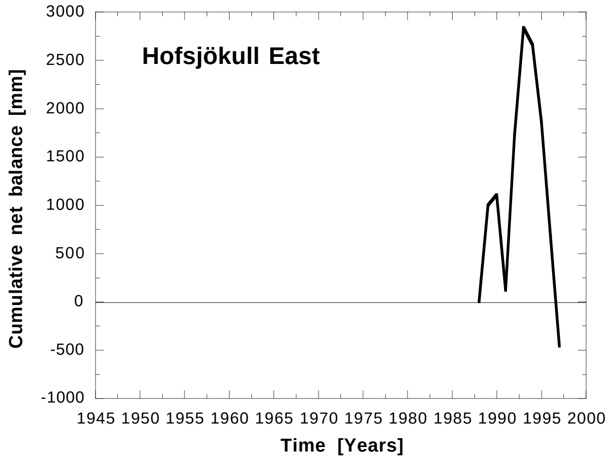


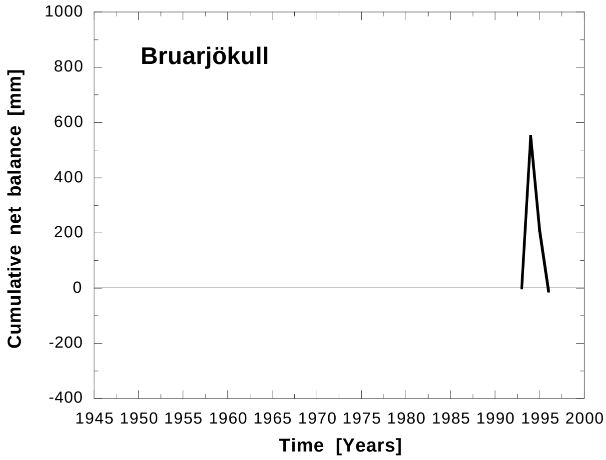
ICELAND

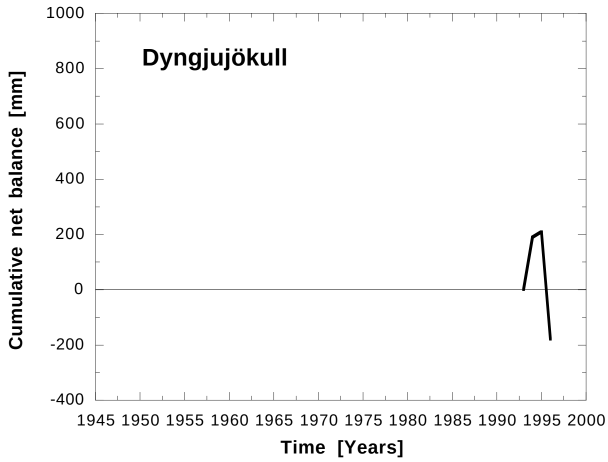


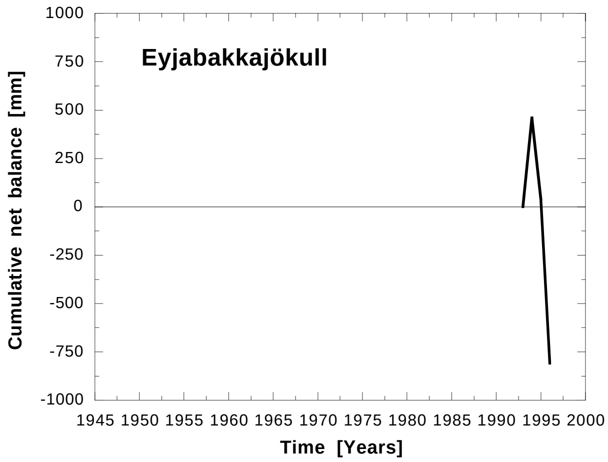


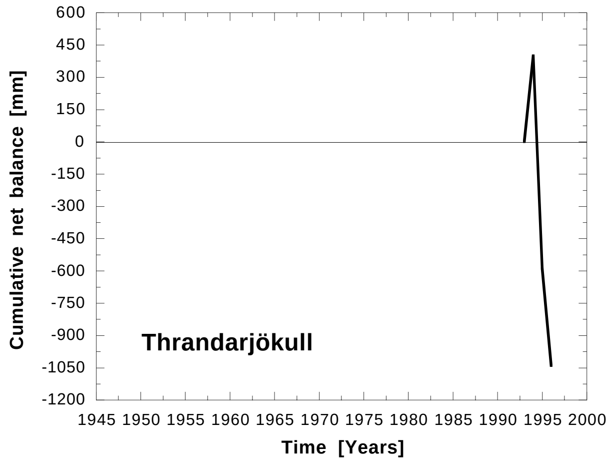
ICELAND


Hofsjökull East
Cumulative net balance [mm]
3000 2500 2000 1500 1000 500 0 -500 -1000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

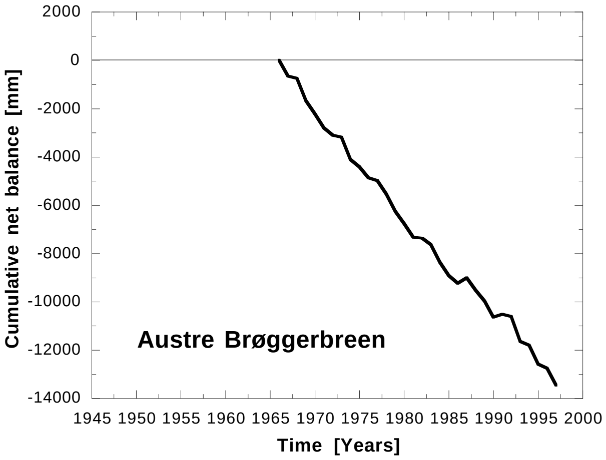

Bruarjökull
Cumulative net balance [mm]
1000 800 600 400 200 0 -200 -400
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

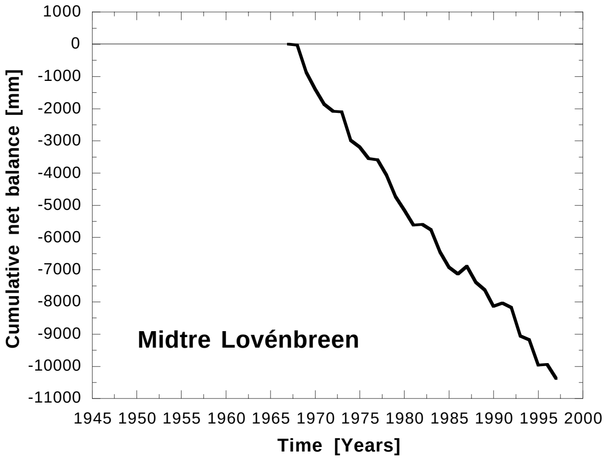

Dyngjujökull
Cumulative net balance [mm]
1000 800 600 400 200 0 -200 -400
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

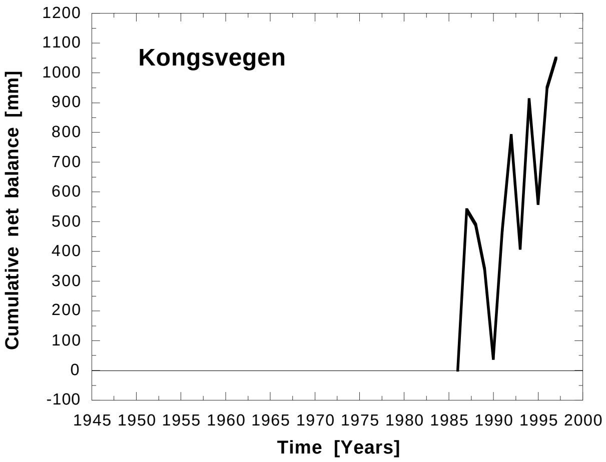

Eyjabakkajökull
Cumulative net balance [mm]
1000 750 500 250 0 -250 -500 -750 -1000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]


Thrandarjökull
Cumulative net balance [mm]
600 450 300 150 0 -150 -300 -450 -600 -750 -900 -1050 -1200
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

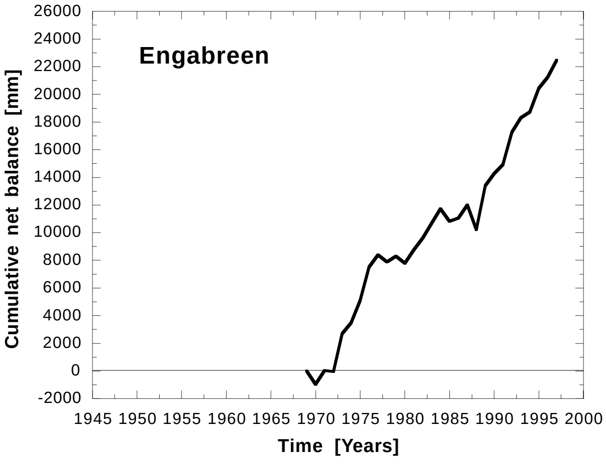
NORWAY (SVALBARD)

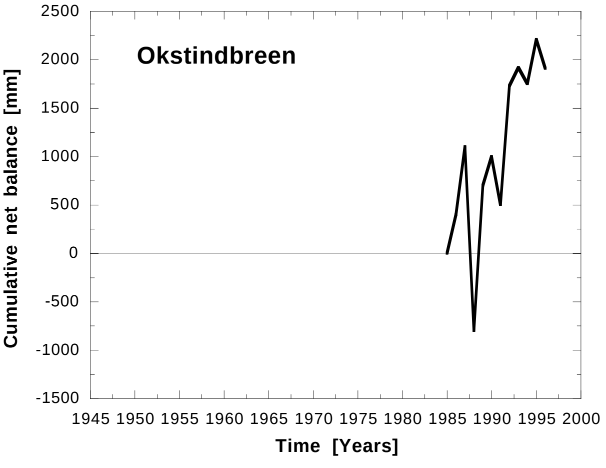




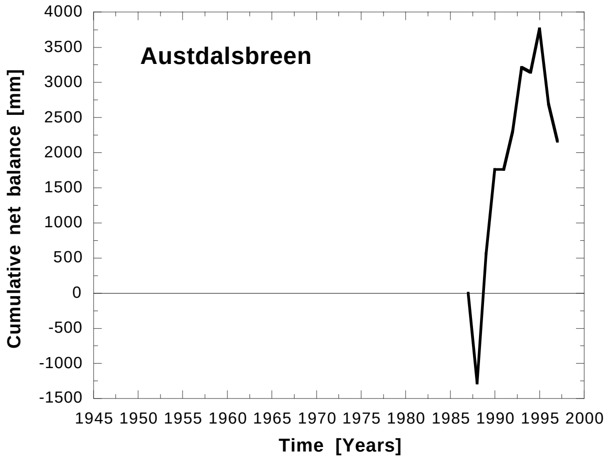


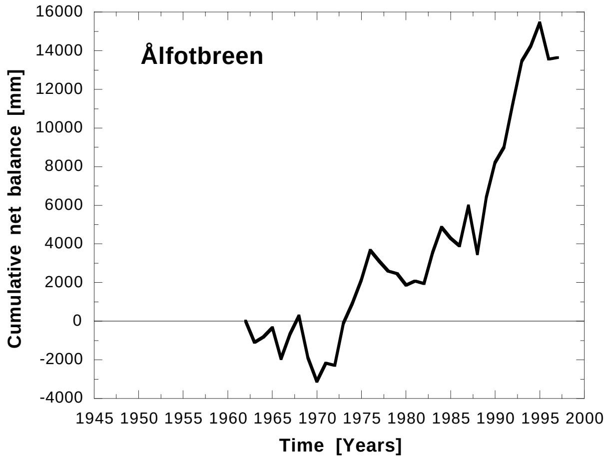
NORWAY

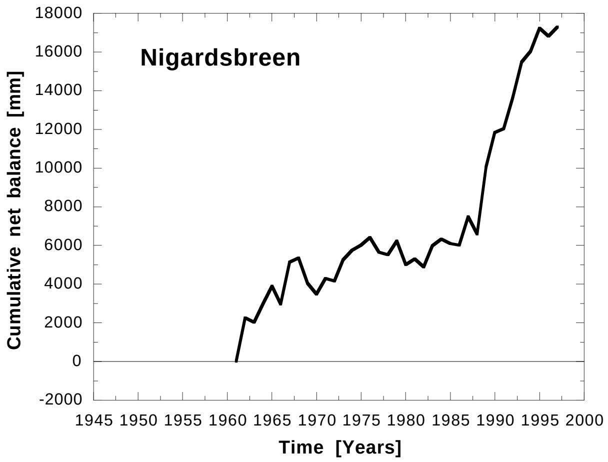


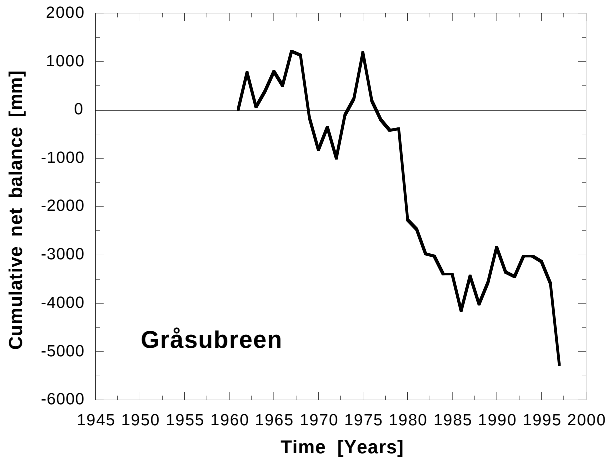


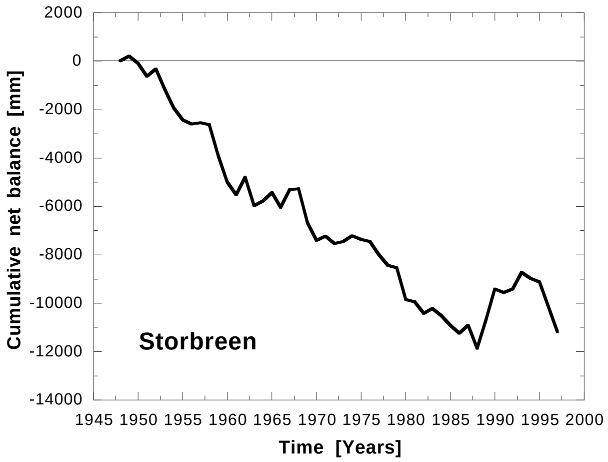
NORWAY

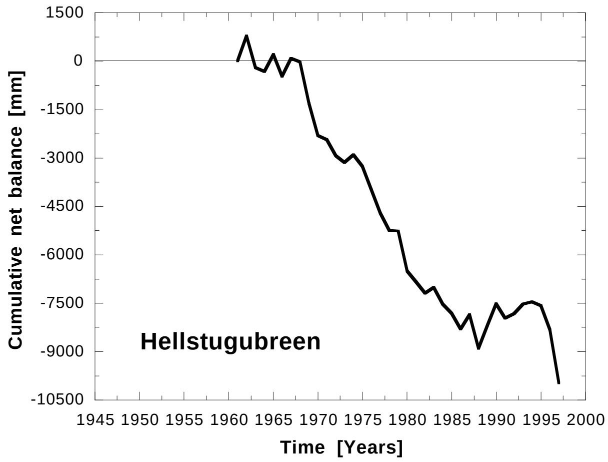

Austdalsbreen
Cumulative net balance [mm]
Time [Years]


Ålfotbreen
Cumulative net balance [mm]
Time [Years]

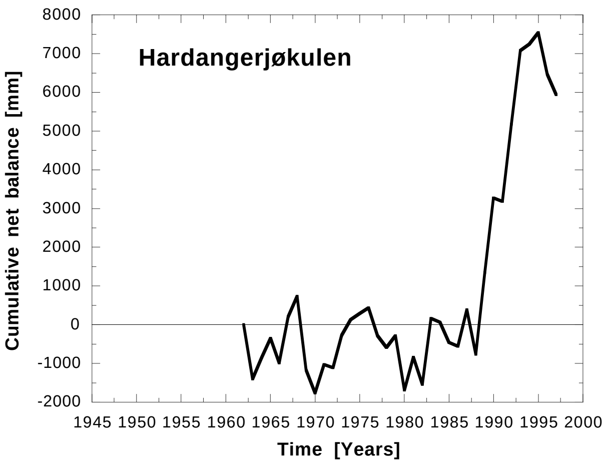

Nigardsbreen
Cumulative net balance [mm]
Time [Years]

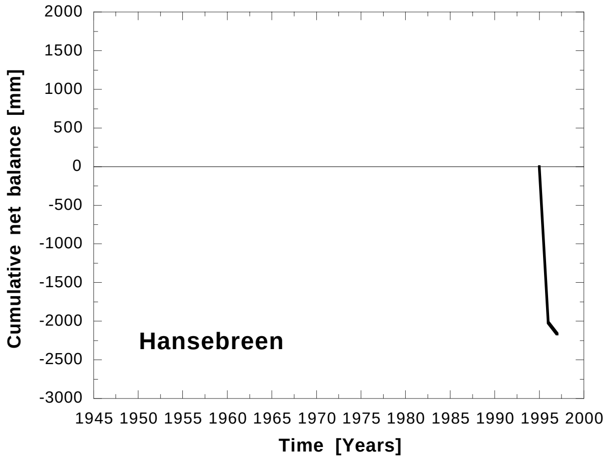

Gråsubreen
Cumulative net balance [mm]
Time [Years]

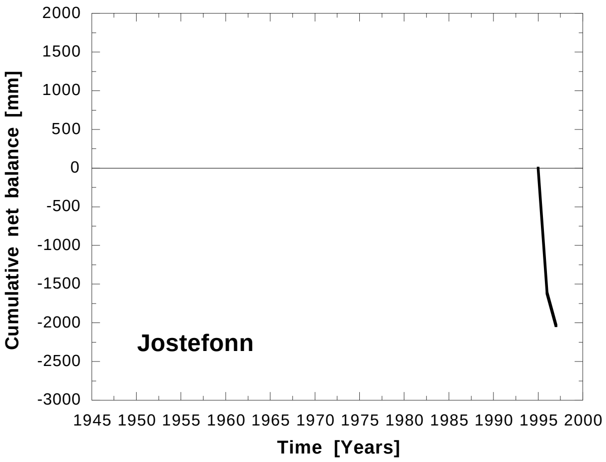

Storbreen
Cumulative net balance [mm]
Time [Years]

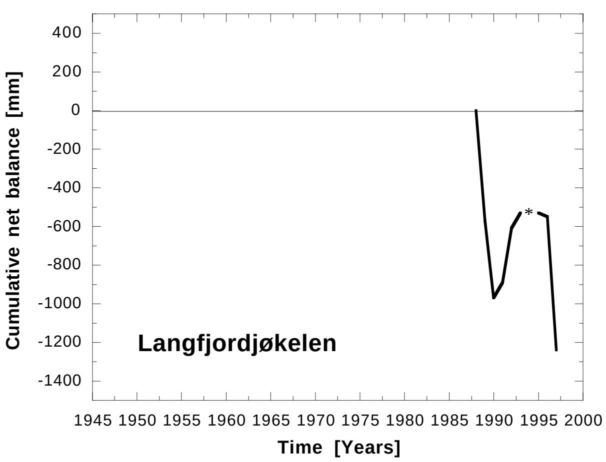

Hellstugubreen
Cumulative net balance [mm]
Time [Years]

NORWAY



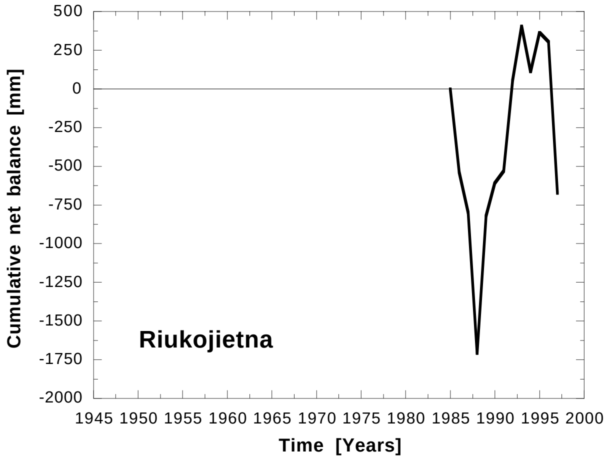


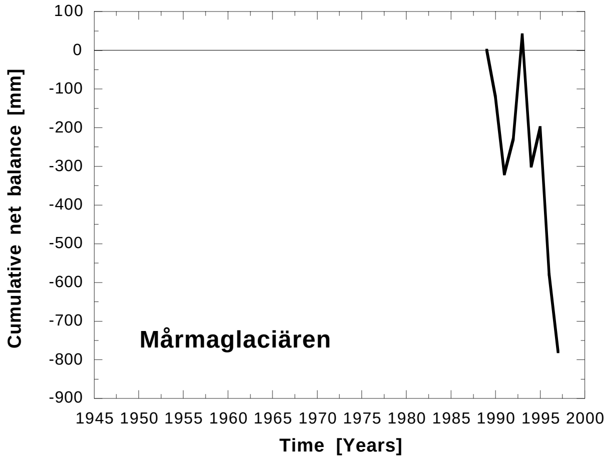


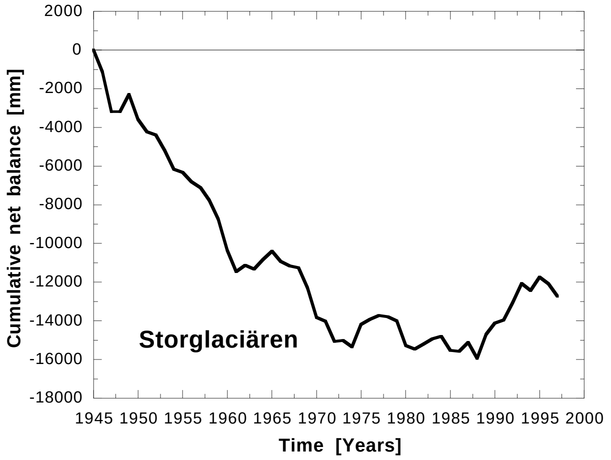


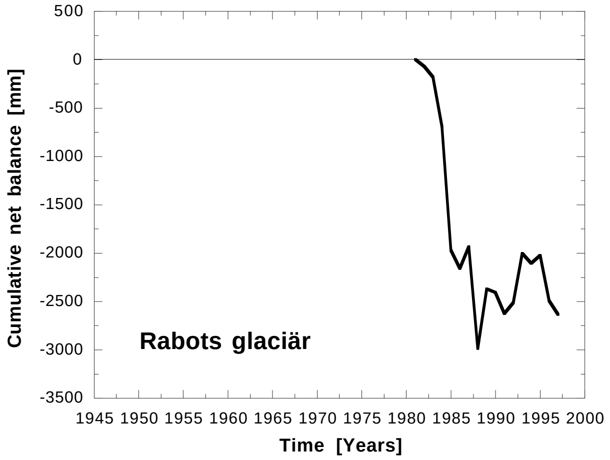
*) missing values in mass balance series

SWEDEN

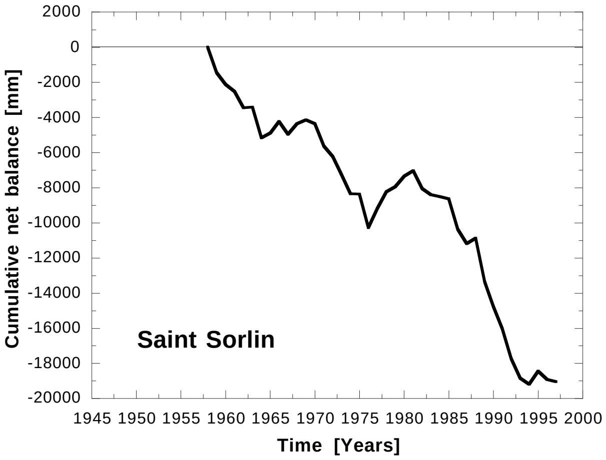

Riukojietna
Cumulative net balance [mm]
Time [Years]

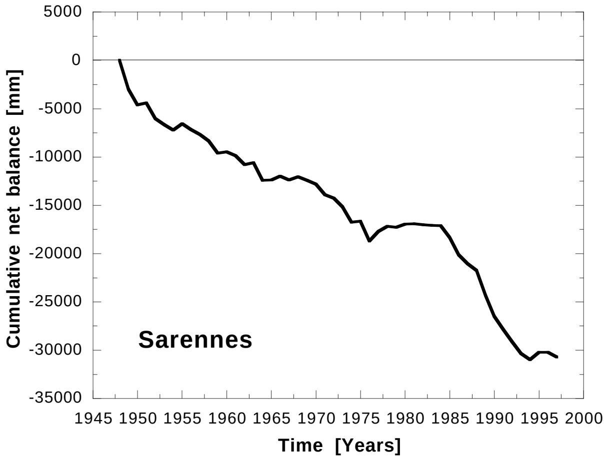

Mårmaglaciären
Cumulative net balance [mm]
Time [Years]


Storglaciären
Cumulative net balance [mm]
Time [Years]

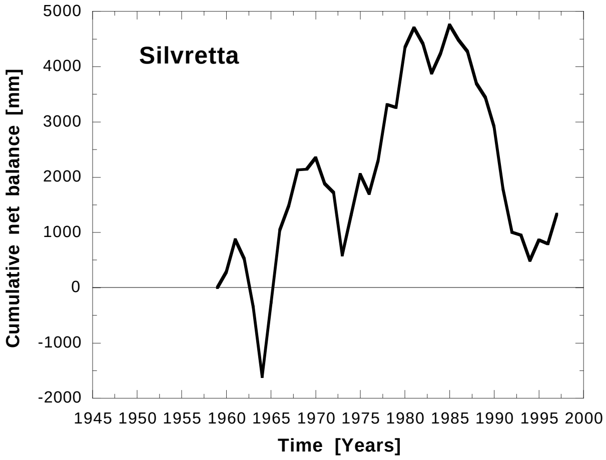

Rabots glaciär
Cumulative net balance [mm]
Time [Years]

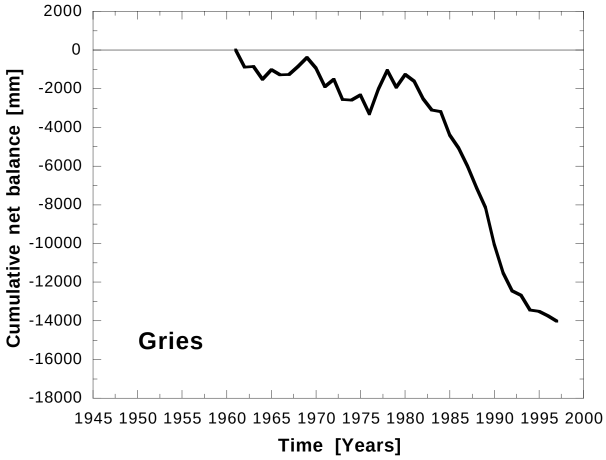
FRANCE



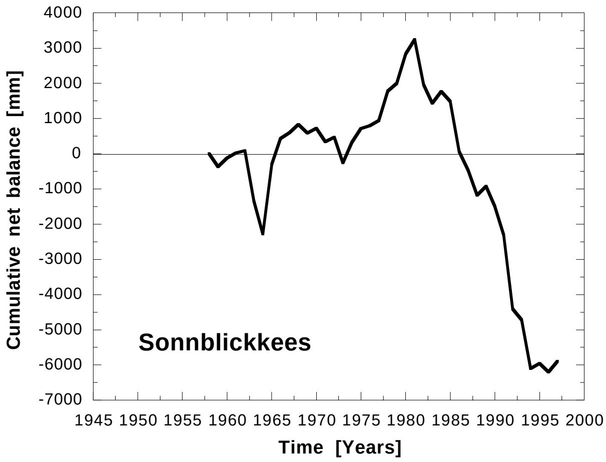


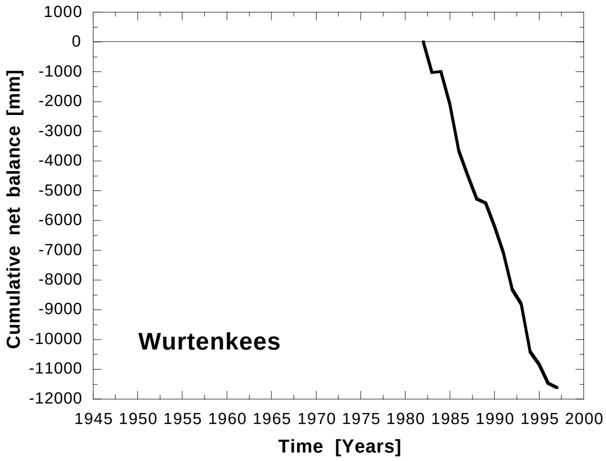
SWITZERLAND



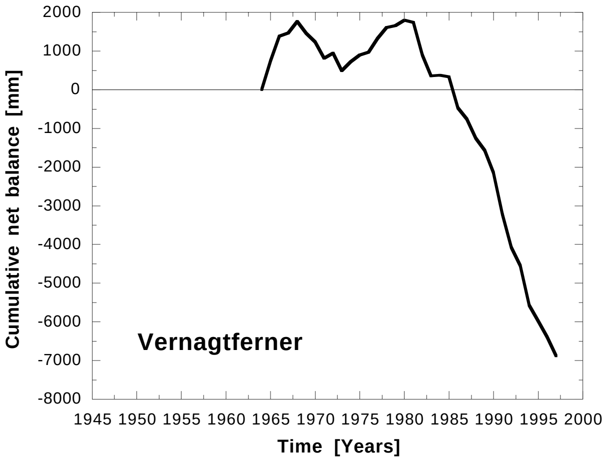


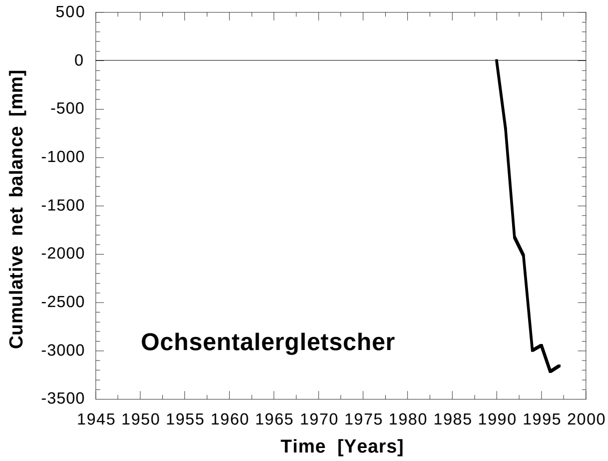
AUSTRIA

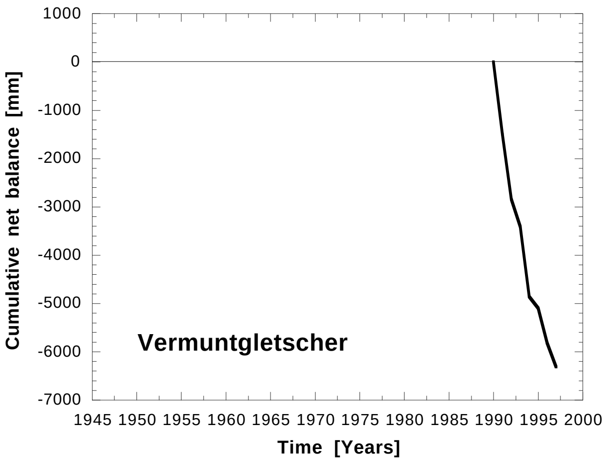


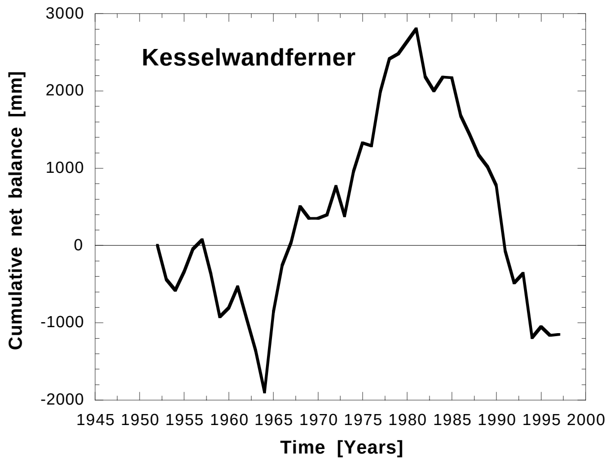


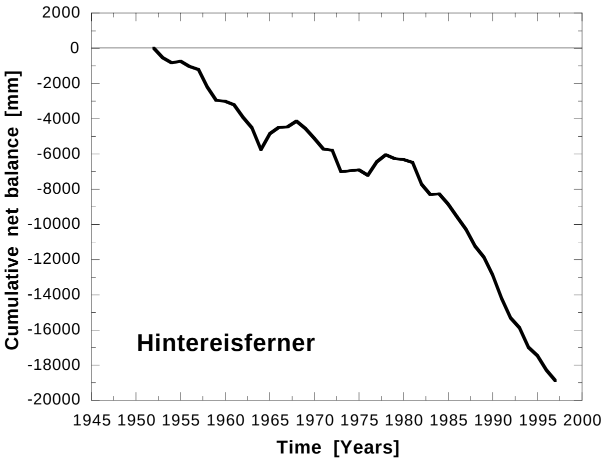
AUSTRIA

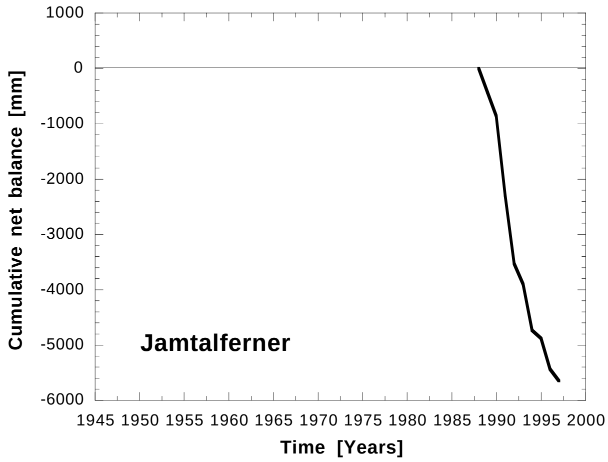

Vernagtferner
Cumulative net balance [mm]
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]


Ochsentalergletscher
Cumulative net balance [mm]
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

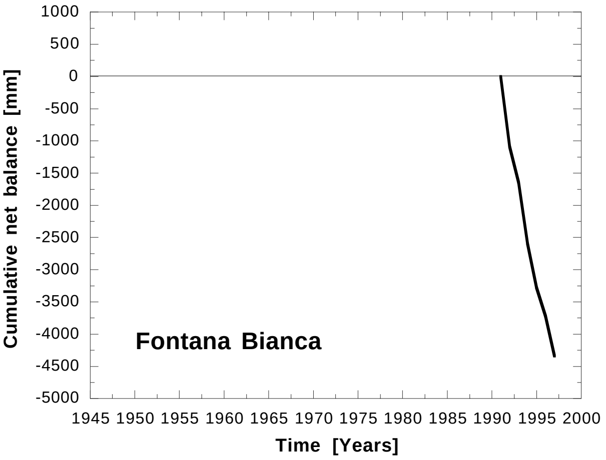

Vermuntgletscher
Cumulative net balance [mm]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

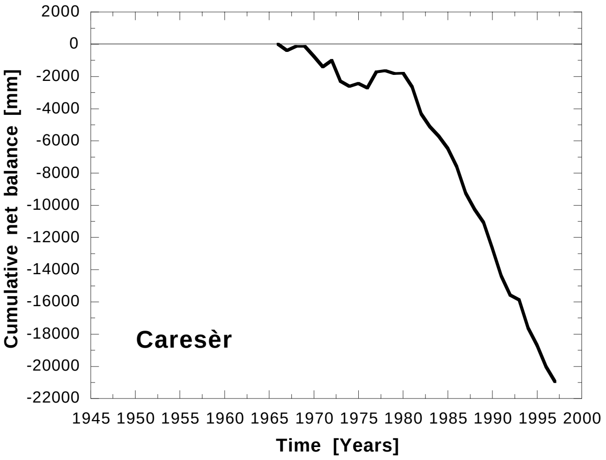

Kesselwandferner
Cumulative net balance [mm]
3000
2000
1000
0
-1000
-2000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]


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

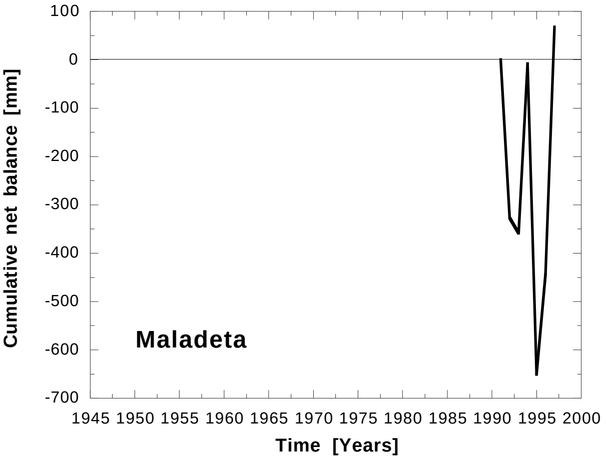

Jamtalferner
Cumulative net balance [mm]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

ITALY

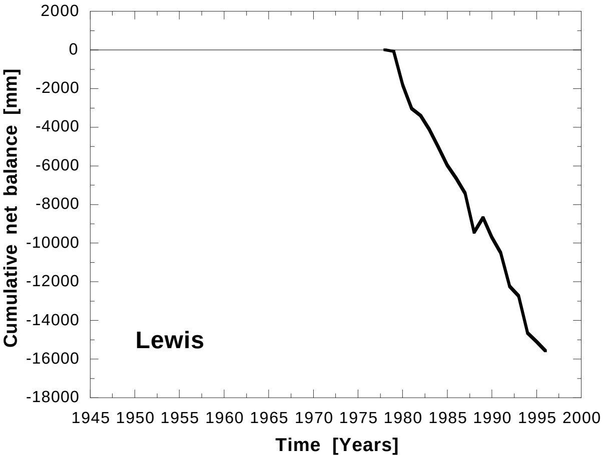




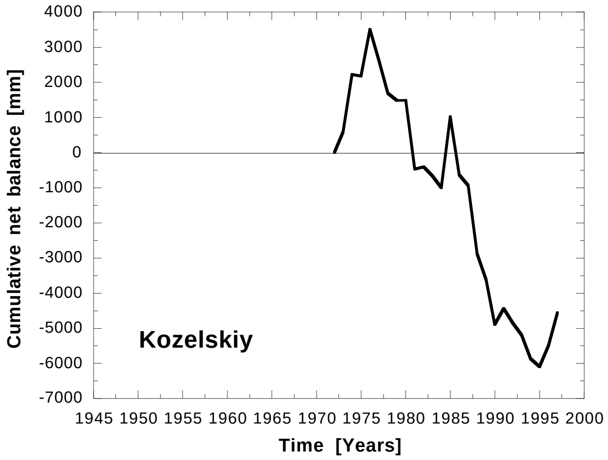
SPAIN

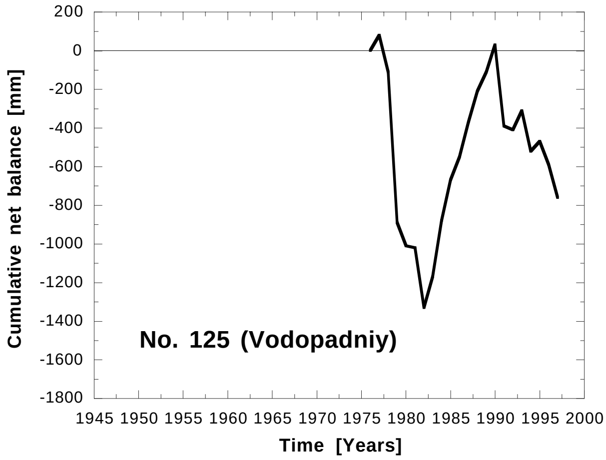


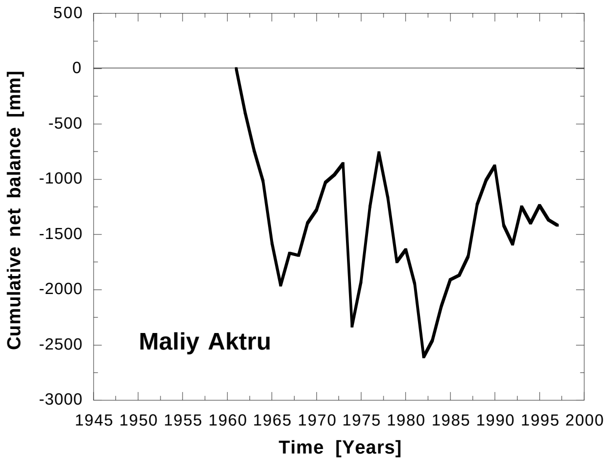
KENYA

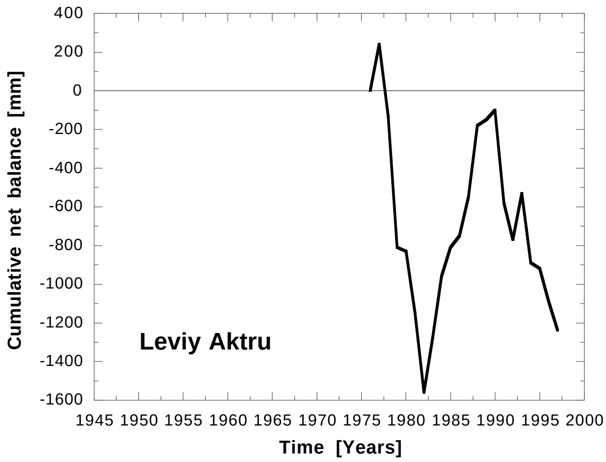


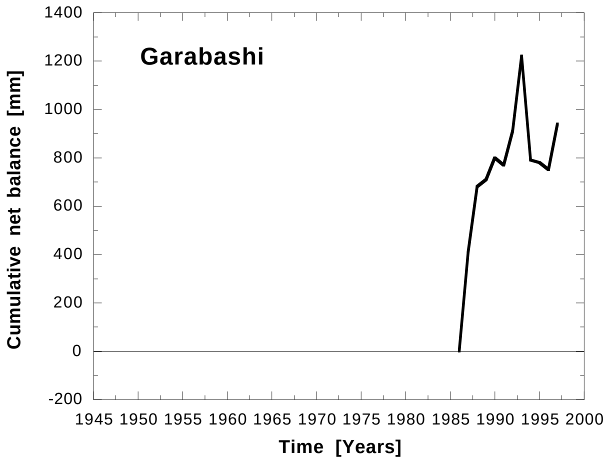
RUSSIA

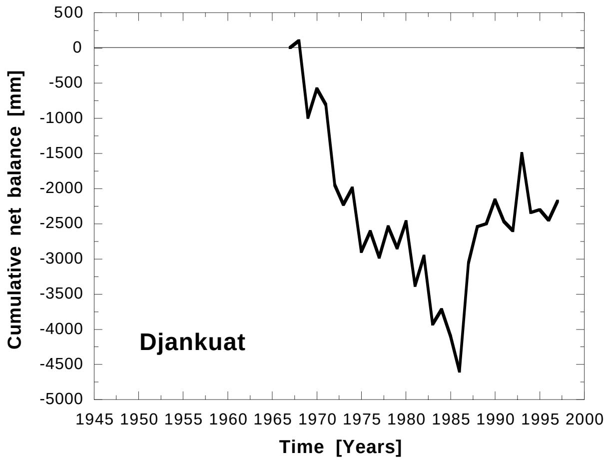

Kozelskiy
Cumulative net balance [mm]
Time [Years]
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000


No. 125 (Vodopadniy)
Cumulative net balance [mm]
Time [Years]
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

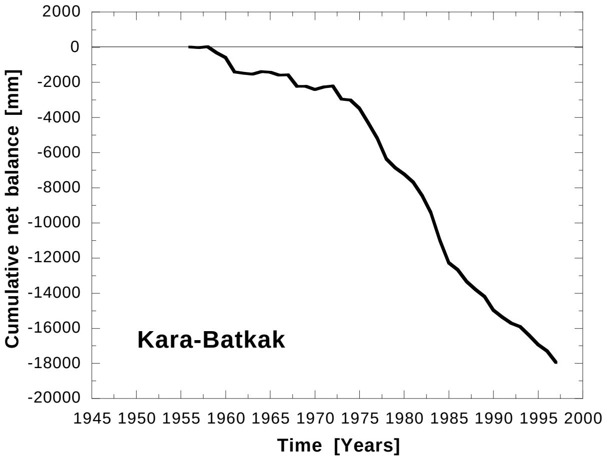

Maliy Aktru
Cumulative net balance [mm]
Time [Years]
500
0
-500
-1000
-1500
-2000
-2500
-3000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

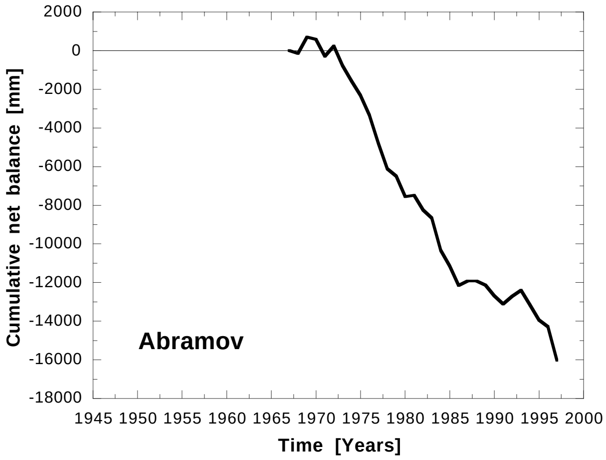

Leviy Aktru
Cumulative net balance [mm]
Time [Years]
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000


Garabashi
Cumulative net balance [mm]
Time [Years]
1400
1200
1000
800
600
400
200
0
-200
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

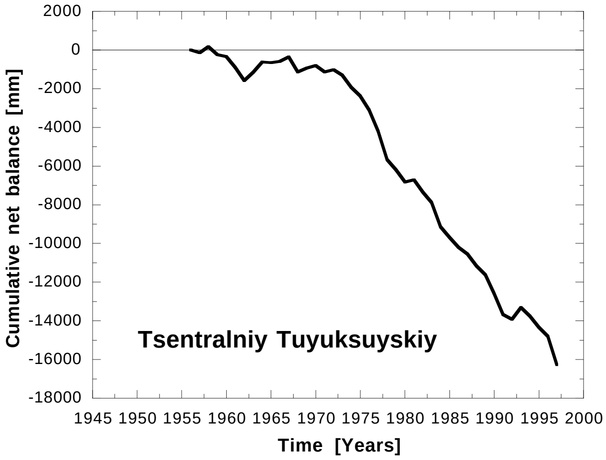

Djankuat
Cumulative net balance [mm]
Time [Years]
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

KIRGHIZSTAN

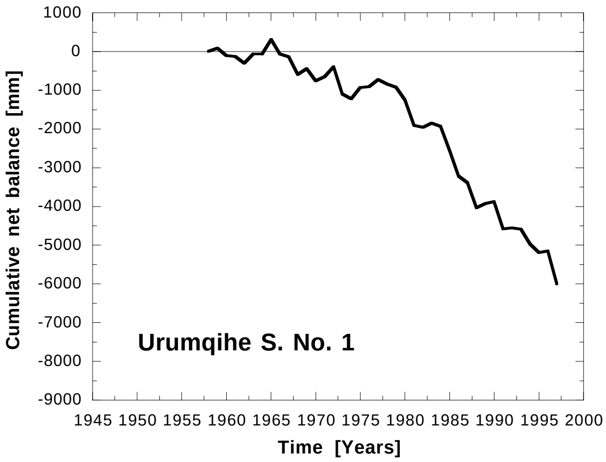




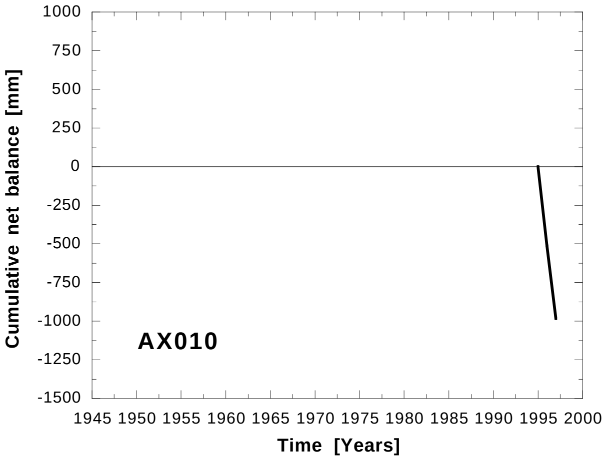
KAZAKHSTAN



CHINA



NEPAL



1000
750
500
250
0
-250
-500
-750
-1000
-1250
-1500
Cumulative net balance [mm]
AX010
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
Time [Years]

3. EXTENSIVE INFORMATION

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

The text gives general information followed by brief comments on the two reported balance years. General information concerns basic geographic, geometric, climatic and glaciological characteristics of the observed glaciers which may help with the interpretation of climate/glacier relations. An oblique photograph showing the entire glacier where possible is also 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 another on most glaciers. In cases with differences between the two reported years, the second one was chosen, i.e., the network from the year 1996/97. The second and third maps are balance maps from the years 1995/96 and 1996/97 respectively, illustrating the pattern of ablation and accumulation distribution. The accuracy of such balance maps depends on the density of the observational network, the complexity of the mass balance distribution and the experience of the local investigators.

A graph of mass balance versus altitude is given for both reported years. The relation between mass balance and altitude or the mass balance gradient is an important parameter in climate/glacier relationships, representing the climatic sensitivity of a glacier and constituting 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 relation 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 in 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 (1995/96, 1996/97) are specially marked in the plots.

Hintereisferner (Austria) was replaced by Vernagtferner (Austria). It is planned to alternate this glacier at a 3-yearly interval with the Austrian glacier Hintereisferner and the Italian glacier Caresèr.

3.1 WHITE (CANADA/HIGH ARCTIC)

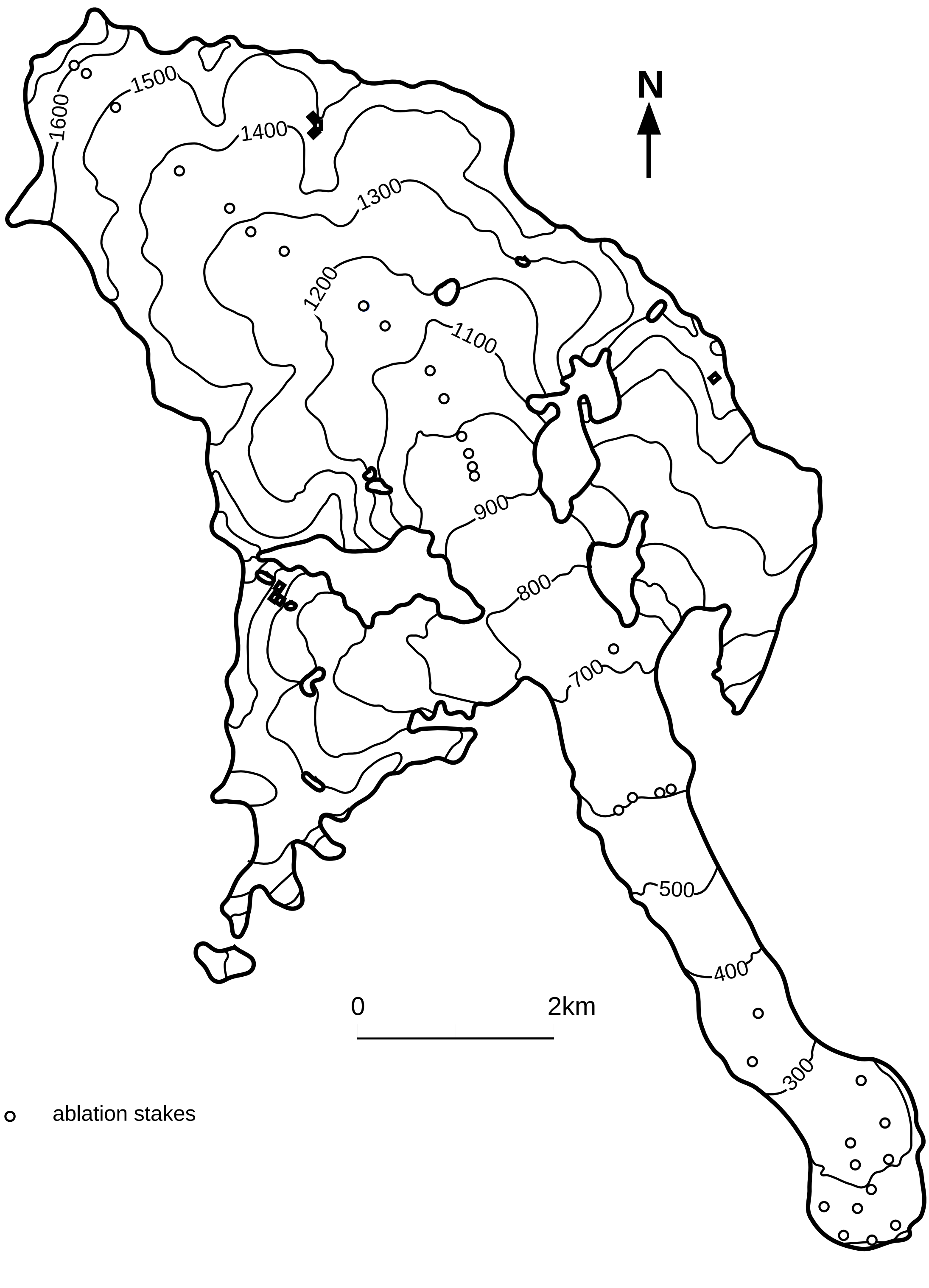
COORDINATES: 79°27' N / 90°40' W

Photo taken by C.S.L. Ommanney (NHRI–Canadien 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 1,782 to 56 m a.s.l. Sea-level temperature in the Expedition Fiord area averages about -20°C and periglacial permafrost is continuous. The glacier is predominantly cold but known to have a bed which is partly unfrozen, at least beneath the valley tongue; ice thickness reaches or exceeds 400 m. Annual precipitation is a few hundred millimeters only. There is now evidence that the retreat of the terminus, previously about 5 m/a, is decelerating. However, the advance of nearby Thompson Glacier continues; the terminuses of the two glaciers have been in contact since at least the time of the earliest photographs in 1948, but, although the two terminuses remain distinguishable, White Glacier has become a tributary of Thompson Glacier.

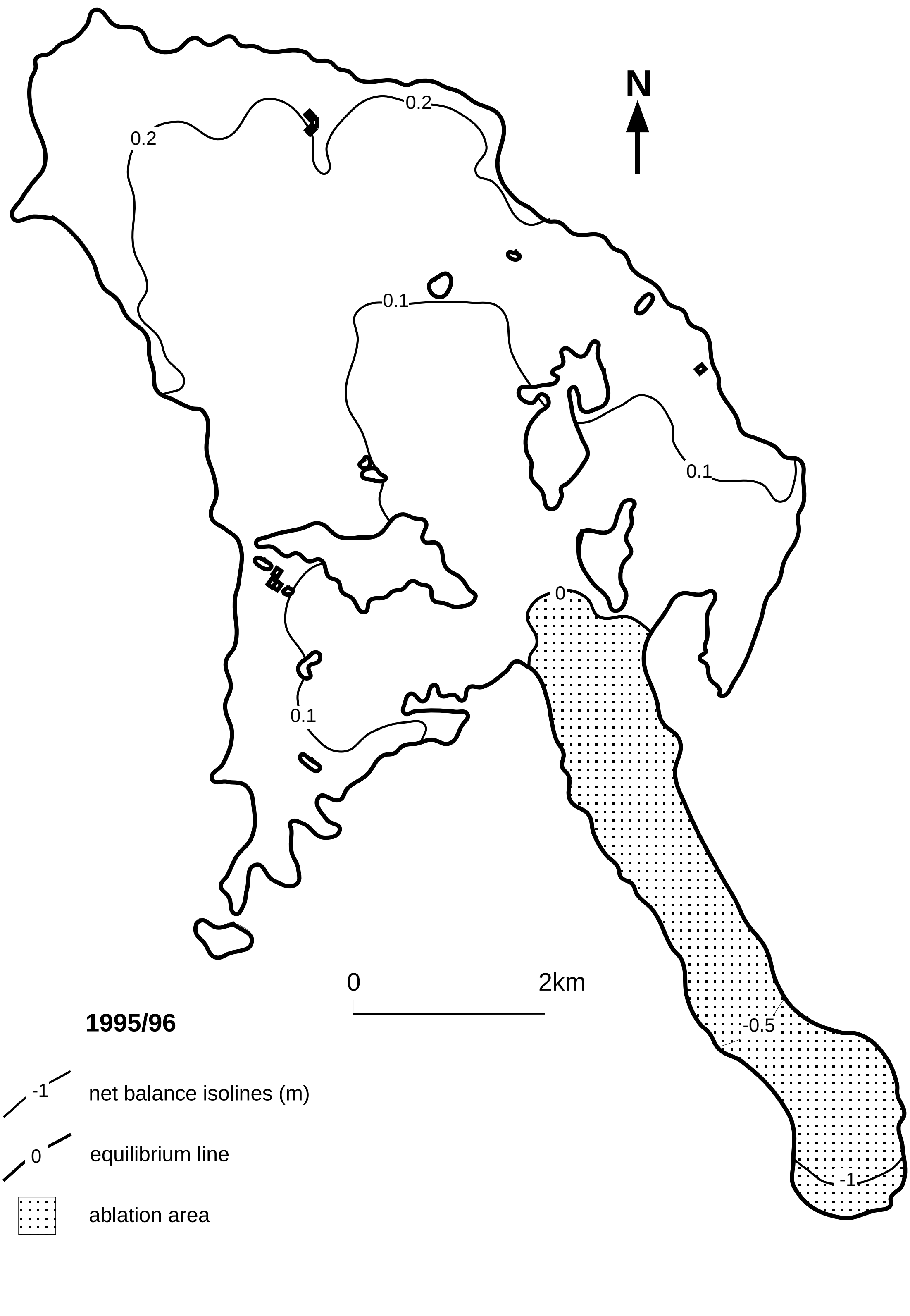
The balance years 1995/96 (38 mm) and 1996/97 (-56 mm) on White Glacier were less negative than normal (-100 ±48 mm for the period 1960 to 1991). 1995/96 was the first year of positive mass balance during the 1990s.

3.1.1 Topography and observational network

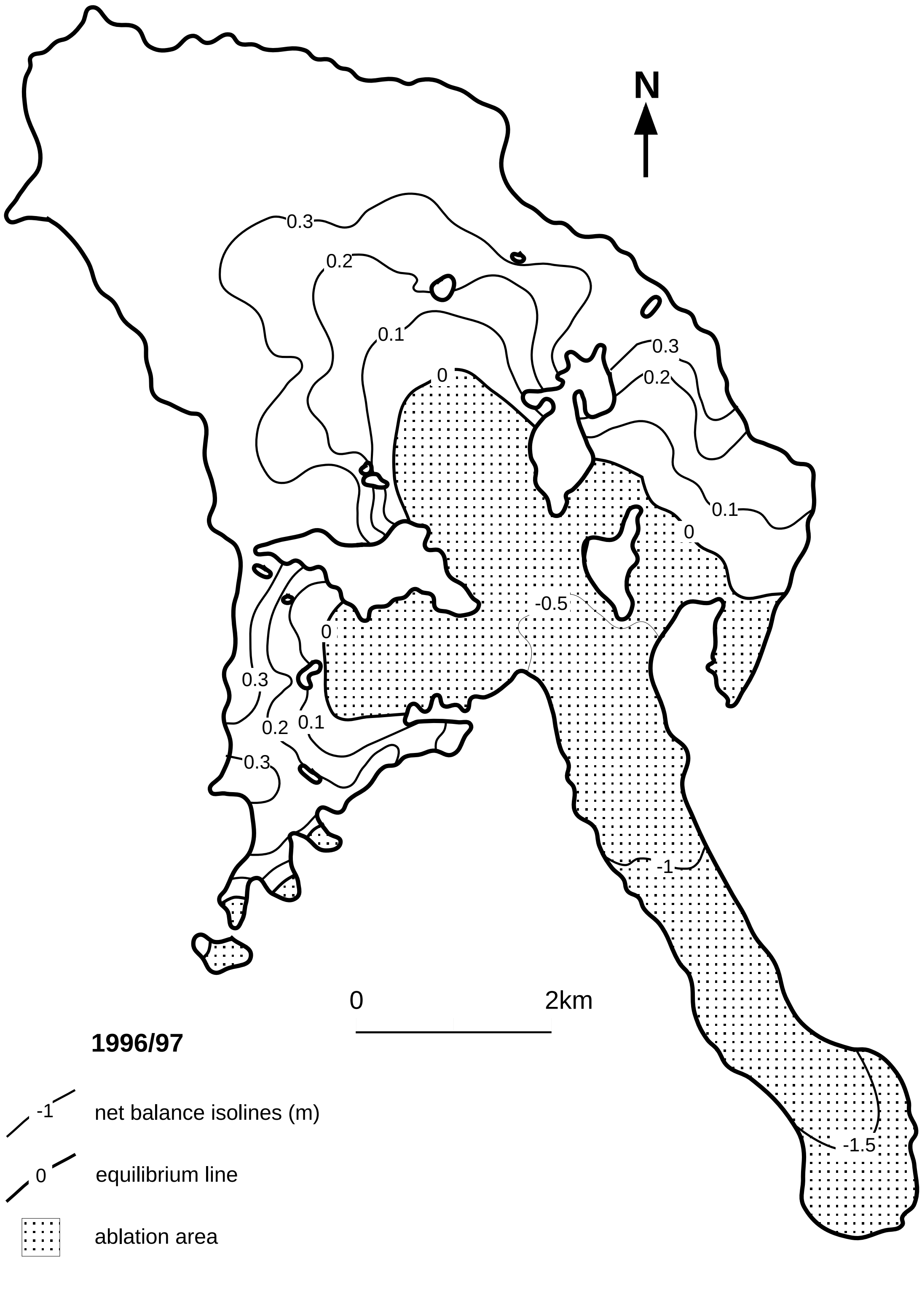


White (CANADA/HIGH ARCTIC)

3.1.2 Net balance maps 1995/96 and 1996/97

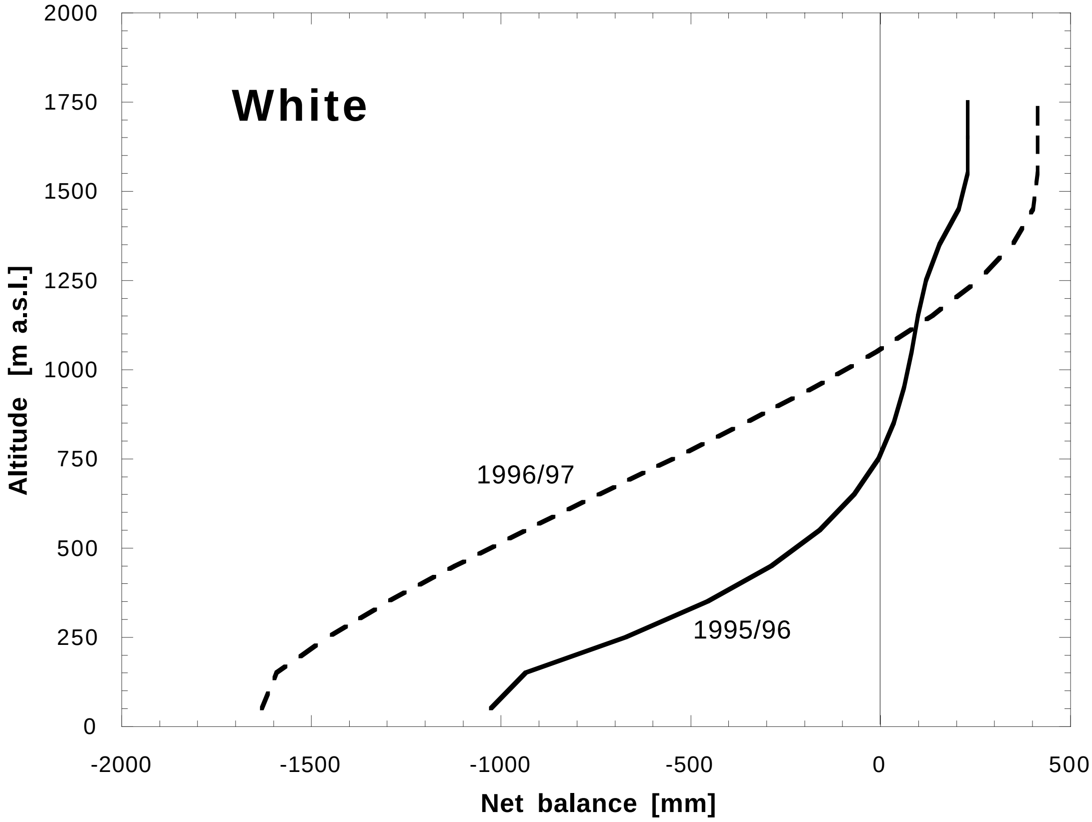


White (CANADA/HIGH ARCTIC)

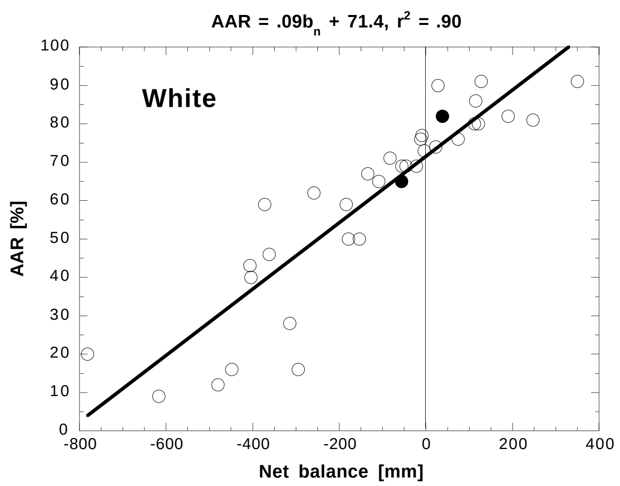


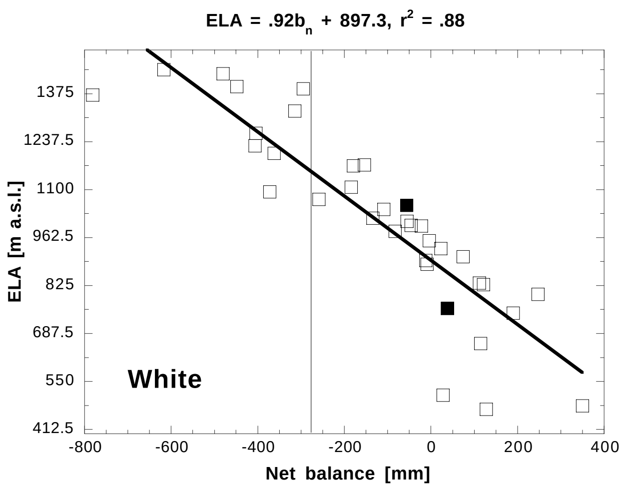
White (CANADA/HIGH ARCTIC)

3.1.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.2 PEYTO (CANADA)

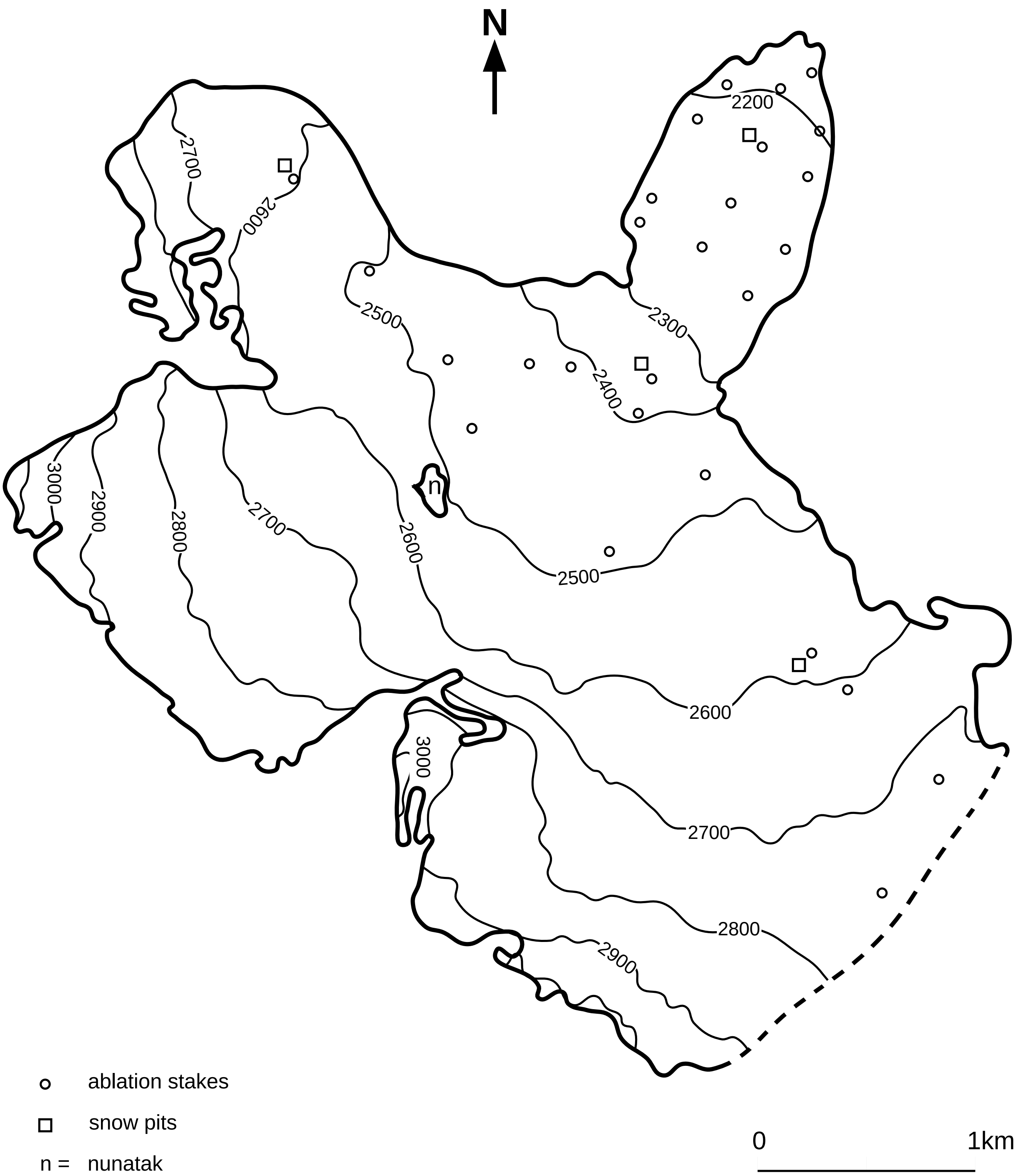
COORDINATES: 51°41’ N / 116°32’ W

Photo taken by W.E.S. Henoch (NHRI–Canadian Glacier Information Centre, 1966)

Peyto Glacier is located in the Canadian Rocky Mountains and contributes flow to the Mistaya River Catchment (12% glacier cover) and the North Saskatchewan River Basin. Peyto Glacier ranges in elevation from 3,180 to 2,140 m a.s.l. and covers an area of approximately 12 km^2. The glacier consists of three extensive accumulation basins that transition, through a relatively steep bedrock step/icefall, to a gently sloping valley glacier configuration. Below this transition the glacier is surrounded by ice-cored moraine. The glacier bed exhibits an over-deepened profile below the transition. Continued terminus retreat should reveal a reverse terminal bed slope (ca. 15–20 years), and possibly the related formation of a terminal lake which would likely influence the thermal, hydraulic and fluvial characteristics of the Peyto Creek.

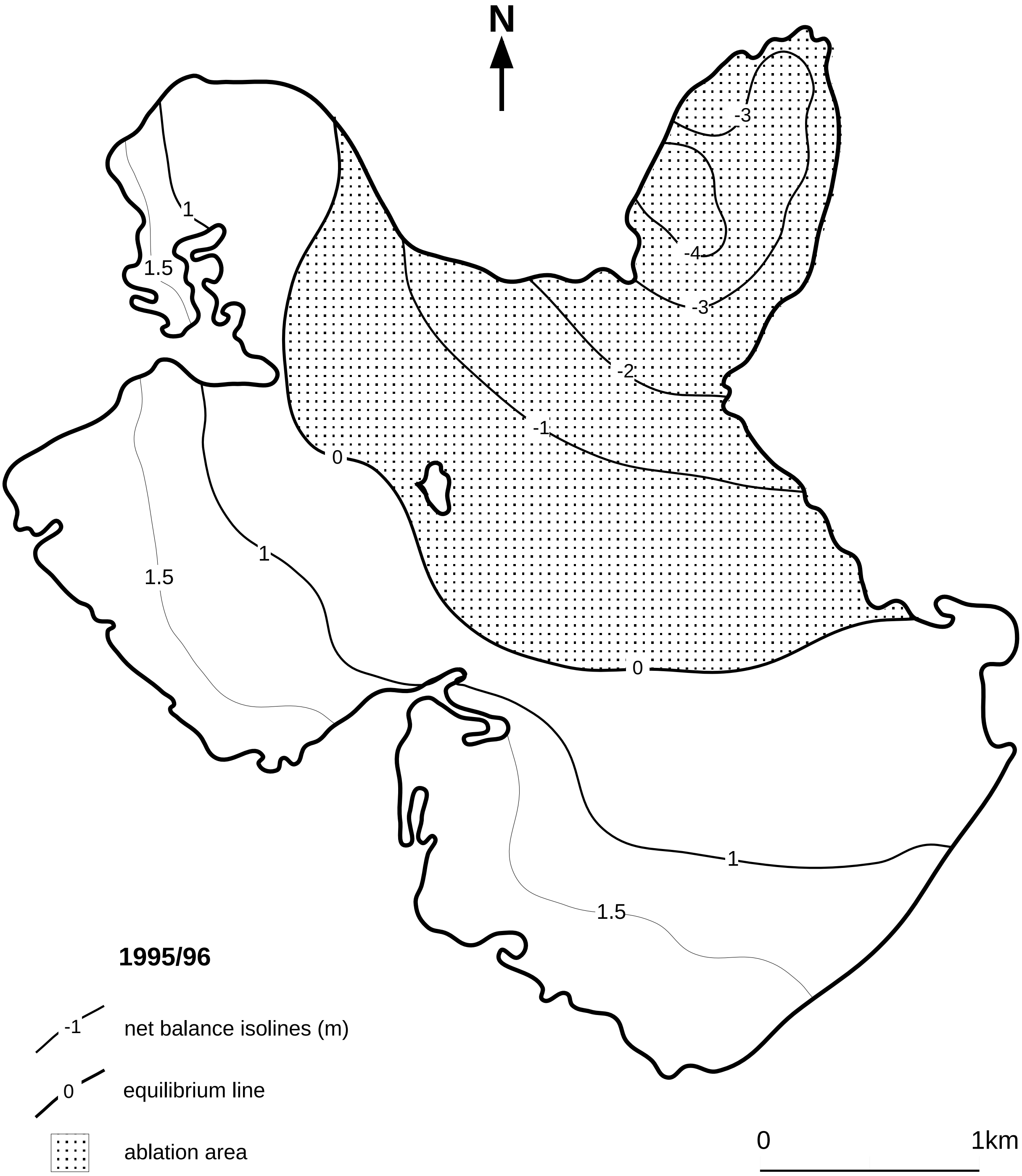
The 1995/96 and 1996/97 balance years represent records of contrast and a general pattern that was coherent for all three glaciers studied in the Canadian Cordillera. In both years, winter accumulation was near the long-term mean. Conditions during the 1996 summer resulted in melt well below the long-term mean and consequently in a slightly positive balance. Notably, this positive balance was the first such occurrence since 1976. Summer ablation in 1997 was close to average overall. However, the glacier tongue continues to be subject to high rates of melt, particularly on the western side of the tongue influenced by the southeast facing moraines and cliffs of Peyto Peak.

3.2.1 Topography and observational network

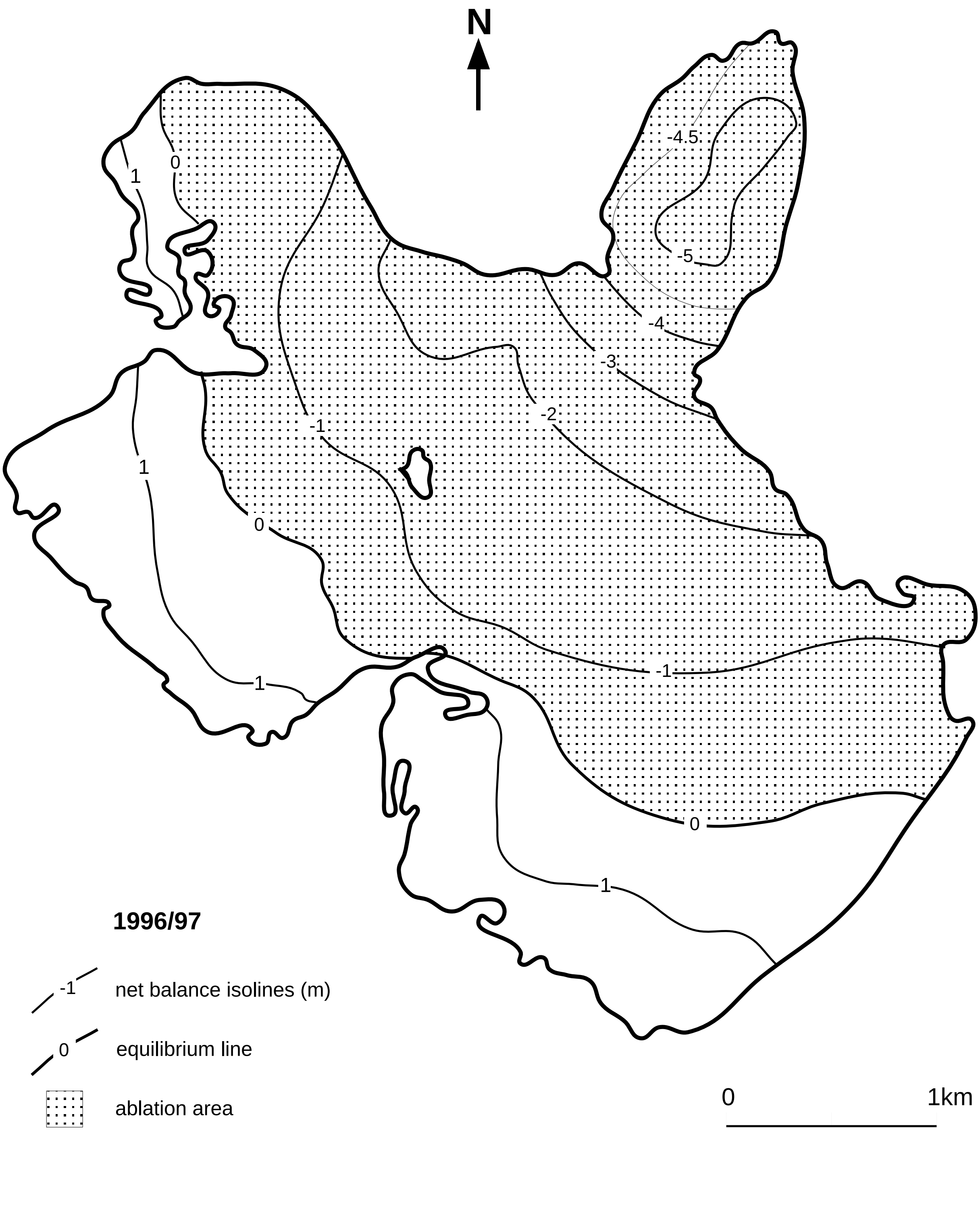


Peyto (CANADA)

3.2.2 Net balance maps 1995/96 and 1996/97

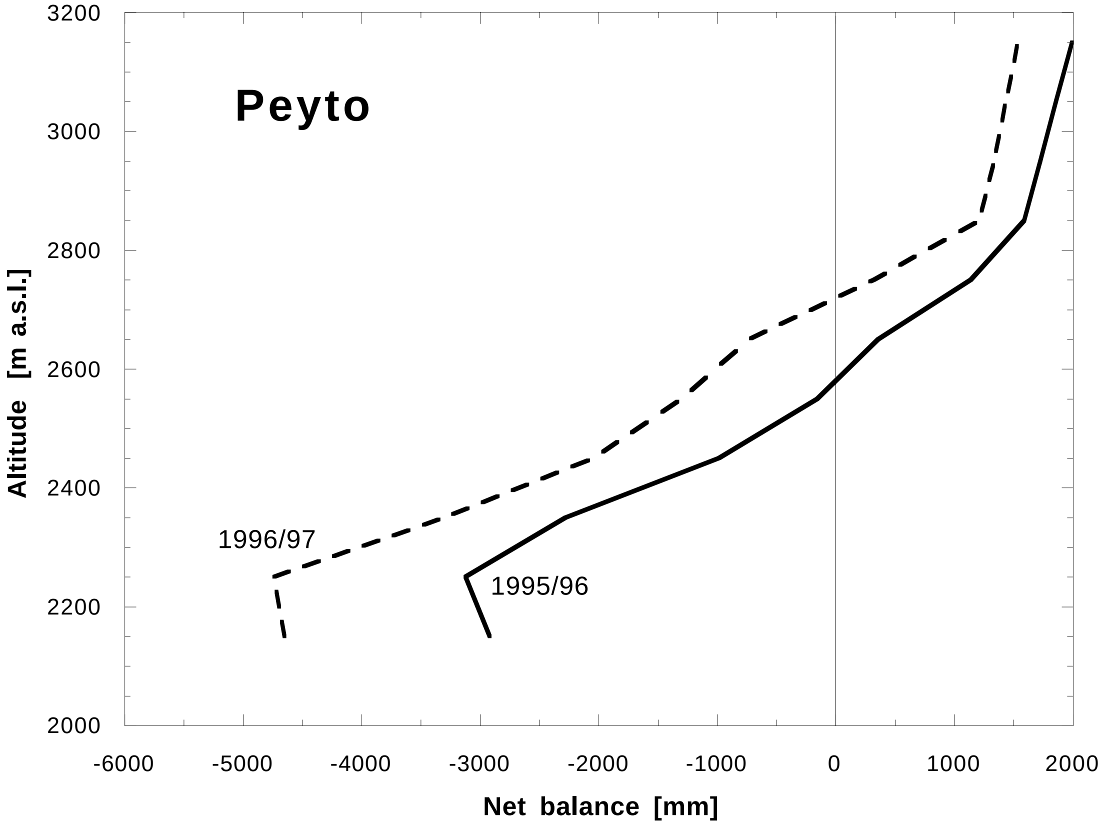


Peyto (CANADA)

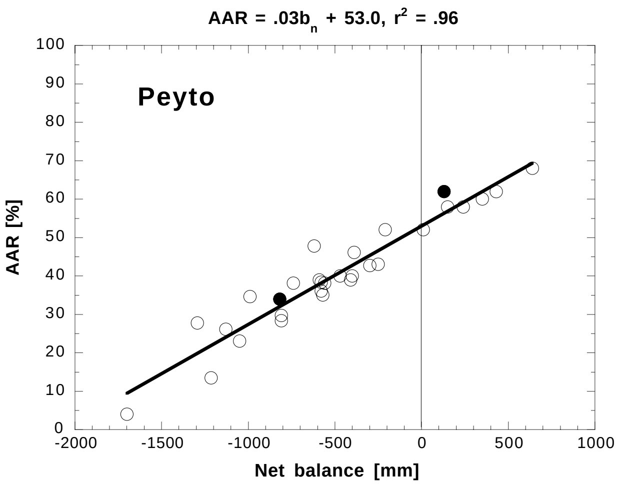


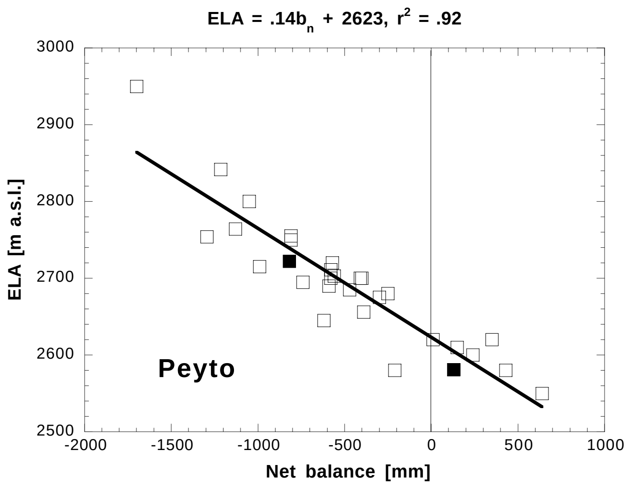
Peyto (CANADA)

3.2.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.3 ZONGO (BOLIVIA)

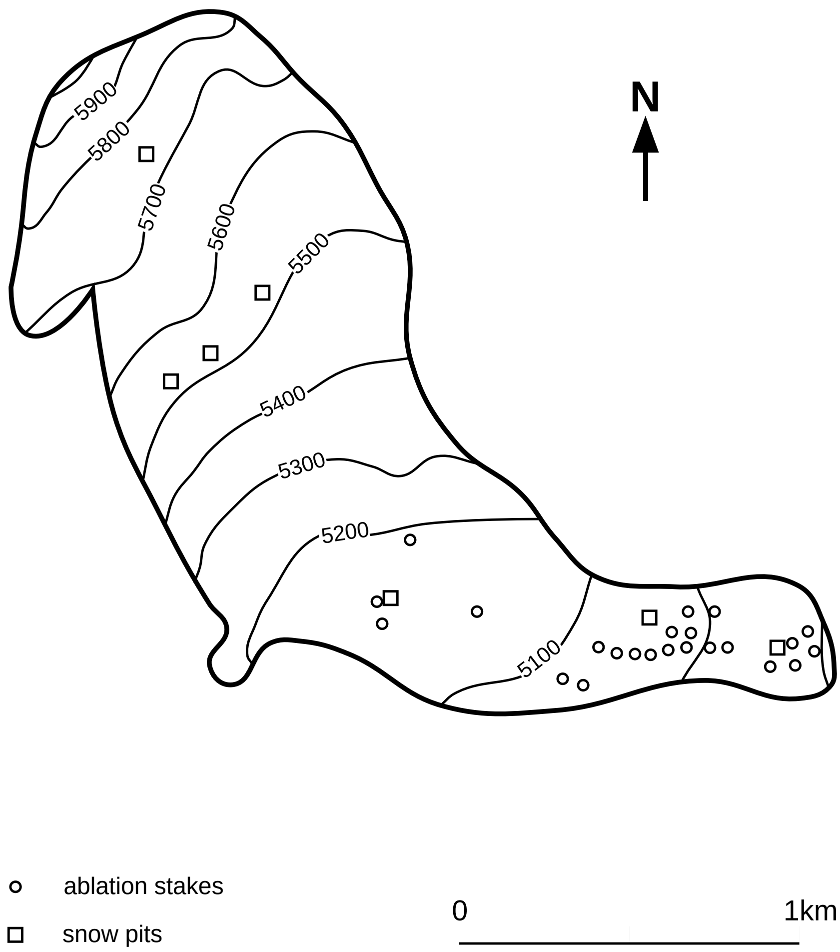
COORDINATES 16° 15' S / 68° 10' W

Author and date of photo not reported.

Zongo is a small valley-type glacier located north-east of La Paz city, at the head of an important hydraulic power station which supplies the city. It is a 3 km long glacier, between 6,000 and 4,900 m a.s.l. and its surface area reaches 2.1 km^2. Exposition is to the south in the upper part and to the east in the lower tongue. Mean temperature at the ELA_0 at 5,250 m a.s.l. is -1.5°C, the glacier is assumed to be temperate and periglacial permafrost is likely to be absent to discontinuous. Mean precipitation at the "Plataforma" was about 900 mm/year (±200 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.

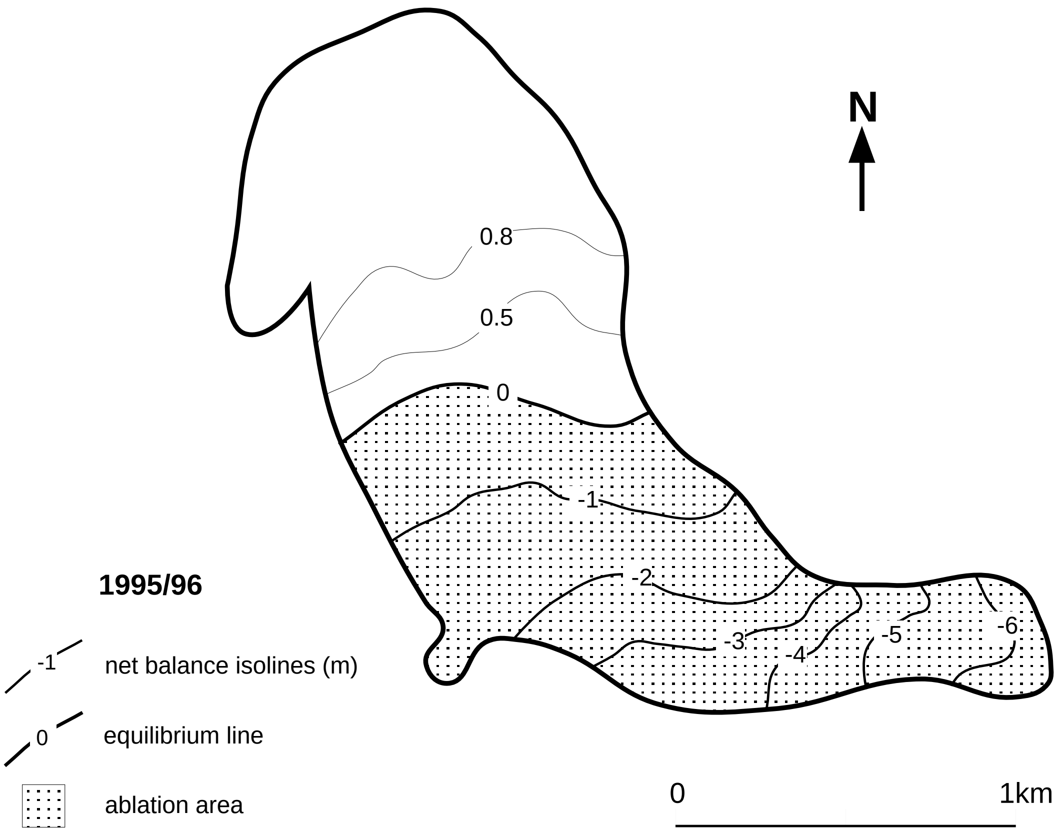
There was a very high contrast between the last two net balances: 1995/96 was negative, with a very strong ablation in October 1995 (1,000 mm at 5,150 m a.s.l.), while 1996/97 was positive (the most positive of the 1991–97 series), marked by extensive precipitation from September to May. During the two years, two types of South Oscillation (SO) situations have occurred in the Pacific: in 1995–96, the SO index was low (a warm-type event), while in 1996/97, the SO index was high (a short cold-type event).

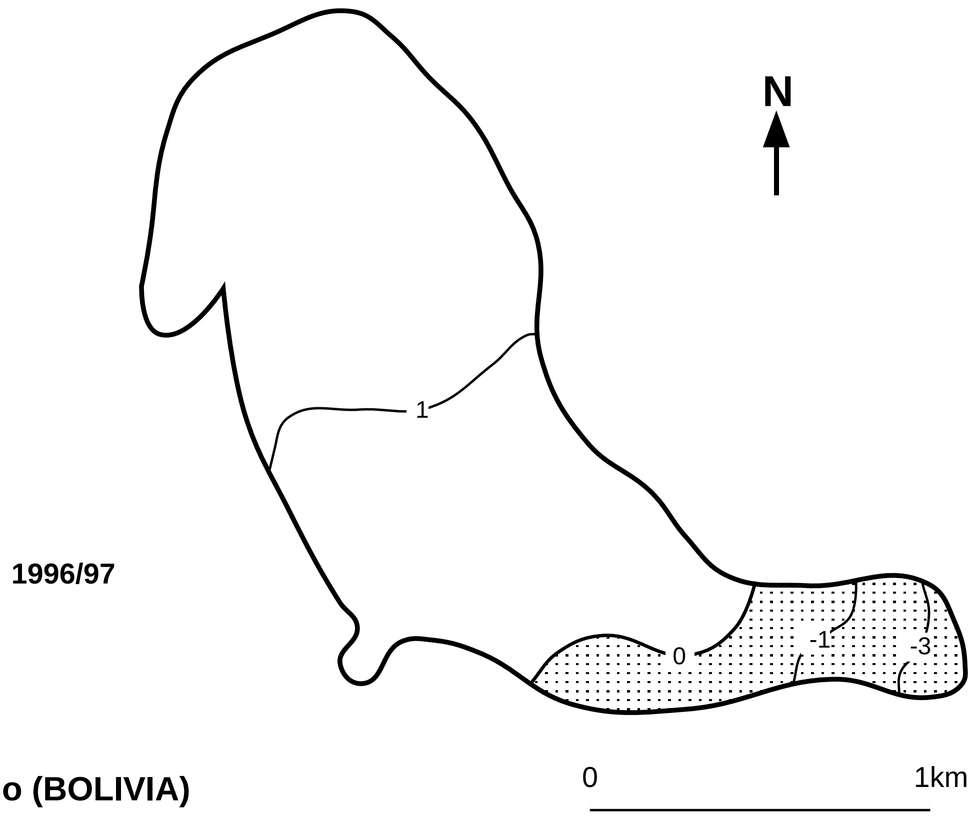
3.3.1 Topography and observational network



Zongo (BOLIVIA)

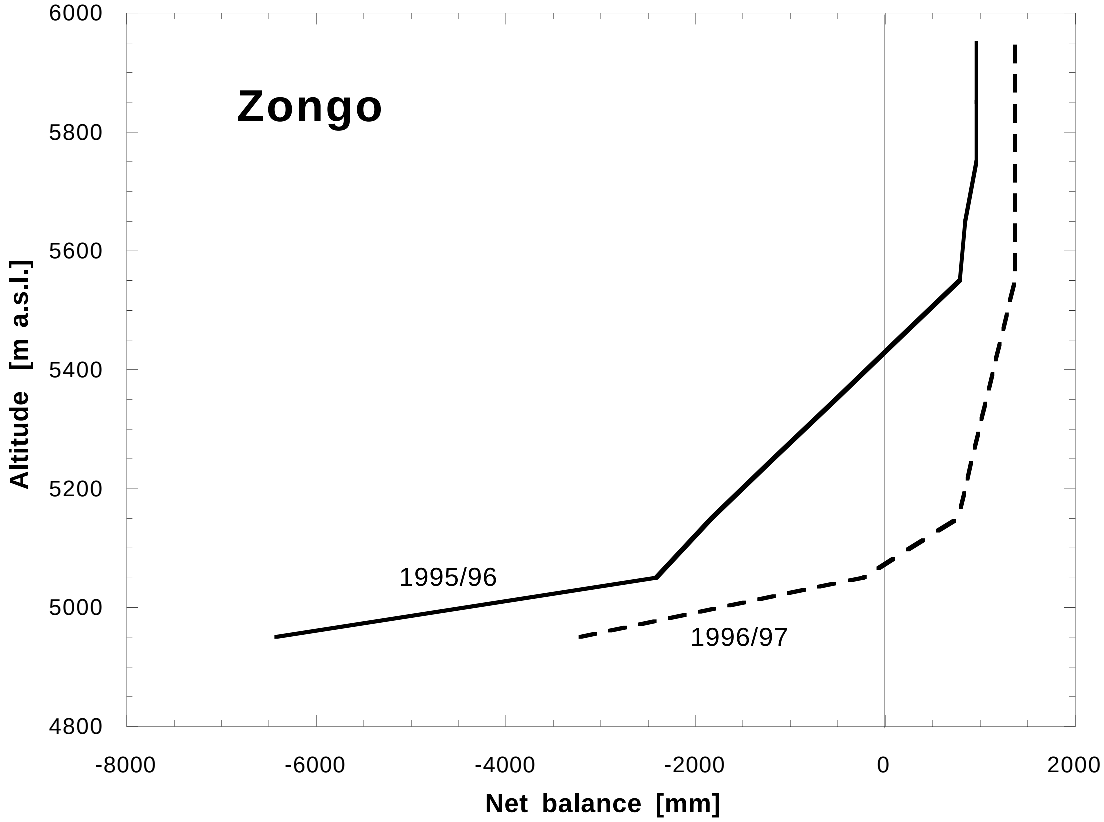
3.3.2 Net balance maps 1995/96 and 1996/97



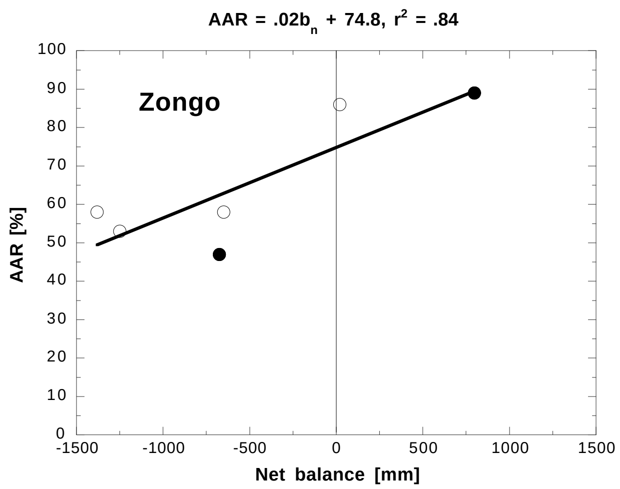


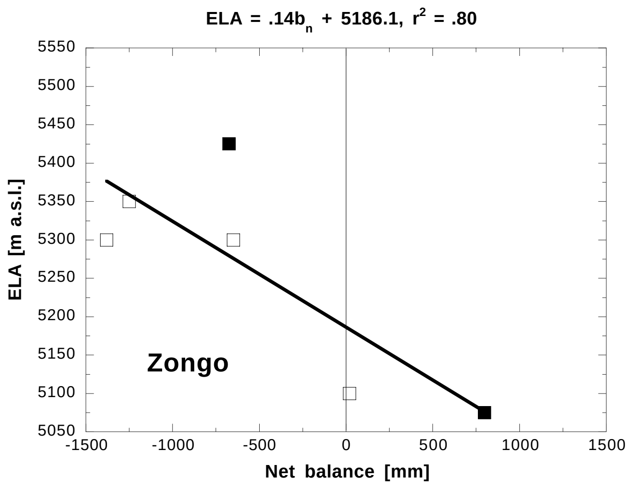
Zongo (BOLIVIA)

3.3.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.4 MIDTRE LOVÉNBREEN (NORWAY/SVALBARD)

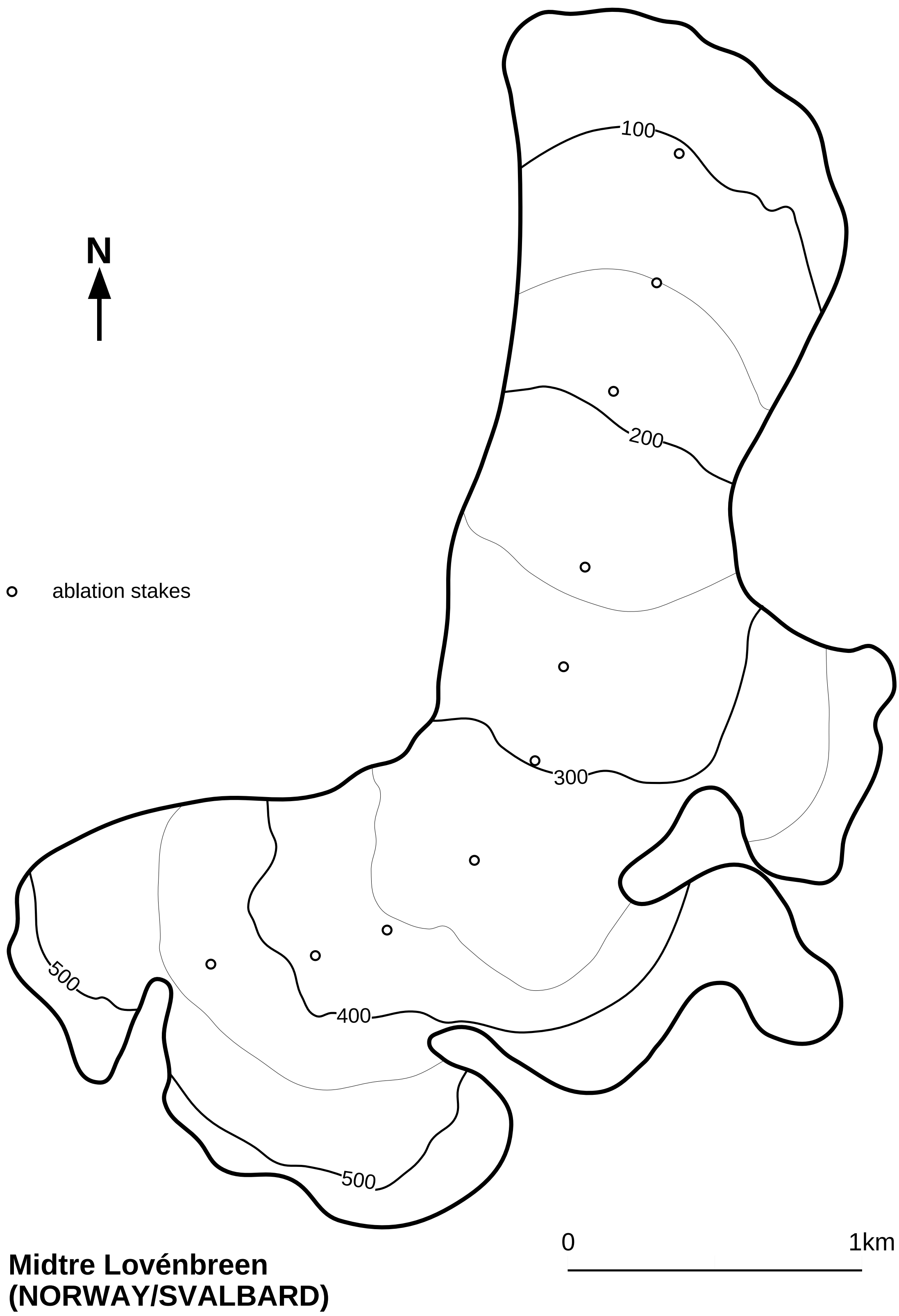
COORDINATES 78° 53’ N / 12° 04’ E

Photo taken in 1936, author not reported.

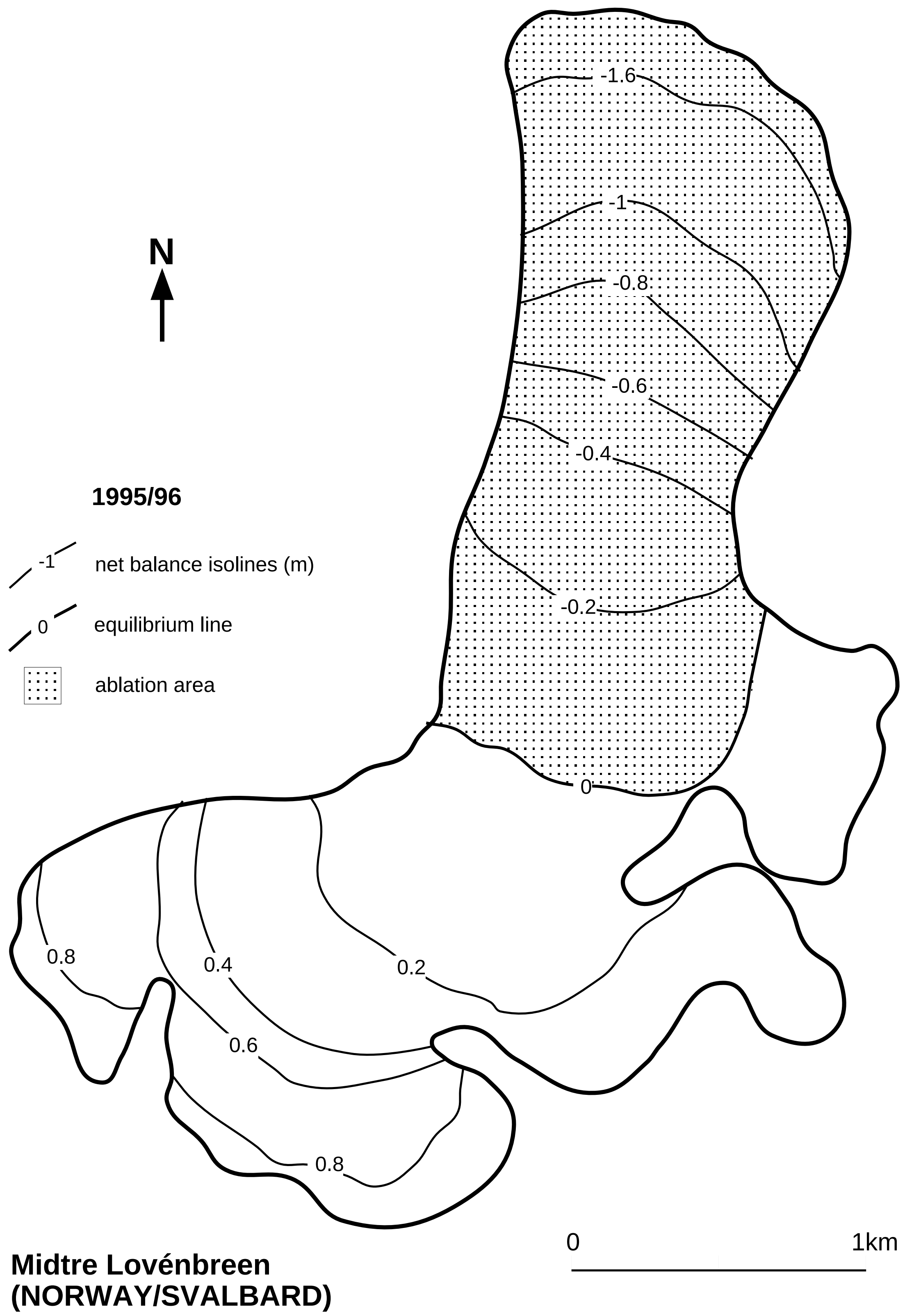
Midtre Lovénbreen is situated in the Kongsfjorden area in the north-western part of Spitzbergen, Svalbard. It is a valley glacier extending from 650 to 50 m a.s.l. Its surface area is 6 km^2, and it is exposed to the north-east. Average annual precipitation at the nearby meteorological station at Ny-Ålesund (40 m a.s.l) is just below 400 mm. Annual mean air temperature at the equilibrium line at about 300 m a.s.l. is close to -8°C. Like Austre Brøggerbeen, Midtre Lovénbreen is surrounded by continuous permafrost. However, Lovénbreen is thicker and partly temperate. During the mea sured time period, Midtre Lovénbreen has had less of a negative balance and less ablation than Brøggerbreen. This is probably due to topographic conditions, and partly to a slightly higher elevation of Lovénbreen. Also during years with heavy melting, Lovénbreen has a much better protected firn zone than Brøggerbreen.

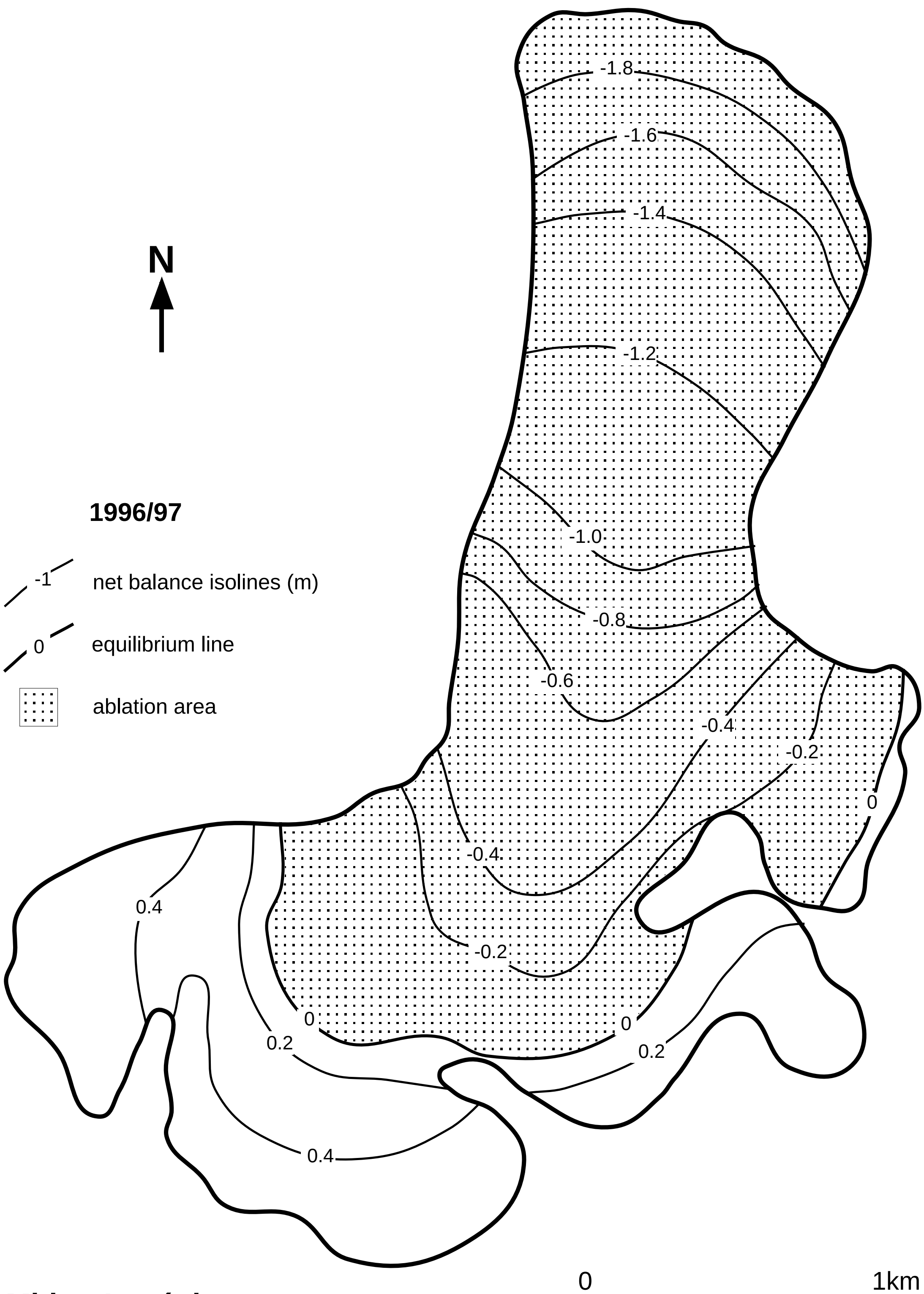
The balance year 1995/96 was slightly positive with 0.02 m water equivalent. The average for the observation period 1968–1997 is -0.35 m water equivalent. The winter accumulation was close to normal while the summer ablation was 20% less than average. Since the mass balance measurements began in 1968 only four years have resulted in a positive net balance. The balance year 1996/97 had a net balance of -0.43 m water equivalent, which is more negative than for an average year. That is due to the low winter accumulation of 0.56 m water equivalent, which is 23% less than the average for the whole measured time period.

3.4.1 Topography and observational network



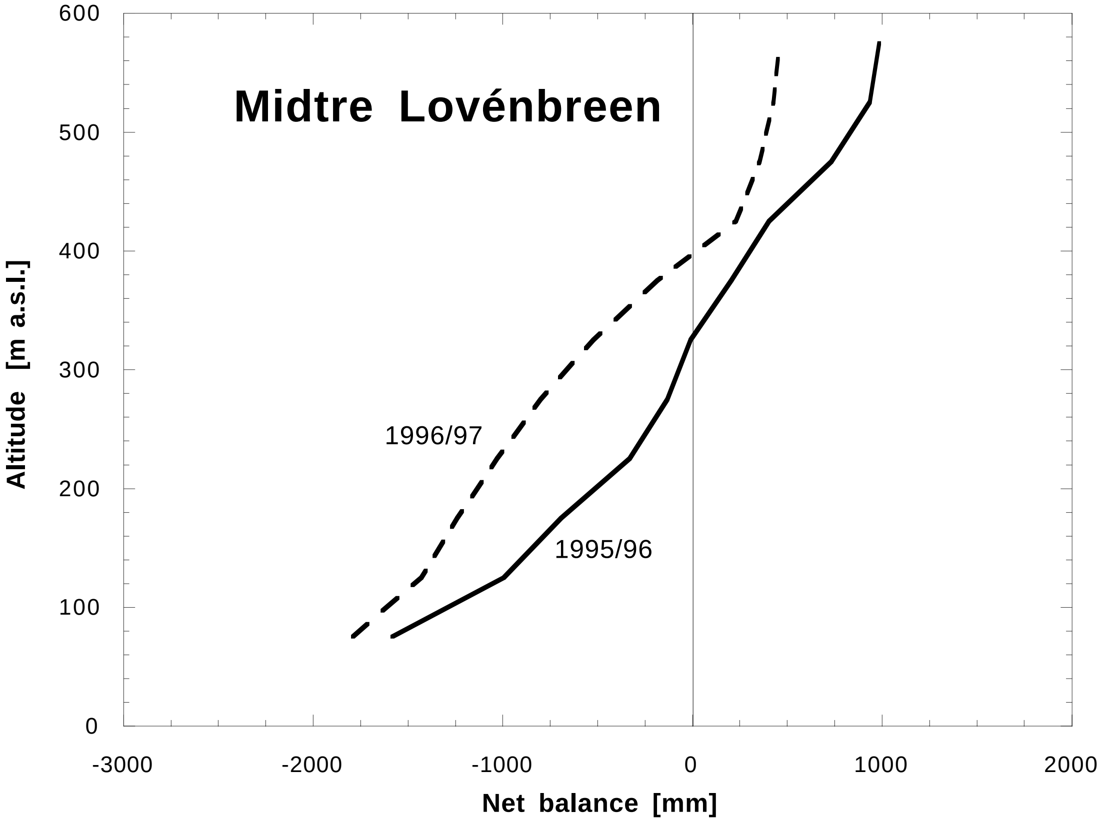
3.4.2 Net balance maps 1995/96 and 1996/97



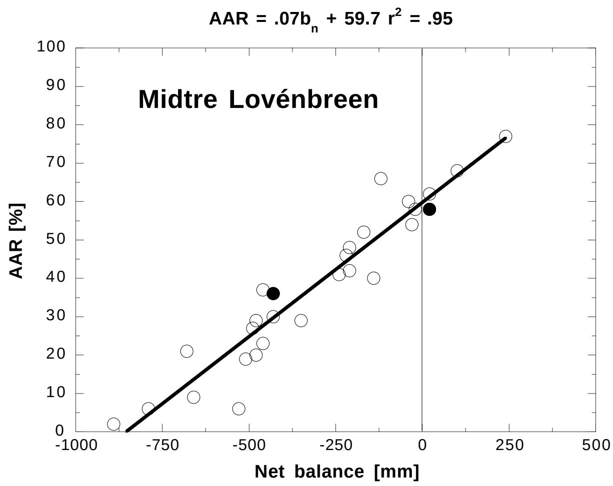


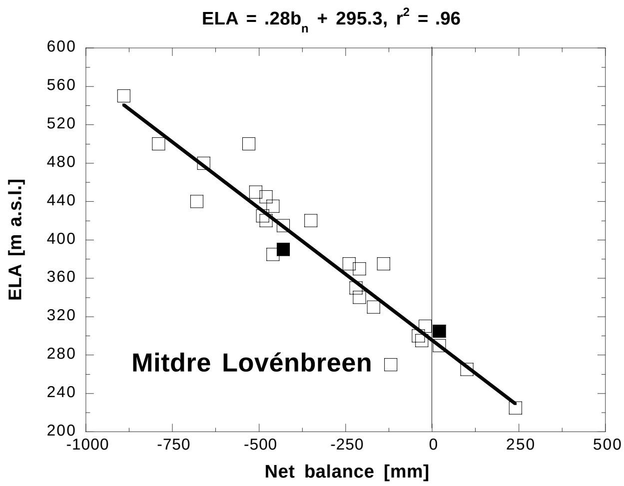
Midtre Lovénbreen (NORWAY/SVALBARD)

3.4.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.5 STORGLACIÄREN (SWEDEN)

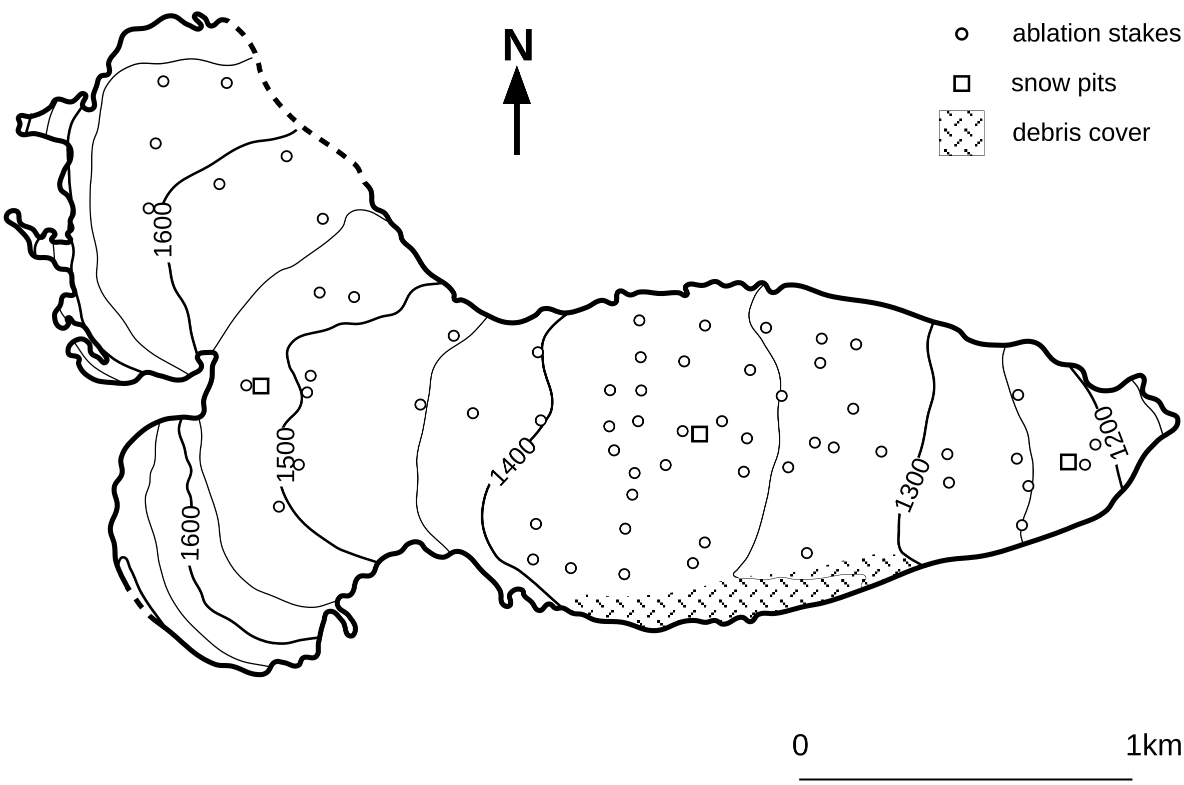
COORDINATES: 67° 54’ N / 18° 34’ E

Photo taken by P. Holmlund in August 1987.

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 1,750 and 1,130 m a.s.l., its surface area is 3.12 km^2 and its average thickness is 95 m (maximum thickness is 255 m). Annual mean air temperature at the equilibrium line of the glacier (around 1,450 m a.s.l.) is about -6°C. The glacier is mainly temperate with a cold surface layer in its lower parts, and it ends in discontinuous permafrost. Average annual precipitation is about 1,000 mm at the nearby Tarfala Research Station.

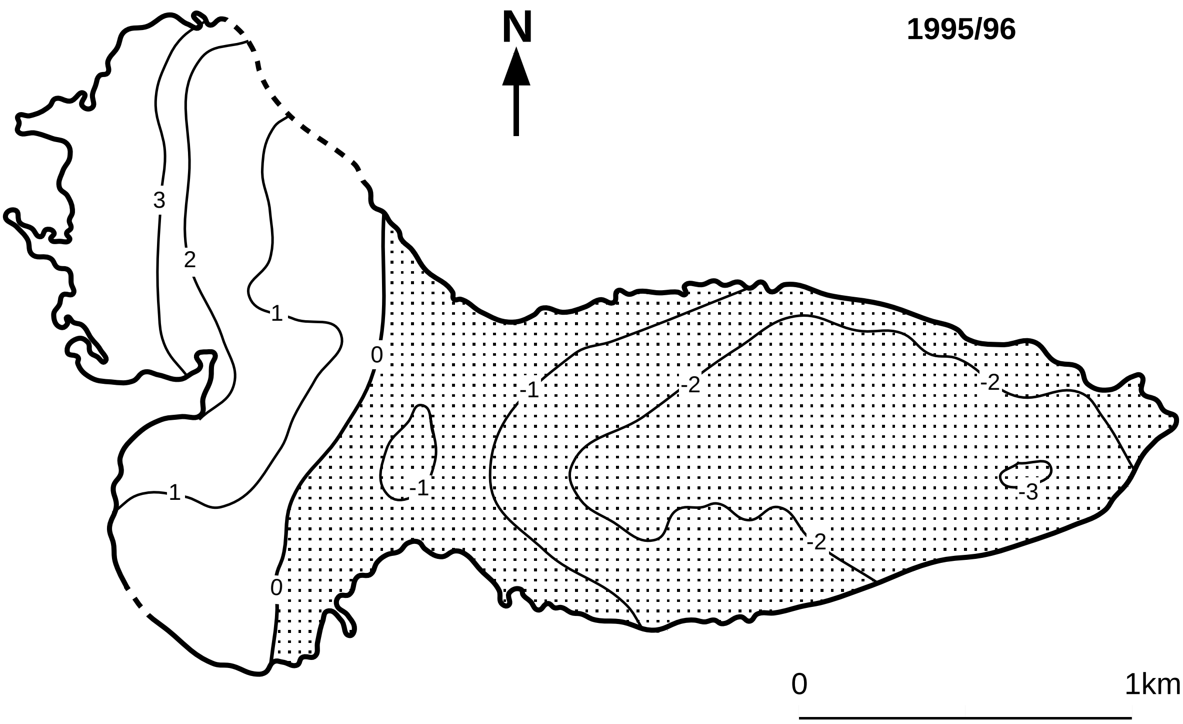
The accumulation for 1995/96 (1.36 m water equivalents) was less than average and the air temperature during winter was 1.4°C higher than normal. The summer was warm with high precipitation giving an ablation rate of 1.72 m w. e. and a net balance of -0.36 m w. e. The following winter of 1996/97 was snow-rich (1.87 m water equivalents) and the temperature was normal. In contrast to preceding winters, the winter accumulation 1996/97 was equally distributed on glaciers over the mountain range giving a negligible east-west gradient, a gradient which normally is prominent with about twice as much snow along the Swedish–Norwegian border as compared to the eastern rim of the mountains. The following summer was 1.8°C warmer than average, giving an ablation of 2.50 m w. e., which is the fifth-highest value in the 51-year record.

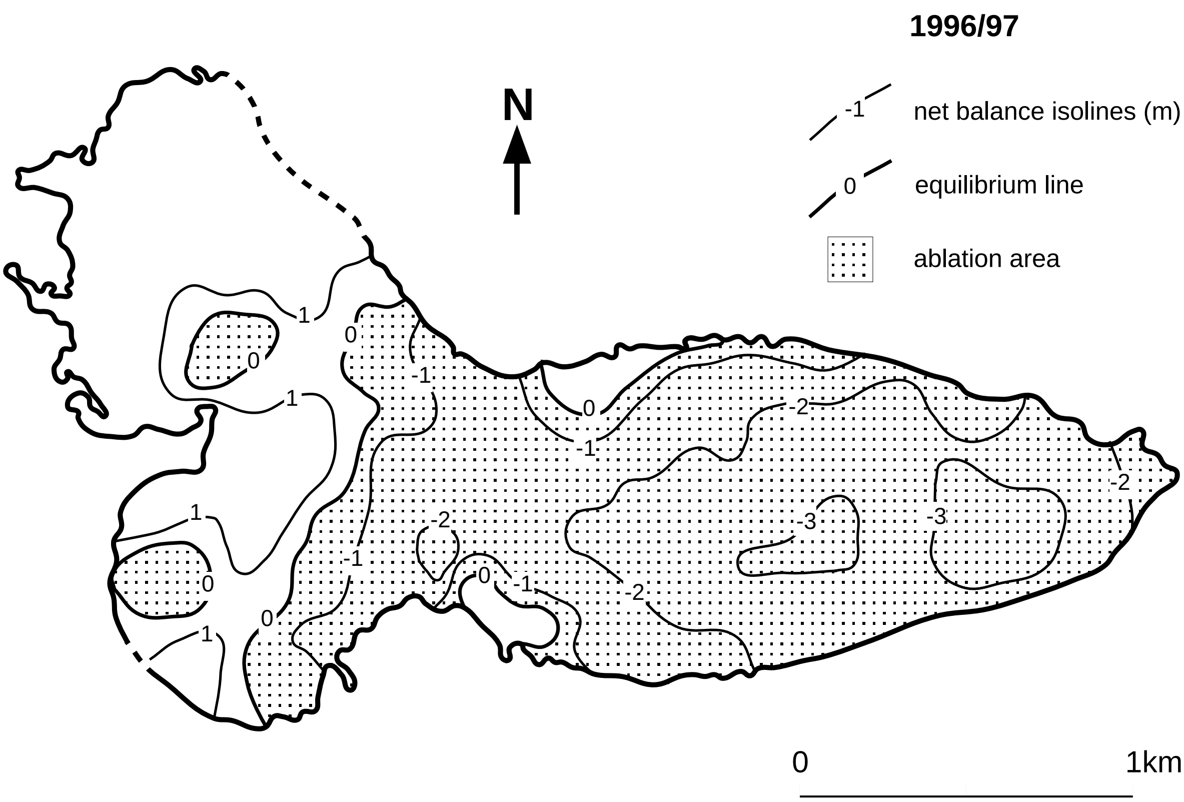
3.5.1 Topography and observational network



Storglaciären (SWEDEN)

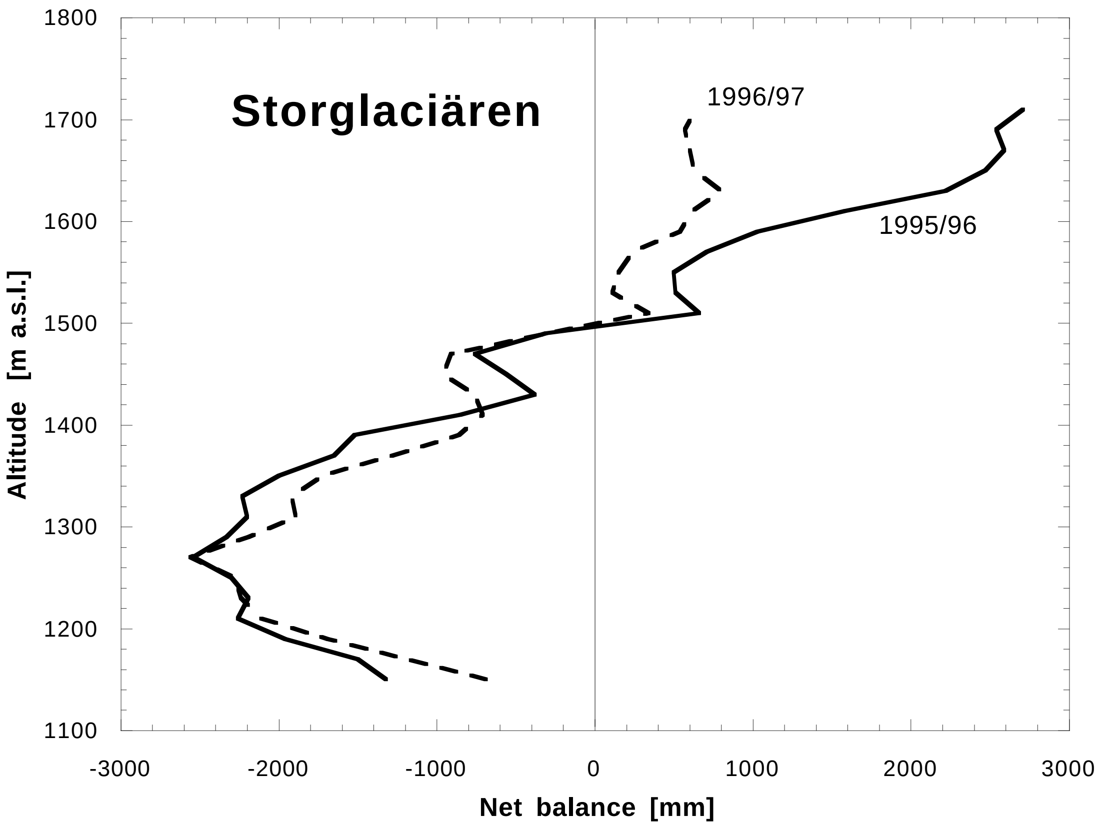
3.5.2 Net balance maps 1995/96 and 1996/97



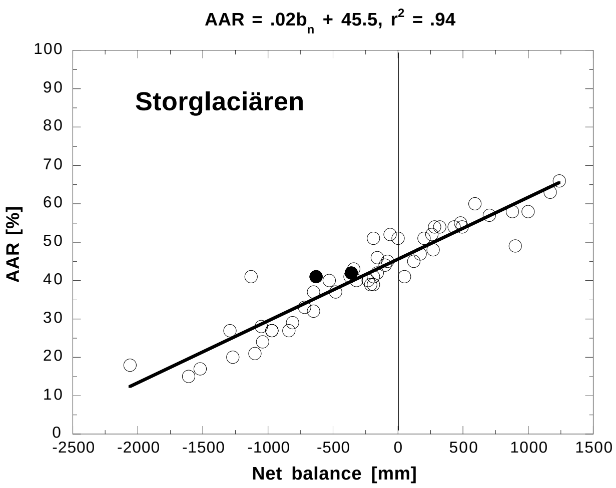


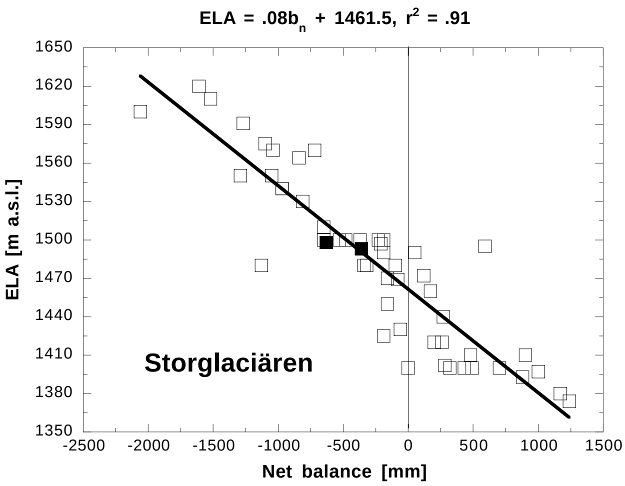
Storglaciären (SWEDEN)

3.5.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.6 VERNAGTFERNER (AUSTRIA)

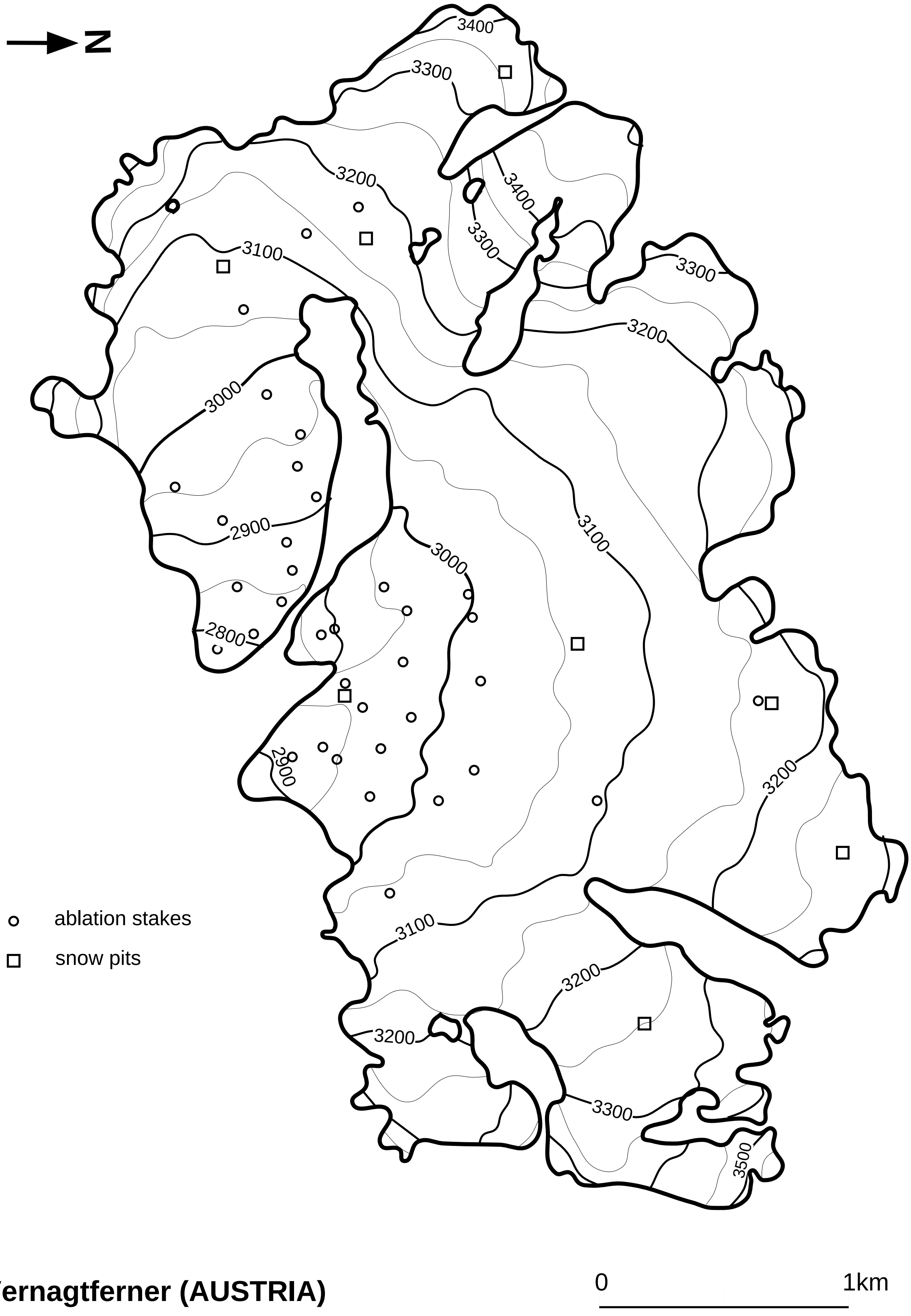
COORDINATES 46° 53’ N / 10° 49’ E

South view of Vernagtferner, 5 August 1998. Note the separation of the tongue areas which were still joined in 1993. Photo: Commission for Glaciology, Bavarian Academy of Sciences.

The rather flat mountain glacier in the southern part of the Oetztal Alps is located not far from Hintereisferner. The surface area of 9.0 km^2 is unevenly distributed between 3,630 and 2,740 m a.s.l. with 80% in the altitude interval between 3,300 and 3,100 m a.s.l. Mean annual air temperature at the equilibrium-line altitude (3,070 m a.s.l. for balanced years) lies between -3.5 and -4.5°C based on records at the Vernagt gauging station at 2,640 m a.s.l. and temporary measurements at 3,050 m a.s.l. The glacier is entirely temperate and probably surrounded by predominantly permafrost-free terrain. Mean annual precipitation for the Vernagt drainage basin (11.4 km^2) amounts to 1550 mm, 65% of which are, on average, deposited during the accumulation season. The glacier has been volumetrically controlled since 1889 and by direct glaciological measurements related to the fixed-date system since 1965. Topographic maps at a 1: 10,000 scale and based on photogrammetric surveys for 1889, 1969, 1979, 1982 and 1990 can be found in various volumes of the Fluctuations of Glaciers.

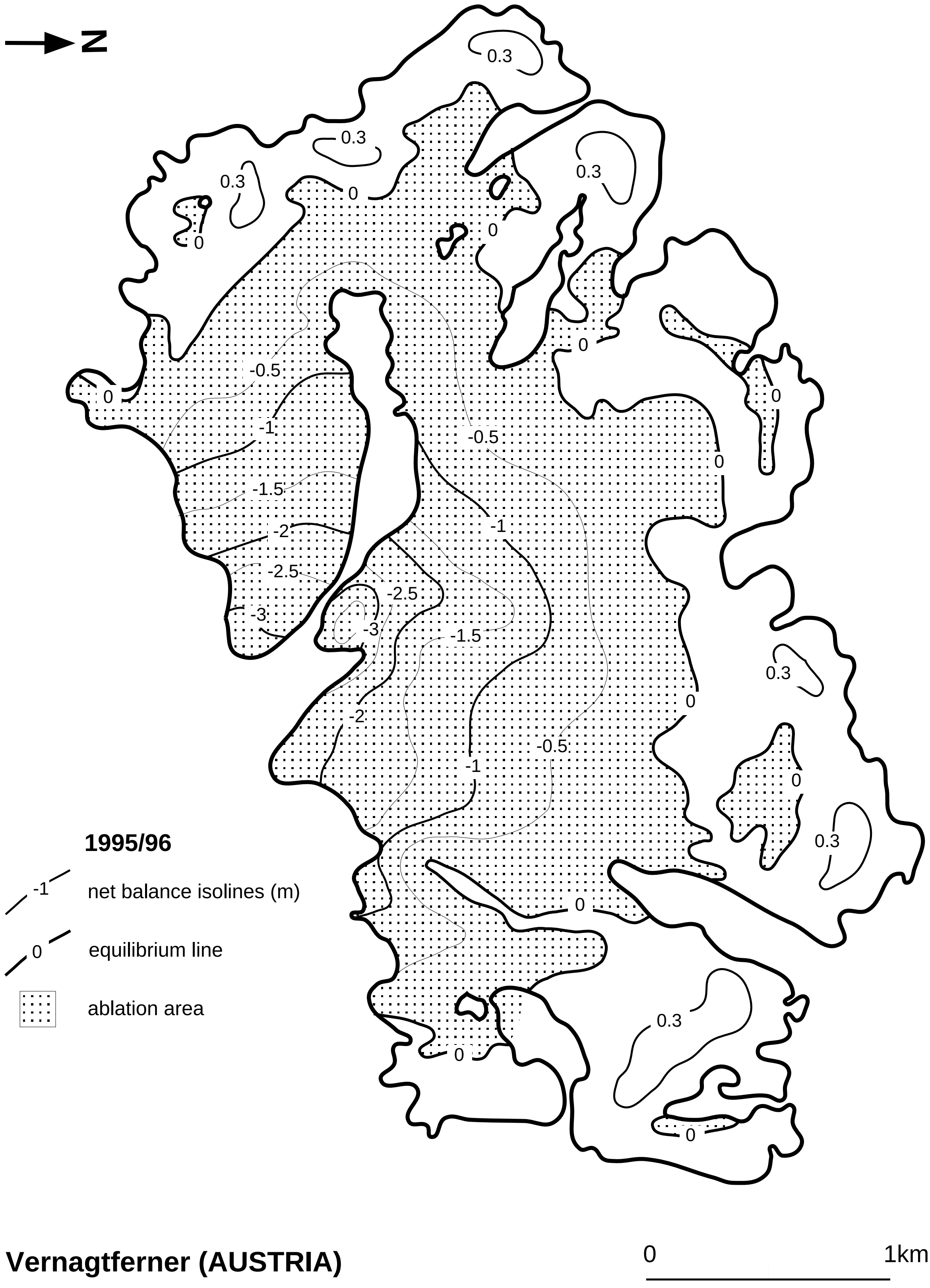
The negative mass balances of 1995/96 and 1996/97 document the continued diminution of Vernagtferner since 1980. An extremely dry winter and a warm early summer were responsible for the mass losses in 1995/96, whereas in 1996/97 they were caused by above-normal winter accumulation followed by high melt rates especially in late summer and fall. In 1995/96 annual discharge at the gauging station at 2640 m a.s.l. was 1630 mm (basin area 11.44 km^2), slightly below the 24-year mean of 1670 mm, and discharge of 1996/97 was 1870 mm (12% above mean). In the six years preceding 1980 mean annual discharge was 1170 mm, and the remarkable increase of the mean is the direct result of the continued glacier mass losses since 1980.

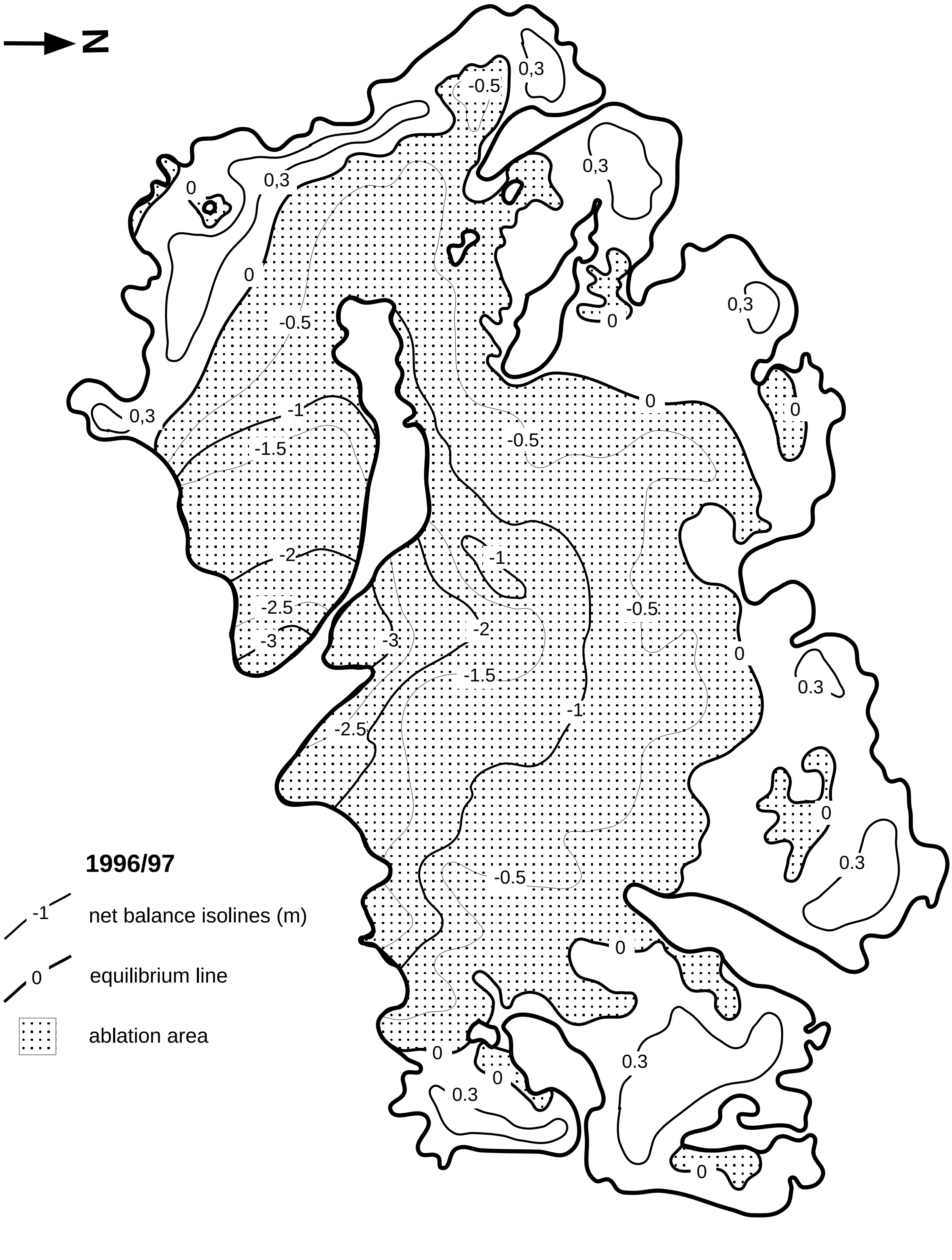
3.6.1 Topography and observational network



Vernagtferner (AUSTRIA)

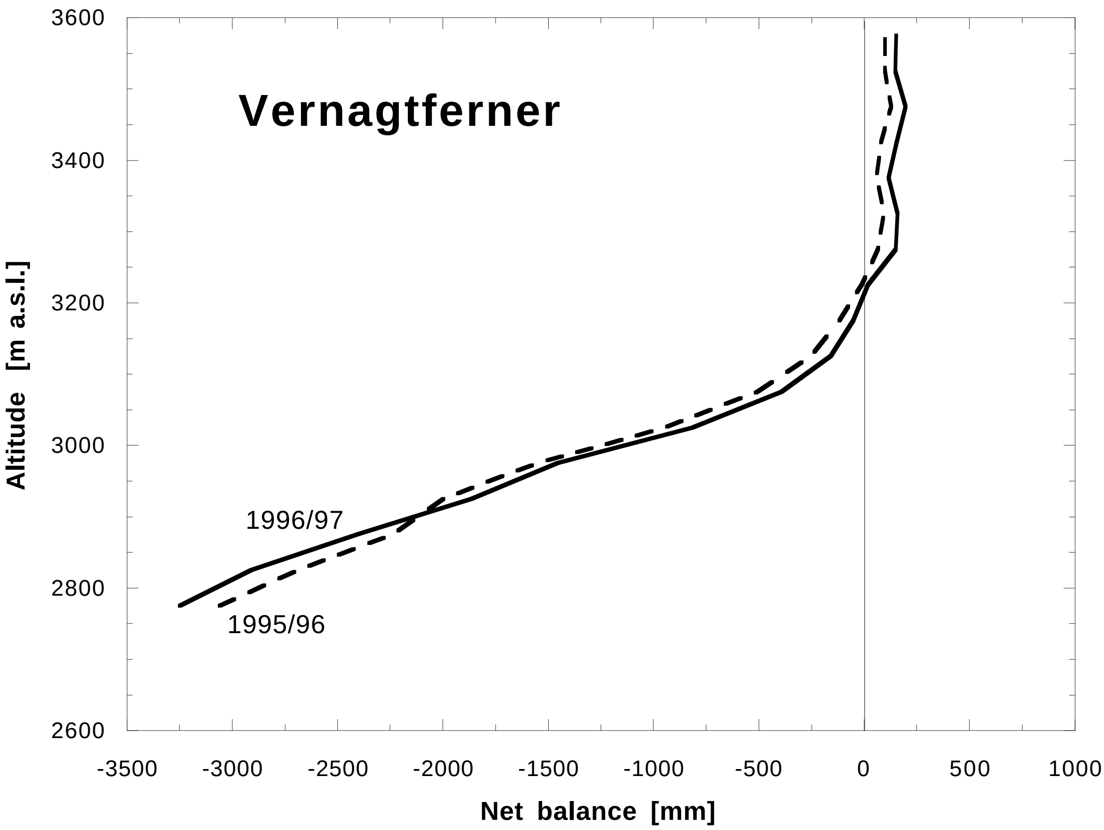
3.6.2 Net balance maps 1995/96 and 1996/97



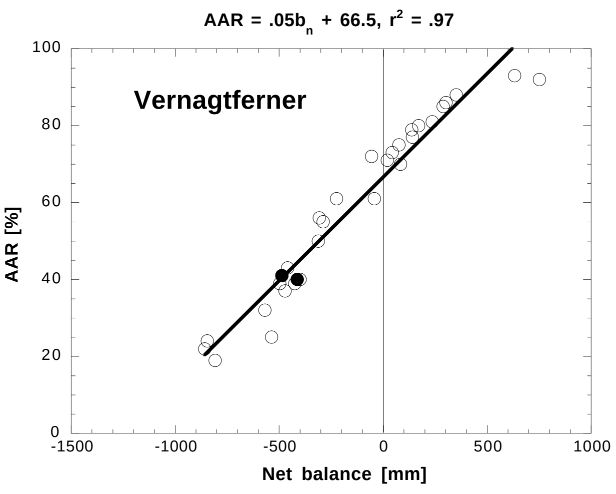


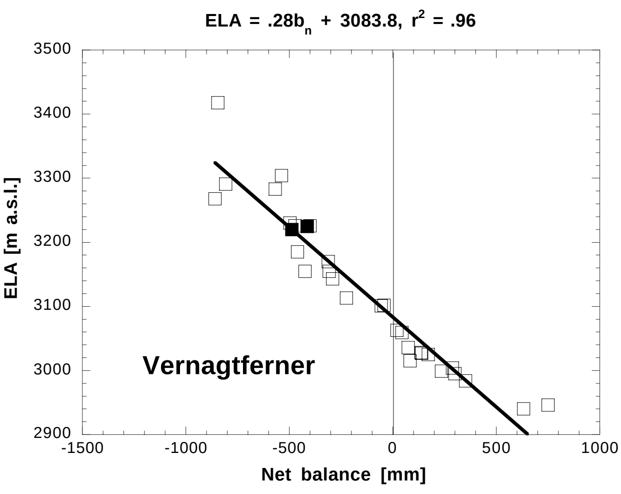
Vernagtferner (AUSTRIA)

3.6.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.7 DJANKUAT (RUSSIA)

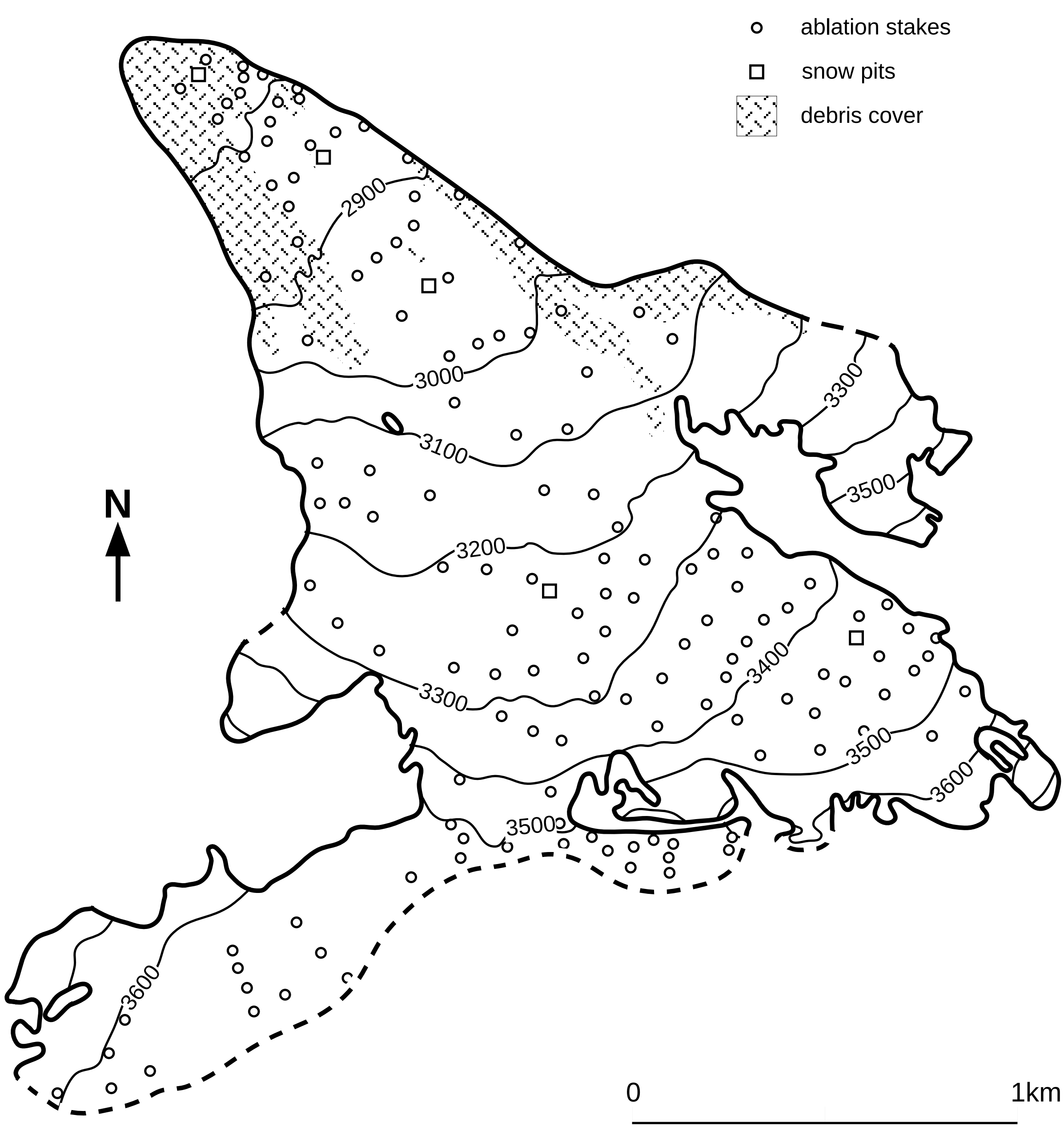
COORDINATES: 43° 12’ N / 42° 46’ E

Photo taken by Ye. A. Zolotaryov and V. V. Popovnin on 22 August 1992.

The valley-type glacier is located on the northern slope of the central section of the Main Caucasus Ridge and extends from 3,830 to 2,700 m a.s.l. Its surface area is 3.10 km^2 and the exposure is NW. Mean annual air temperature at the ELA (ca. 3,200 m a.s.l) is -3 to -4.5°C, and the glacier is temperate. Periglacial permafrost is highly discontinuous. Average annual precipitation as mea sured near the snout is 1,100–1,200 mm but roughly three times that amount at the ELA. Five 1:10,000 topographic maps (of 1968, 1974, 1984, 1992 and 1996) exist at the 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.

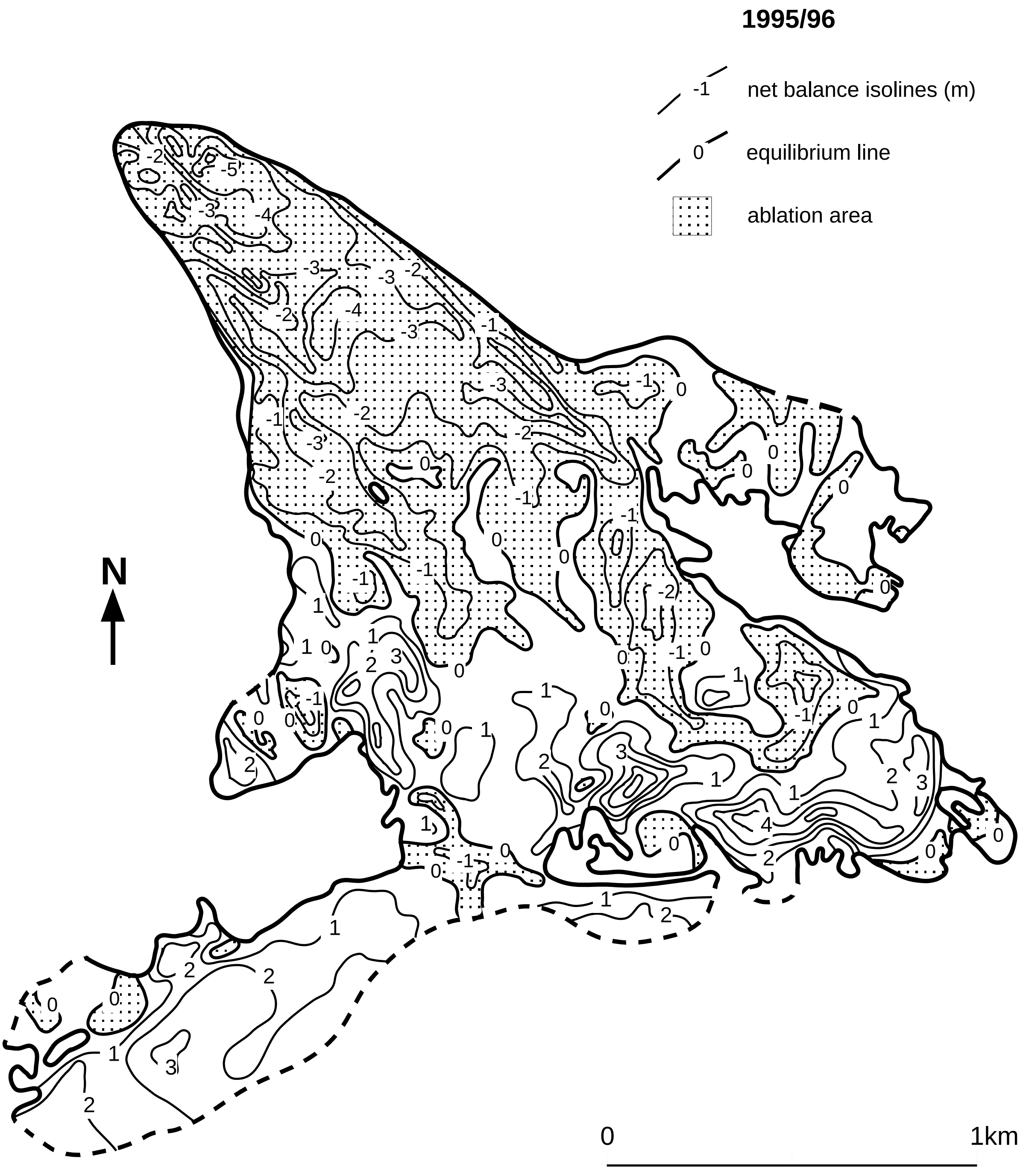
In 1995/96 external mass exchange were reduced as compared to the long-term mean: accumulation by 5% (important snowfalls occurred only in November and April–May) and ablation by 2% (the influence of a rather warm July was compensated by heavy snowfalls in August). The melting period was shortened both in spring and autumn. The resulting mass loss of 0.15 m w.e. was only slightly more negative than average. 1996/97 was more favourable for the glacier. Snow was abundant in winter (17% anomaly, the third-highest throughout the whole 30-year-long observation period); the accumulation pattern was greatly affected by tremendous snow avalanches. Summer was very warm and dry, but the melting season ceased extremely early (3 September on the most of the glacier area), like a year before; hence, ablation was only 3% higher than usual. Mass gain made up 0.28 m w.e.

3.7.1 Topography and observational network



Djankuat (RUSSIA)

3.7.2 Net balance maps 1995/96 and 1996/97



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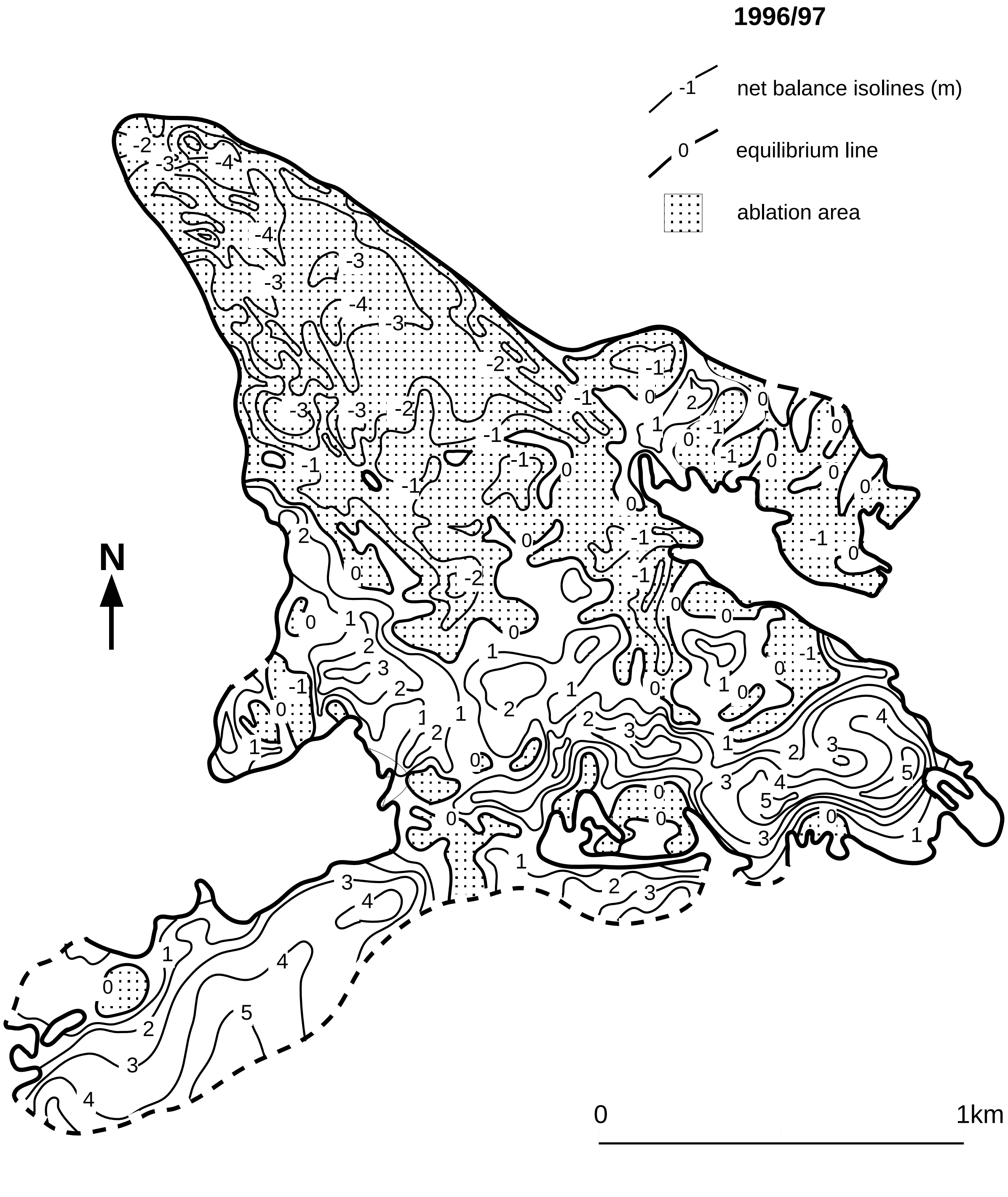
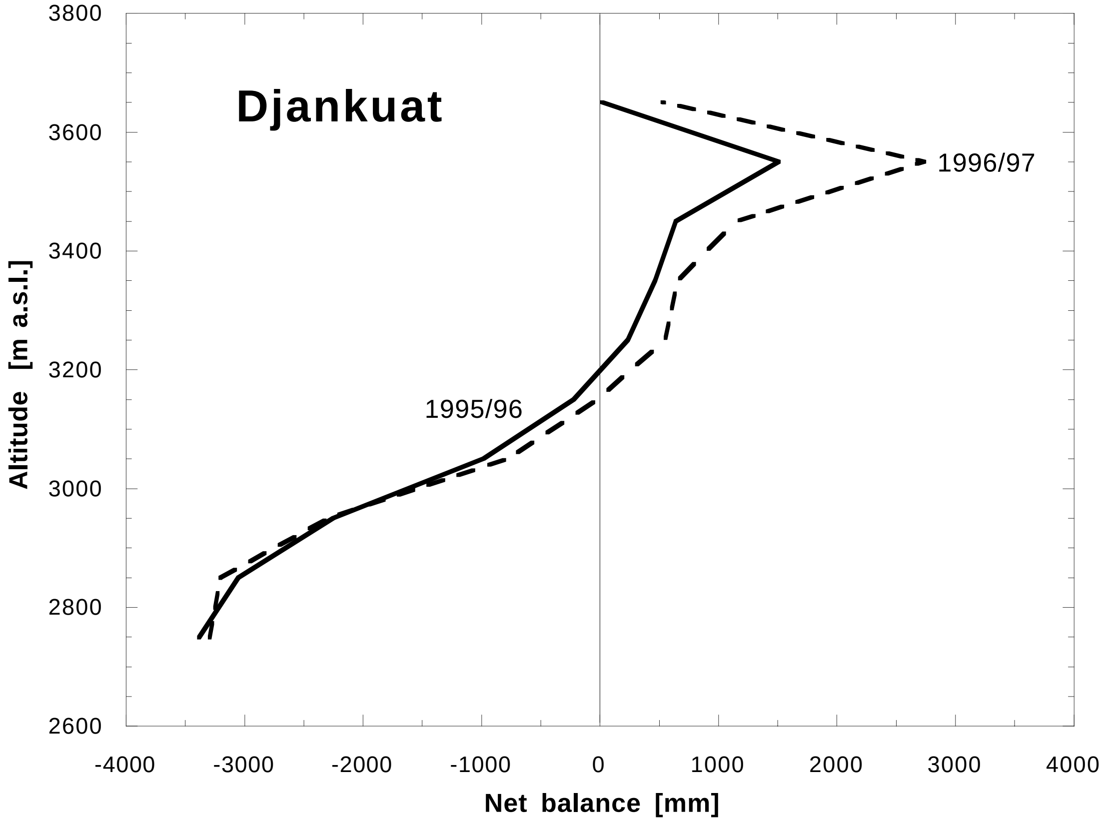
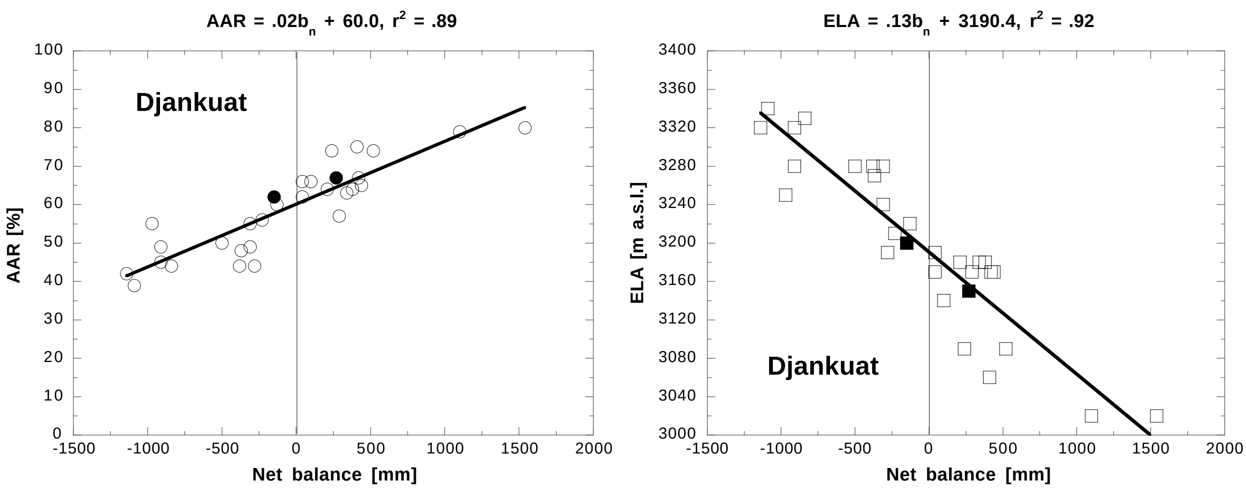


Djankuat (RUSSIA)

3.7.3 Net balance versus altitude (1995/96 and 1996/97)



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



3.8 ABRAMOV (KIRGHIZSTAN)

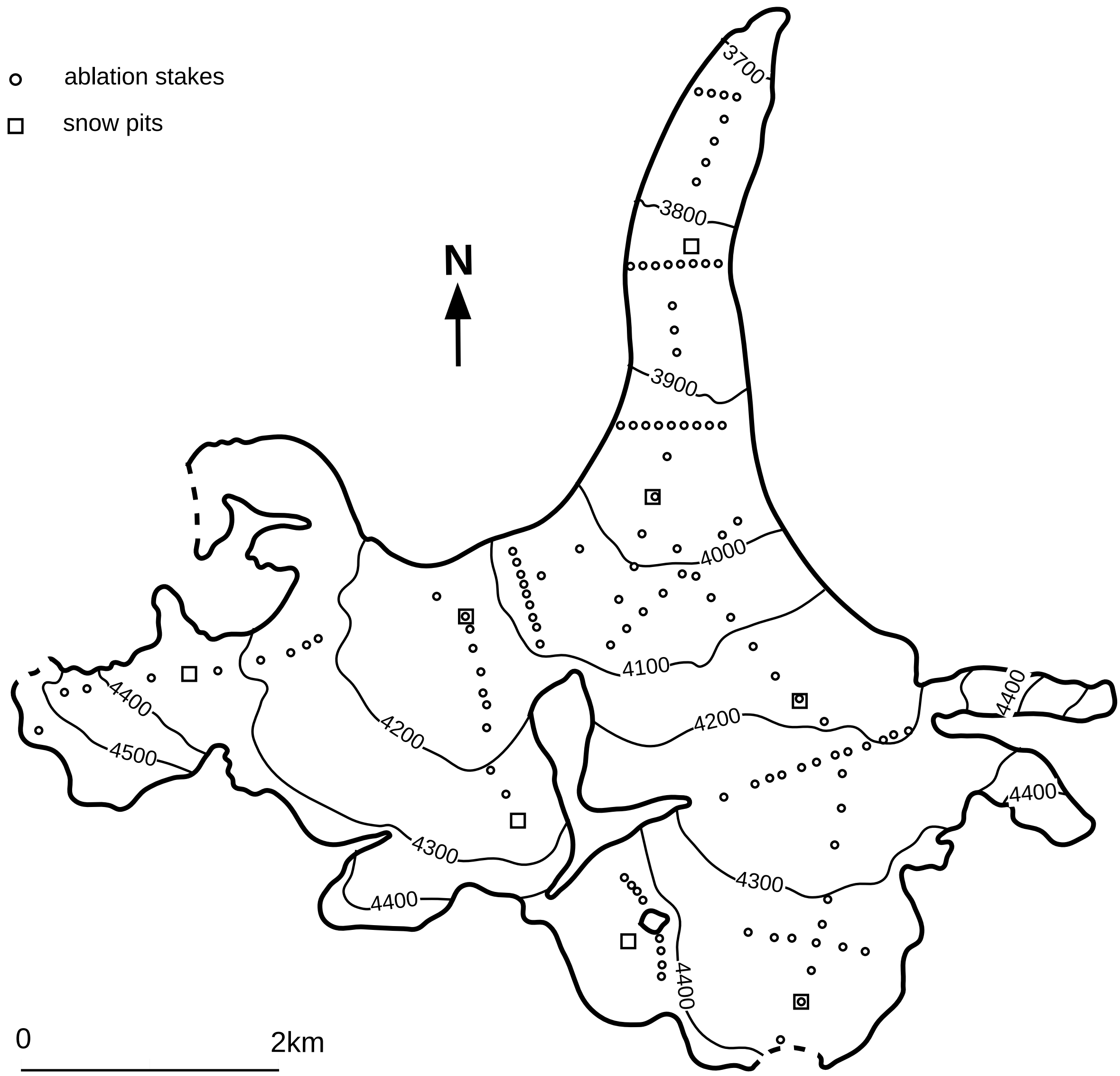
COORDINATES: 39° 38’ N / 71° 34’ E

Photo taken by G.M. Kamnyanskiy in 1978.

The valley-type glacier of the Amudarya river basin is located in the Southern Alai Range and extends from 4,960 to 3,625 m a.s.l. Its surface area is 26.21 km^2 and the exposure is to the north. Annual mean air temperature at the equilibrium line of the glacier (around 4,200 m a.s.l.) is -6.5 to -8 °C. The glacier has a temperate accumulation zone but cold ice near the surface of the ablation area. Periglacial permafrost is probably discontinuous. Average annual precipitation as measured at 3,840 m a.s.l. is about 750 mm. A 1:25,000 topographic map of the glacier is still unpublished. Air temperatures of the summer season (June–September) were distinctively higher than the long-term average, with a standard deviation of +0.5 for 1995/96 and +2.0 for 1996/97. Annual precipitation was in the average range, with a standard deviation of +0.6 in 1995/96 and -0.6 in 1996/97.

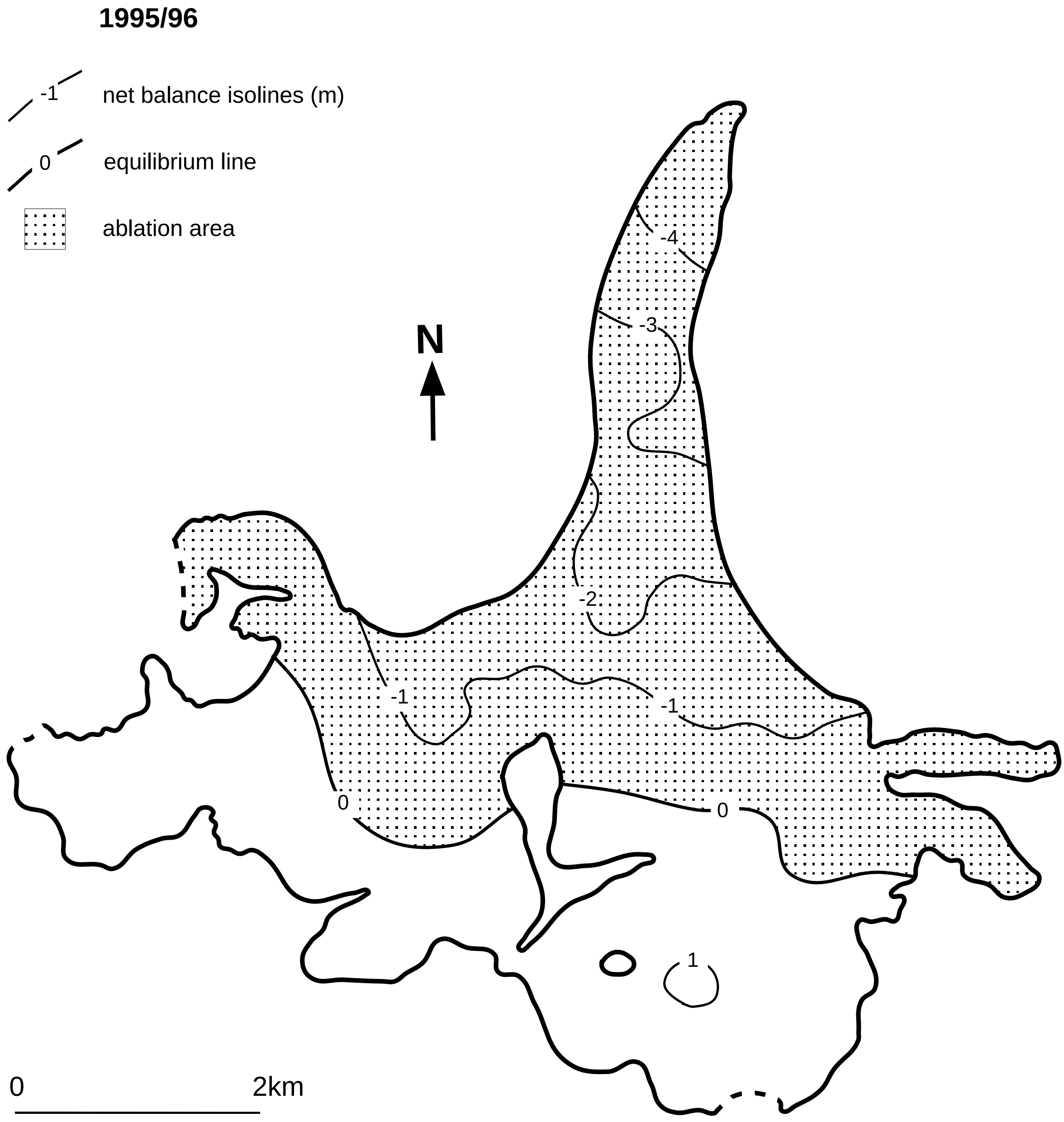
As one can see, the main reason of negative mass balances during 1995/96 and 1996/97 are the hot summers. The summer of 1997 was the hottest one for the period of observations, and in combination with the lowered precipitation, it caused the extremely low mass balance of 1996/97.

3.8.1 Topography and observational network

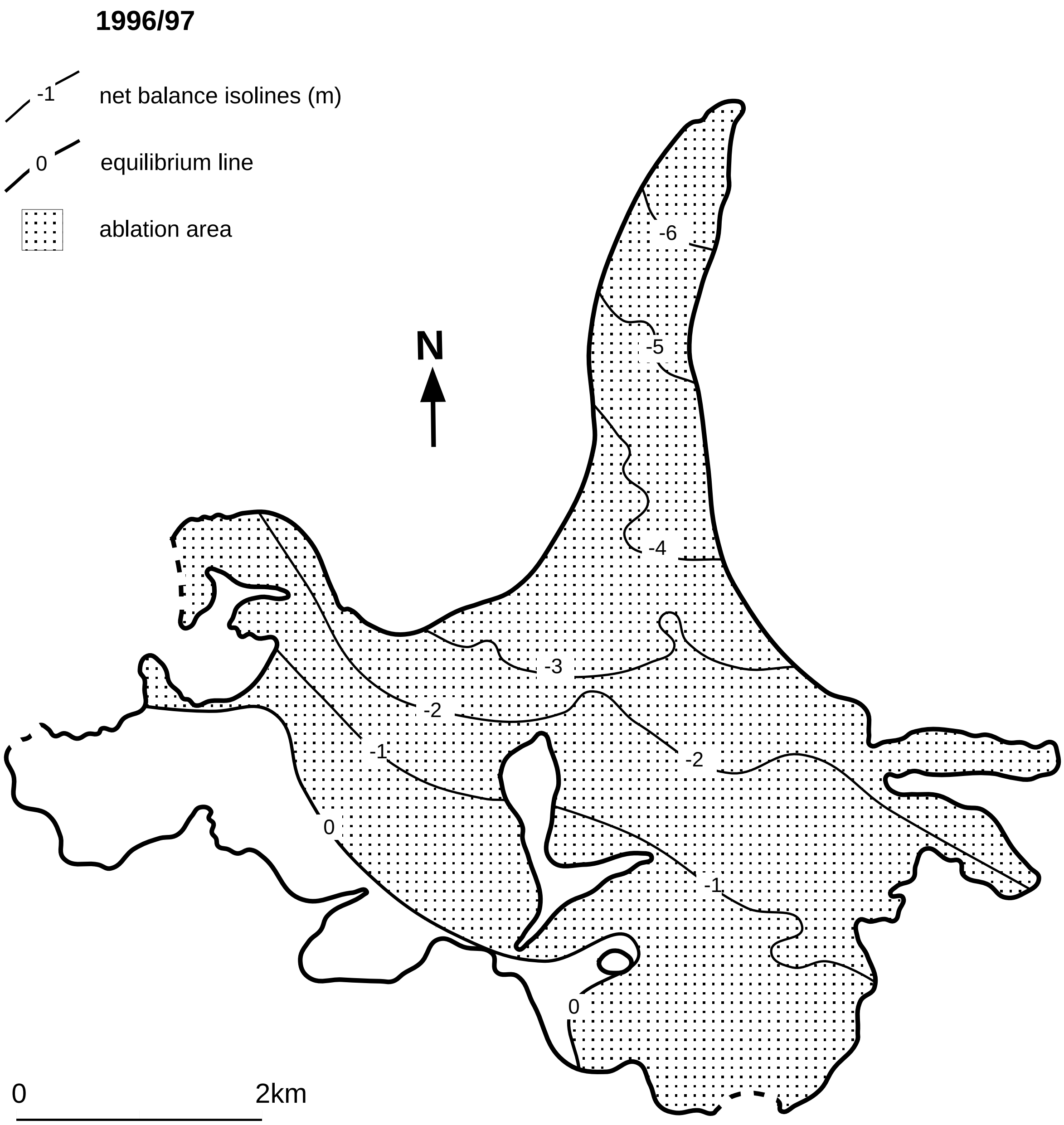


Abramov (KIRGHIZSTAN)

3.8.2 Net balance maps 1995/96 and 1996/97

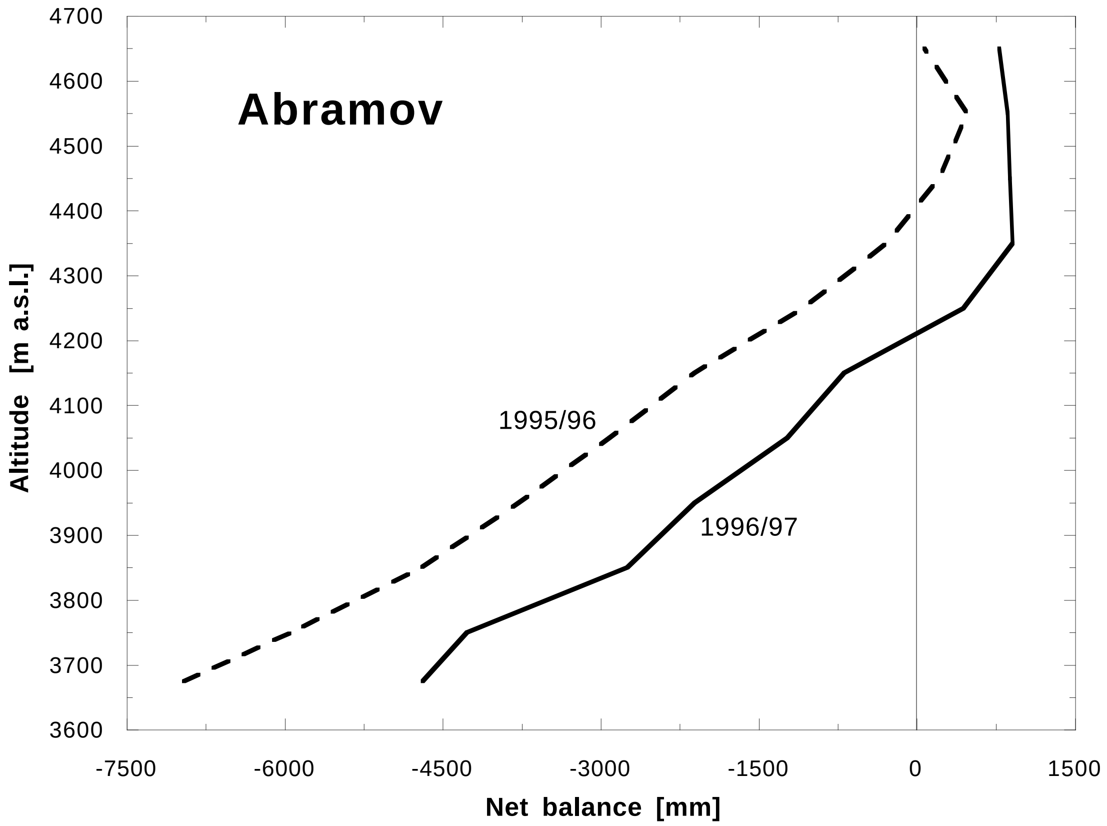


Abramov (KIRGHIZSTAN)

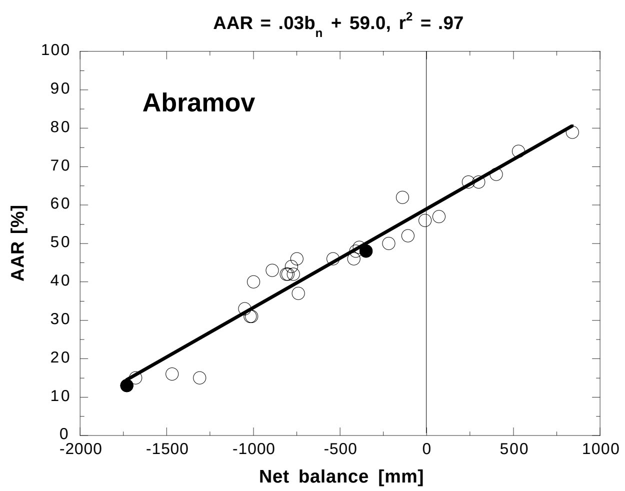


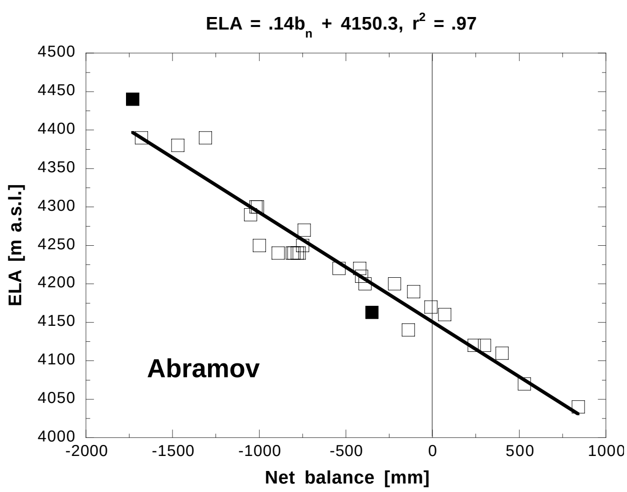
Abramov (KIRGHIZSTAN)

3.8.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.9 TSENTRALNIY TUYUKSUYSKIY (KAZAKHSTAN)

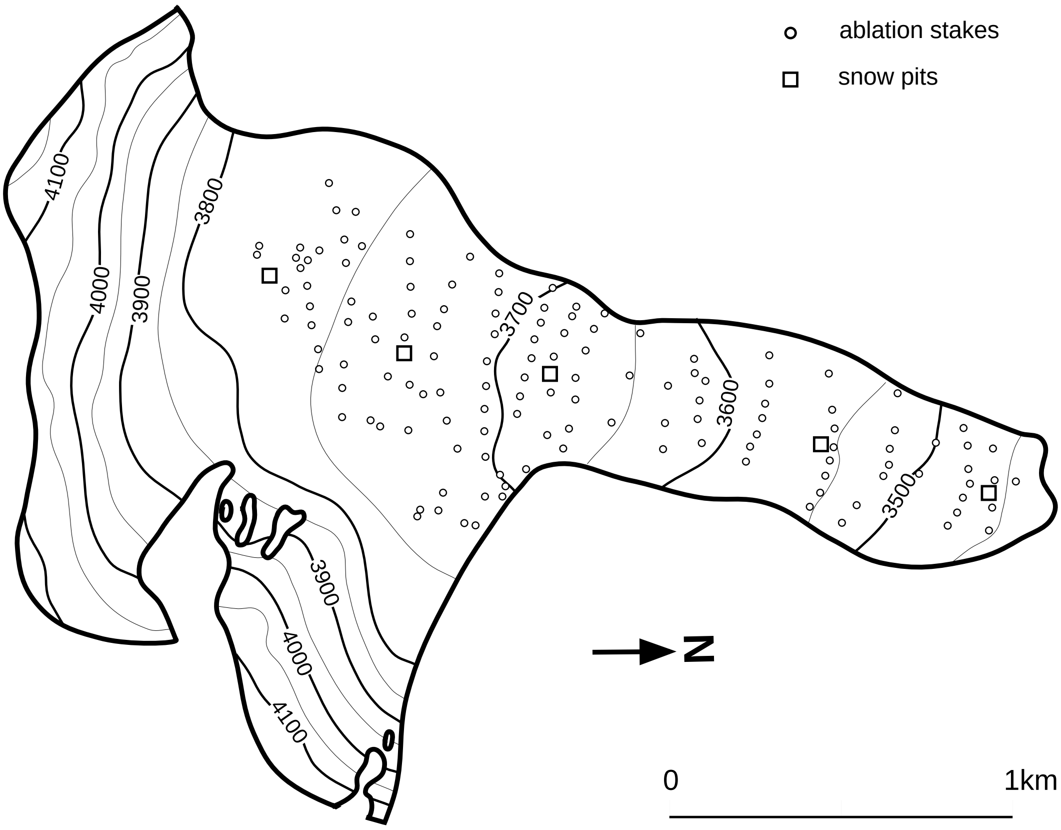
COORDINATES: 43° 03’ N / 77° 05’ E

Photo taken by K.G. Makarevich in August 1970.

The valley-type glacier in the Zailiyskiy Alatau Range of the Kazakh Tien Shan is also called Tuyuksu Glacier. It extends from 4,220 to 3,400 m a.s.l. and by 1995 it had a surface area of 2.87 km^2 (including ice under debris cover), with the exposure being to the N. Annual mean air temperature at the equilibrium line of the glacier (around 3,800 m a.s.l) is -6 to -7°C and the glacier is considered to be cold. Continuous permafrost surrounds the glacier. Average annual precipitation as measured with 19 precipitation gauges is about 1,000 mm in the glacier belt. The characteristic features of the glacier existence under the conditions of highly continental climate are usually the stable winter anti-cyclone, low air temperatures, summer peak of precipitation (ca. 60% of annual sum) and co-existence of accumulation and ablation processes during the warm season. Regime and intensity of summer precipitation (mixed, mainly snow) play the key role for the mass balance.

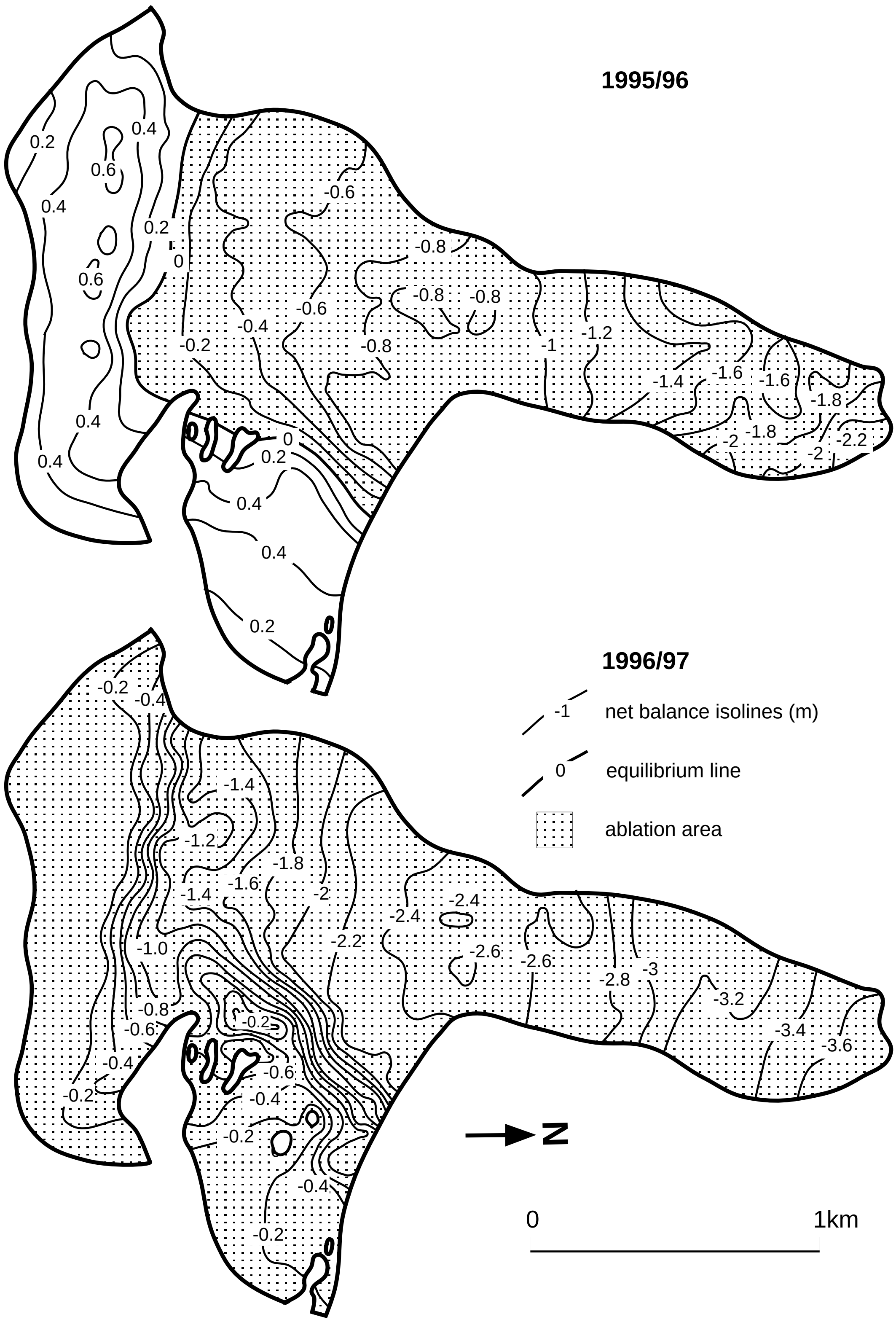
In 1995/96, precipitation was close to average (in winter somewhat higher and in summer somewhat lower), while thermal conditions in summer were moderate. The resulting mass loss of 0.46 m w.e. reflected the characteristic present glacier state, though snowline rose a bit higher. In 1996/97, winter snow amount was close to the norm but summer was too dry and warm (mean air temperature at the terminus was as high as 5.8°C in June–August). The ablation period turned out to be very protracted and lasted until 14 October. As a result , all the snow melted off, snowline rose above the highest glacier limit, and mass balance became strongly negative (loss of 1.47 m w.e.)

3.9.1 Topography and observational network



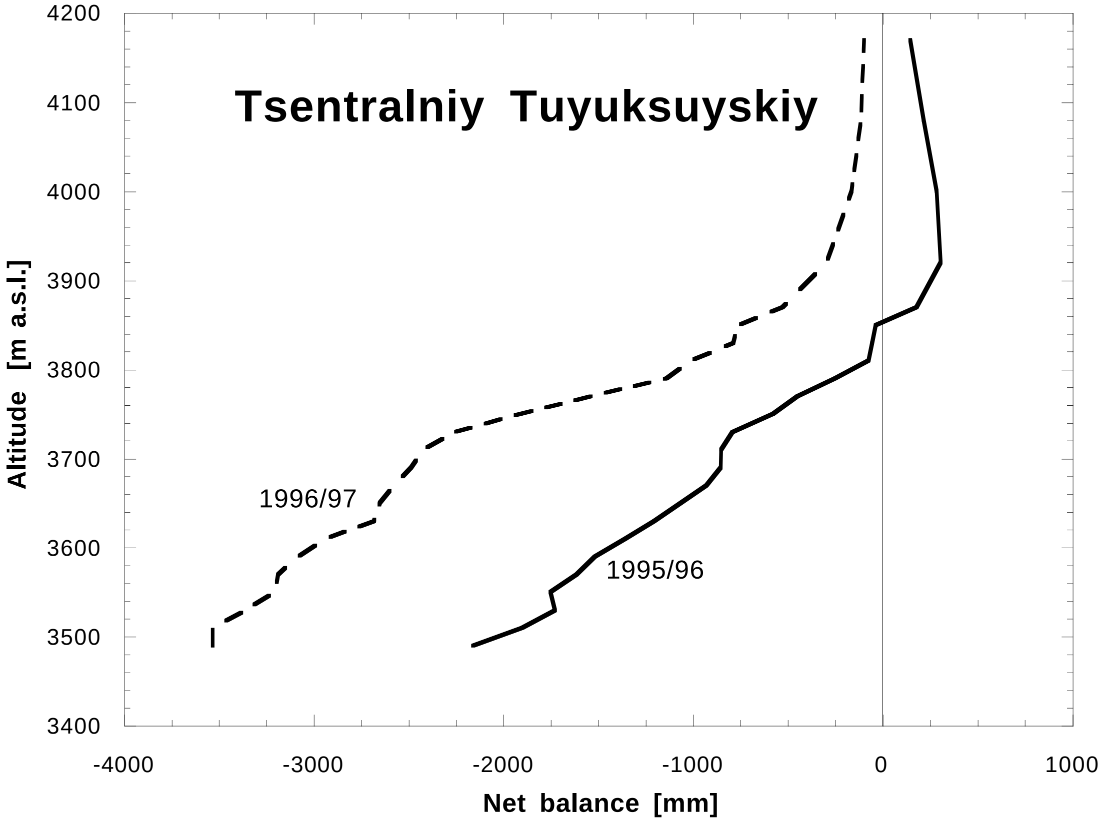
Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.9.2 Net balance maps 1995/96 and 1996/97

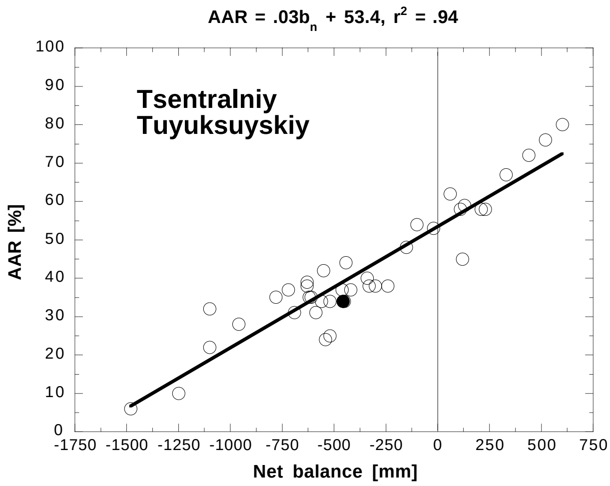


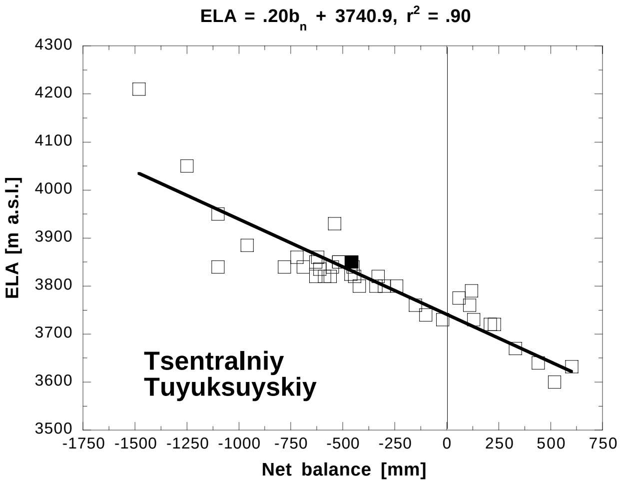
Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.9.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.10 MALIY AKTRU (RUSSIA)

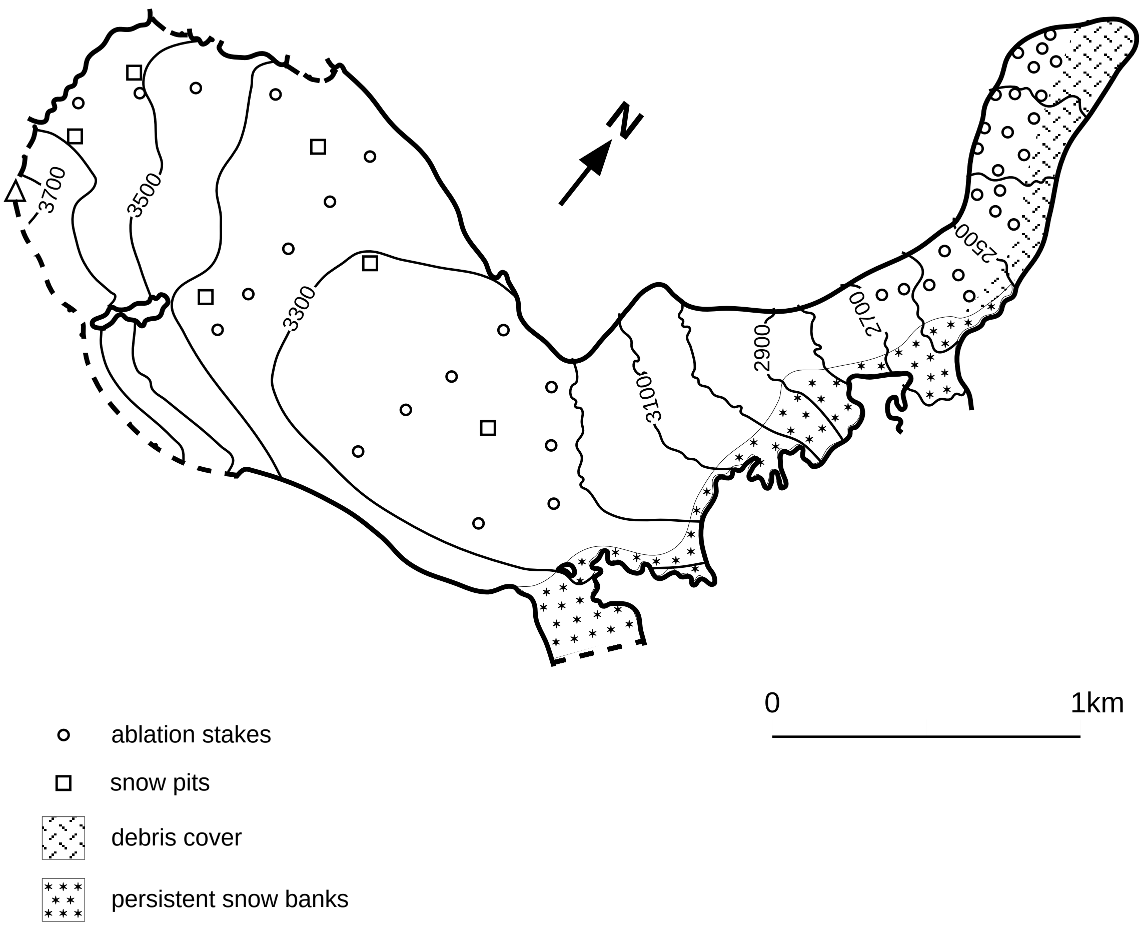
COORDINATES: 50° 05’ N / 87° 45’ E

Photo taken by Yu. K. Narozhniy on 2 July 1992.

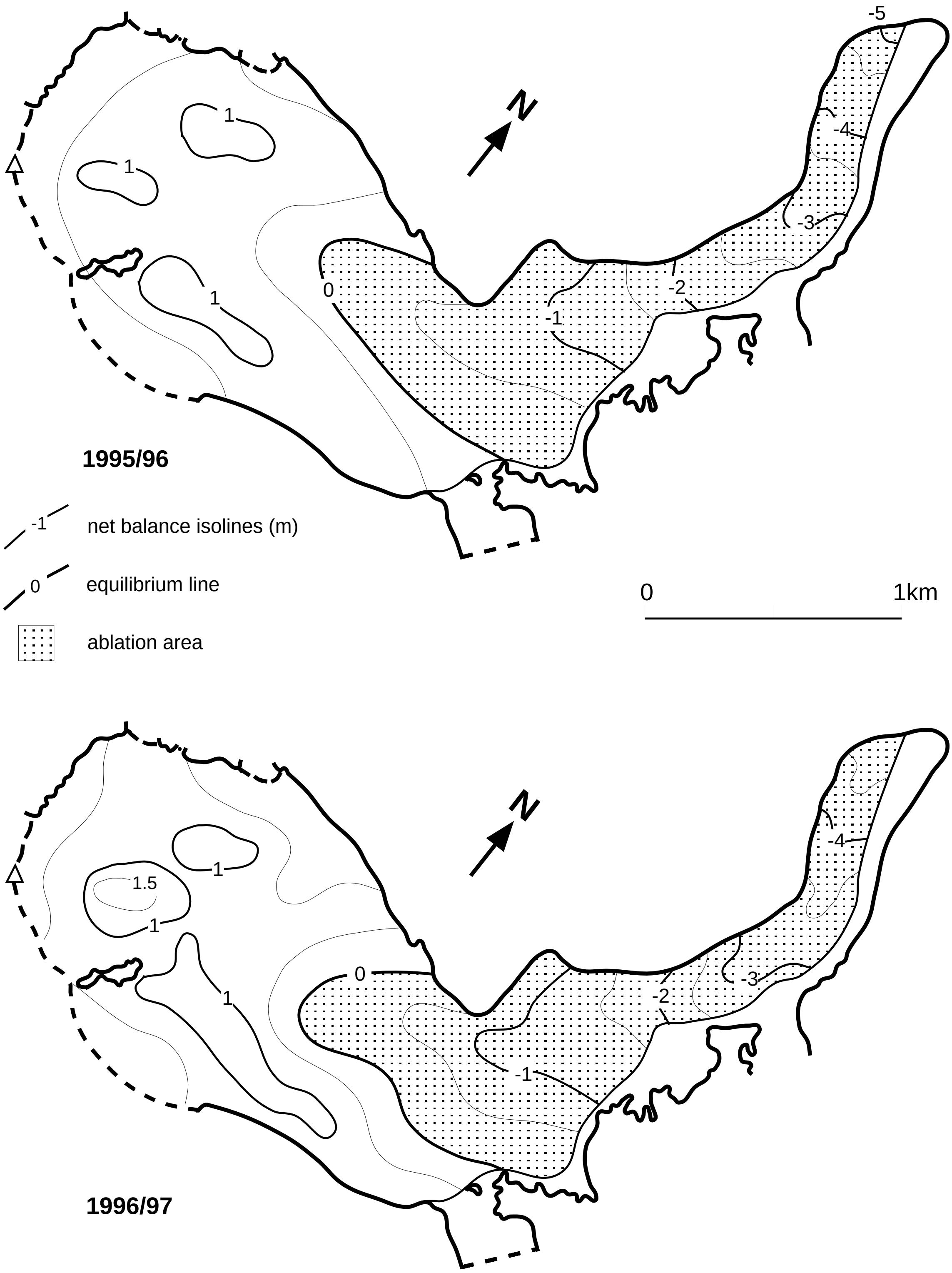
The valley-type glacier is located on the northern slope of the North Chuyskiy Range of the Rus sian Altai Mountains. It extends from 3,714 to 2,224 m a.s.l., has a surface area of 2.73 km^2 and is exposed to the east and north. With an average thickness of 90, m total volume is estimated as 0.25 km^3. Annual mean air temperature at the equilibrium line of the glacier (around 3,130 m a.s.l.) is -9 to -10°C. The glacier is polythermal and surrounded by continuous to discontinuous permafrost. Average annual precipitation as measured at 2,130 m a.s.l. is about 520 mm. Mass balances of two glaciers within the same basin are being determined.

In 1995/96, snow accumulation was close to the mean value, while ablation rate was 6% above average. The glacier lost 0.13 m w.e.. The 1996/97 balance year appeared to become unusual. Total accumulation exceeded its average by 21%. However, the snowmelt period began extremely early (13 April), and monthly mean air temperatures in April–May were 2–4°C higher than normal. Such unique weather conditions had never been recorded before during the entire observation period. As a result, melting was 19% more intensive than usual and compensated for all the excess of winter snow, making balance slightly negative (0.05 m w.e.).

3.10.1 Topography and observational network

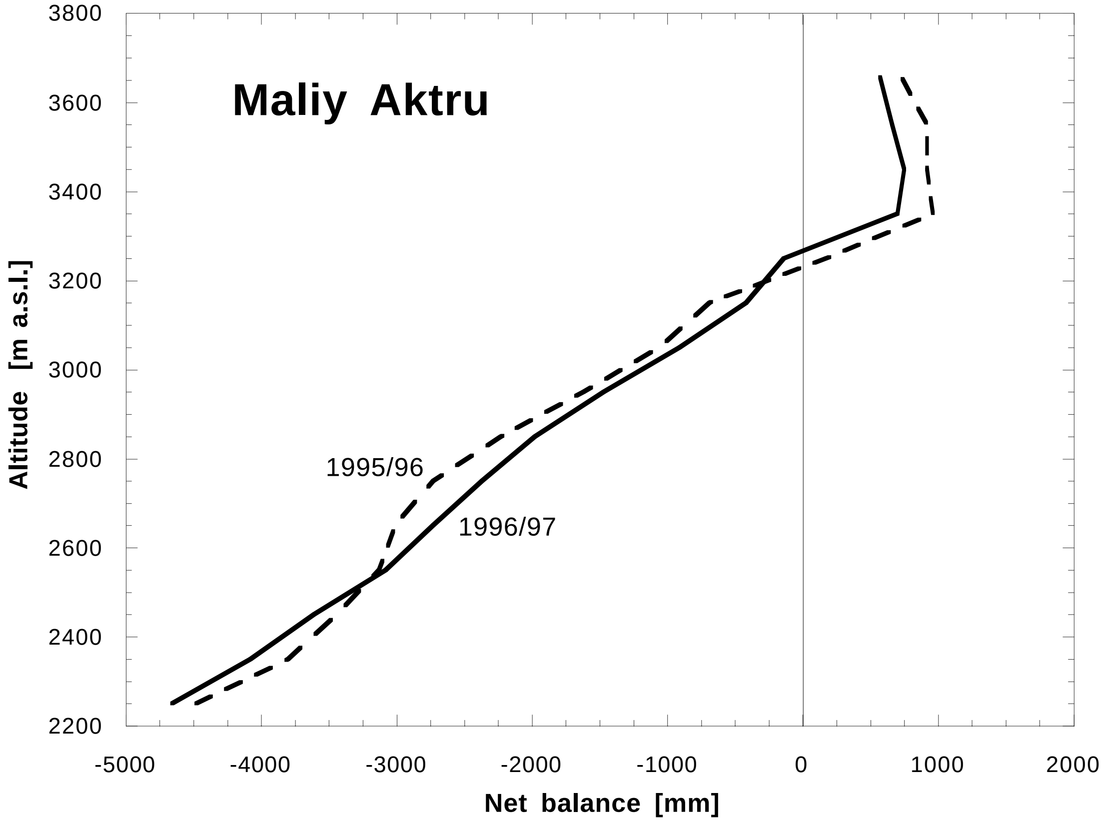


3.10.2 Net balance maps 1995/96 and 1996/97

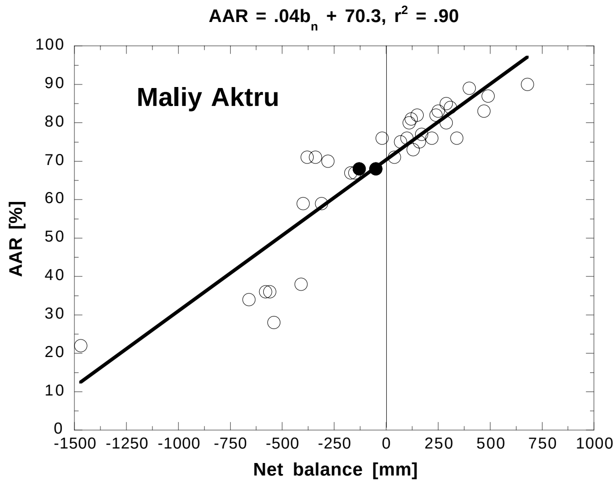


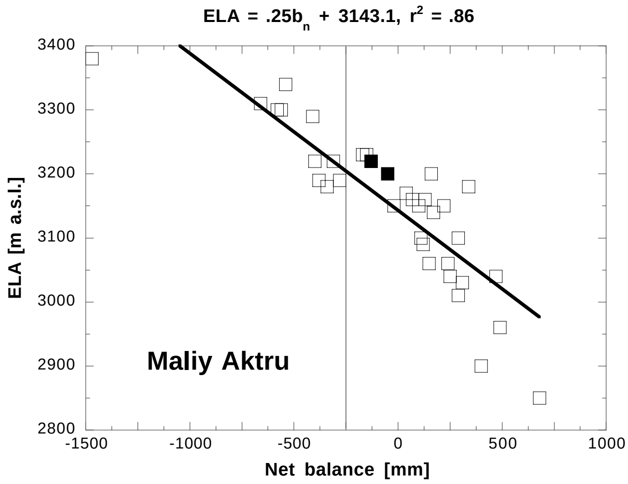
Maliy Aktru (RUSSIA)

3.10.3 Net balance versus altitude (1995/96 and 1996/97)



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





3.11 URUMQIHE S. NO. 1 (China)

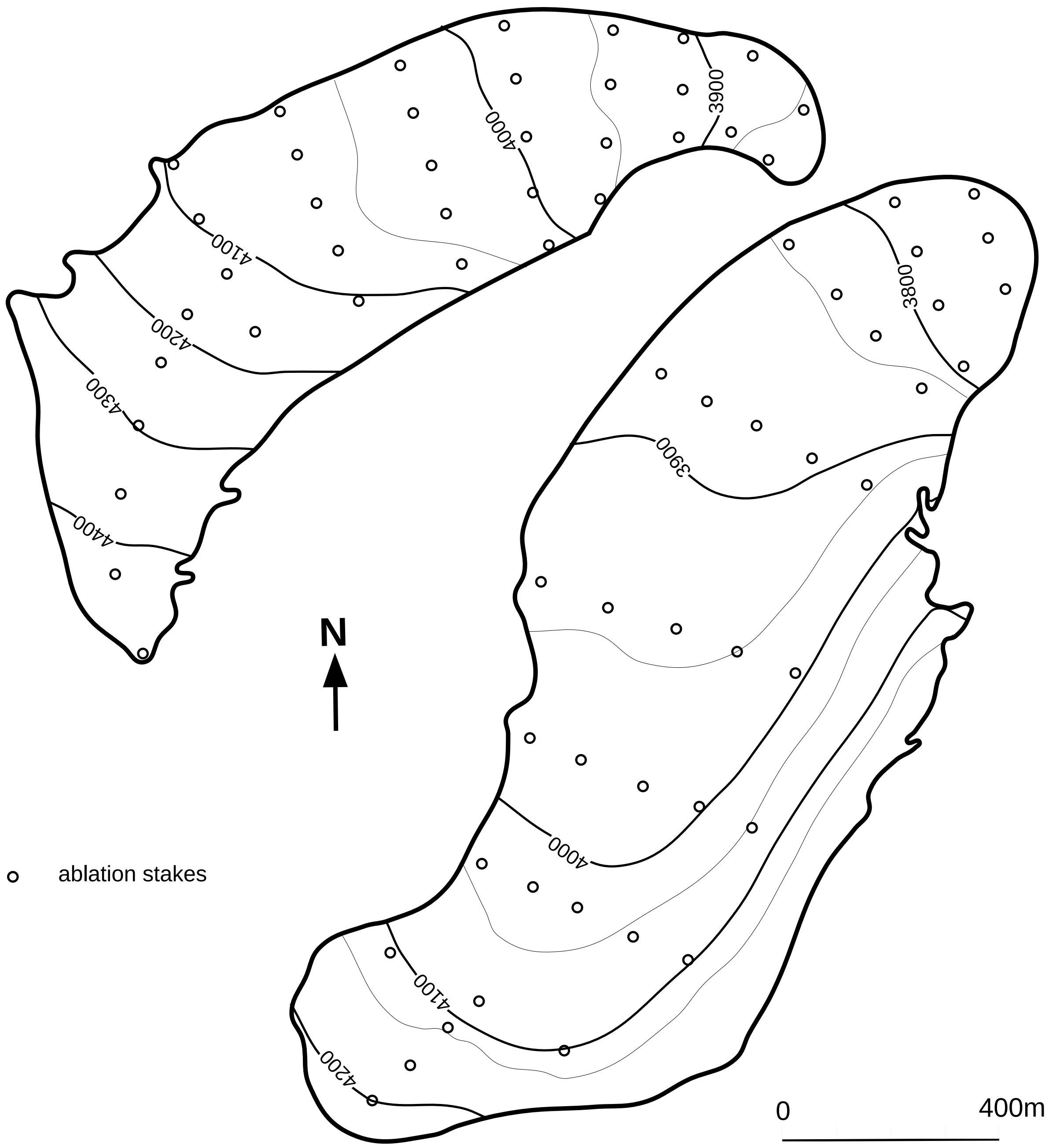
COORDINATES: 43° 05’ N / 86° 49’ E

Author and date of photo not reported.

Glacier No. 1 in the headwaters of Urumqi River in the Chinese Tian Shan is a small valley-type glacier with a total surface area of 1.84 km^2 and consisting of two branches, both exposed to the north-east. The highest and lowest points of the glacier are at 4,486 and 3,740 m a.s.l. Annual mean air temperature at the equilibrium line of the glacier (4,024 m a.s.l. for balanced years) is estimated at -12.3°C according to the Daxigou meteorological station and using an environmental lapse rate of 0.65°C/100 m. The predominantly cold glacier is surrounded by continuous permafrost but reaches melting temperatures over wide areas of the bed. Average annual precipitation measured at the nearby meteorological station at 3539 m a.s.l. is 400 to 500 mm and 600 to 700 mm at the glacier. Mass gain and ablation both take place primarily during the warm season and the formation of superimposed ice on this continental-type glacier is important. A 1:5,000 topographic map of the glacier and its forefield in 1980 can be found in Vol. 5 of the Fluctuations of Glaciers.

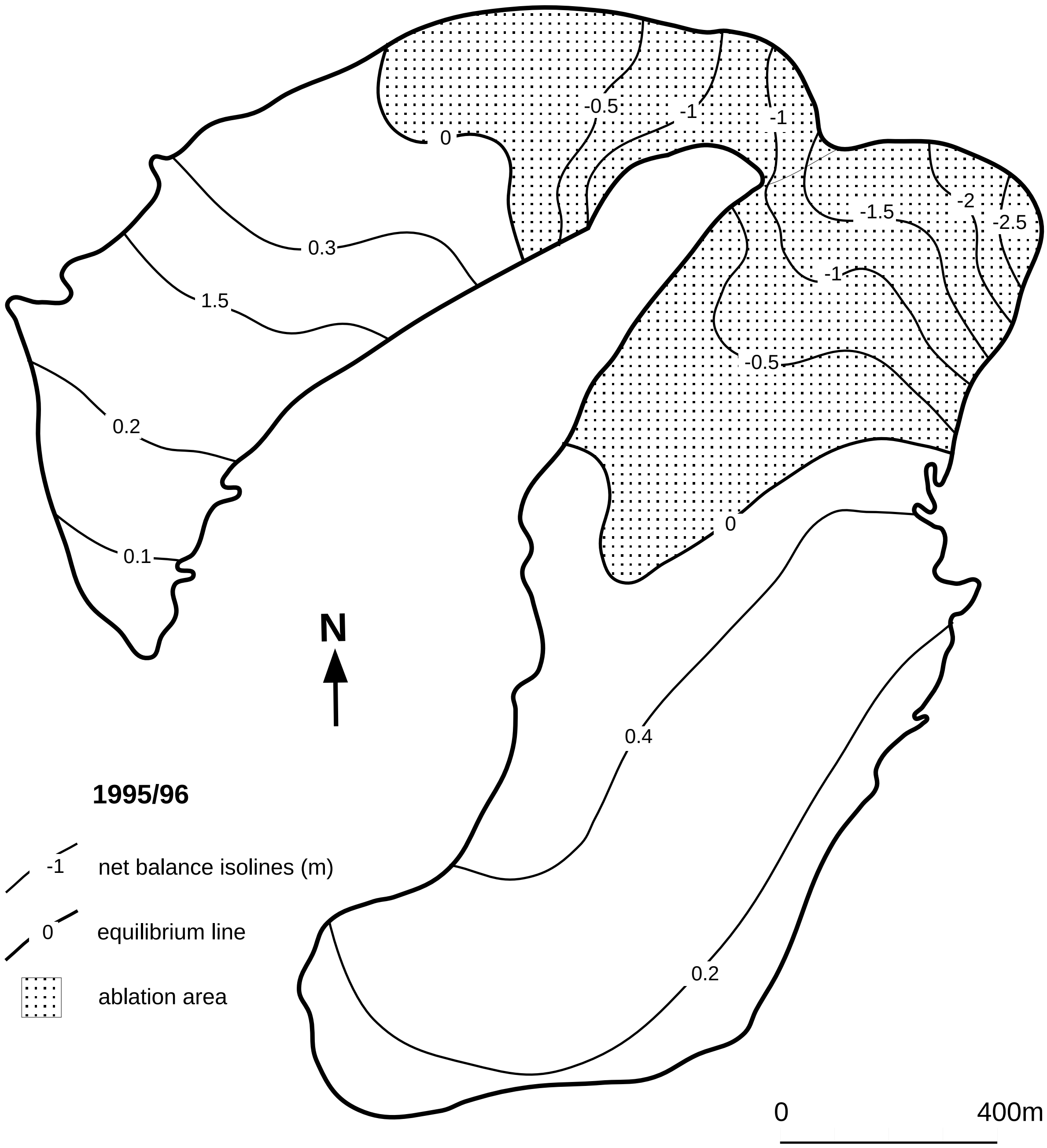
The reported mass balance years represent years of contrast. While the balance year 1995/96 was positive (+0.04 m w.e.), mass balance in the year 1996/97 reached the most negative value (-0.85 m w.e.) since the beginning of the measurements in 1959. In 1997 the eastern and western branches of the glacier became completely separated.

3.11.1 Topography and observational network

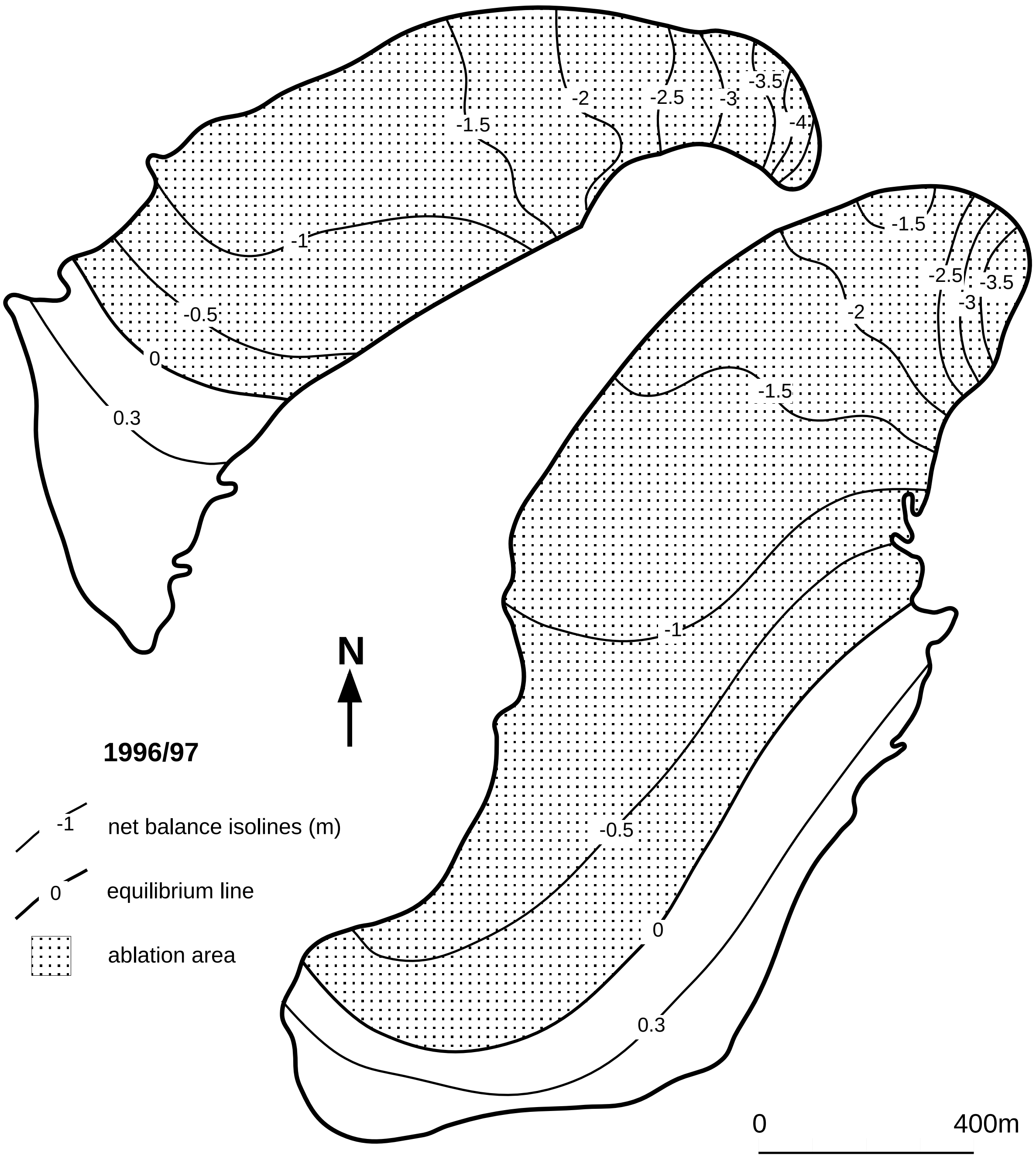


Urumqihe S. No.1 (CHINA)

3.11.2 Net balance maps 1995/96 and 1996/97

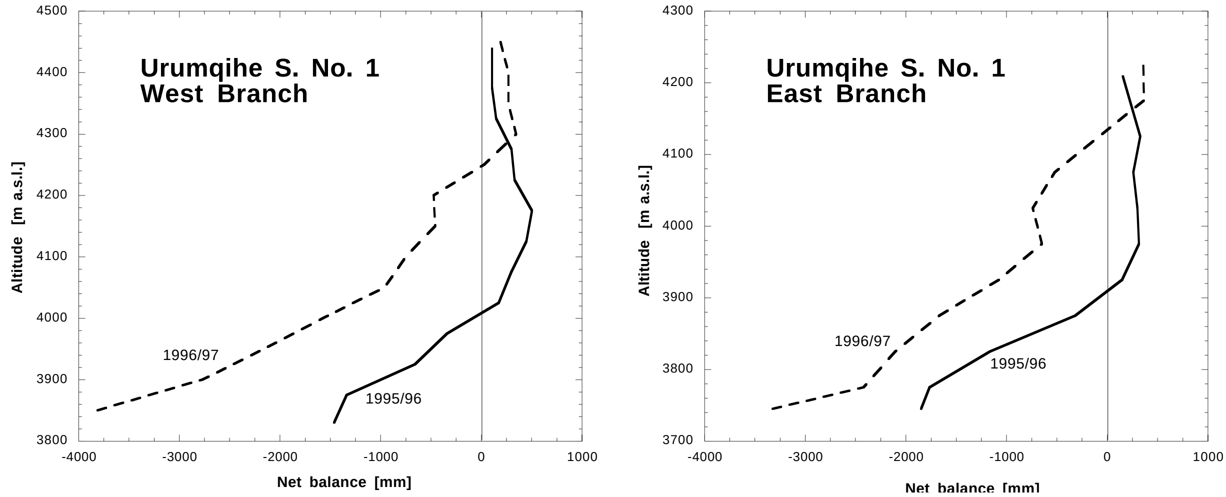


Urumqihe S. No.1 (CHINA)

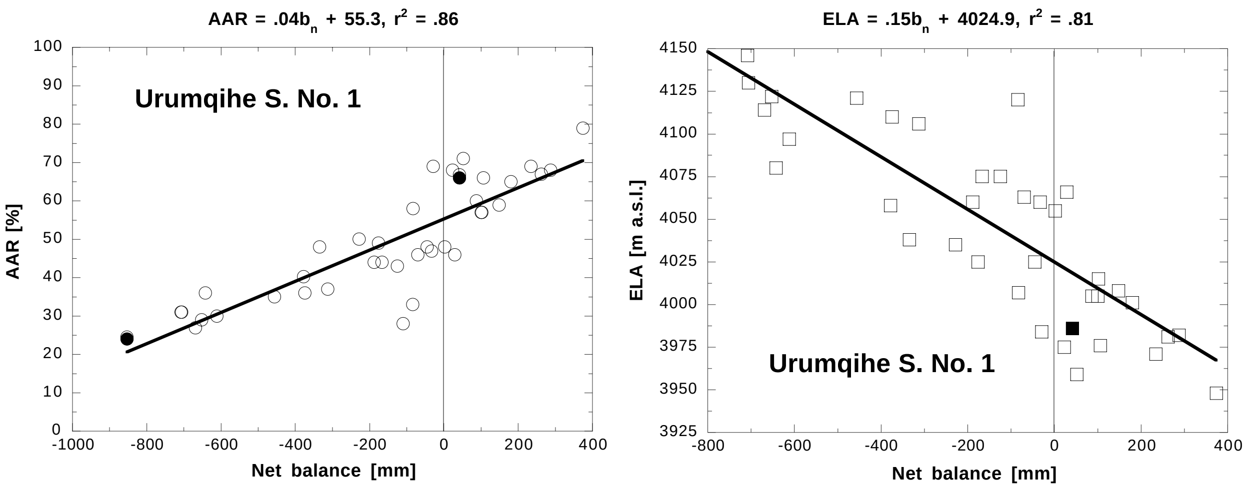


Urumqihe S. No.1 (CHINA)

3.11.3 Net balance versus altitude (1995/96 and 1996/97)



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



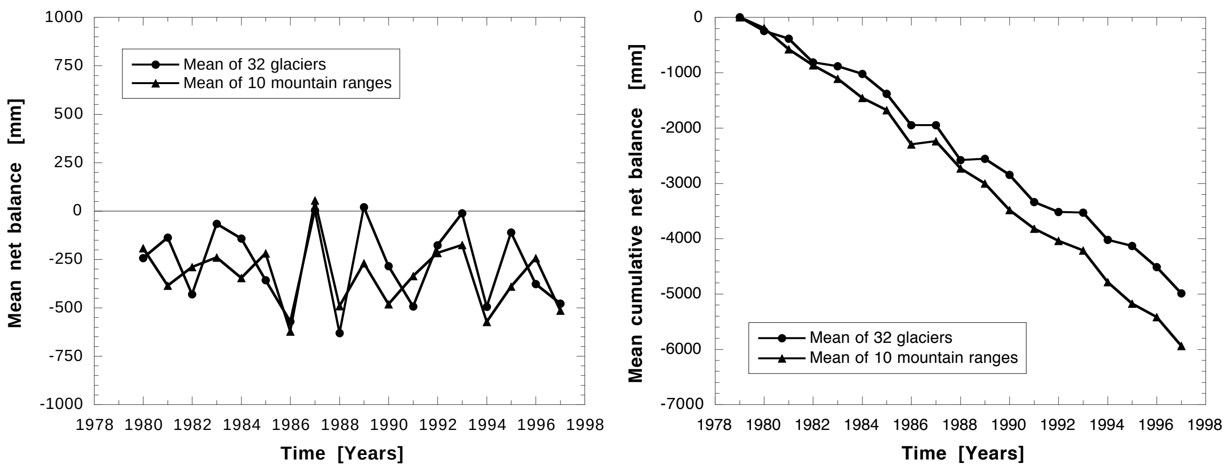
4. FINAL REMARKS AND ACKNOWLEDGEMENTS

Continuous mass balance records for the period 1980–1997 are now available for 32 glaciers. The corresponding results of this sample from glaciers in North America and Eurasia can be summarized as follows:

	1980–1995	1995/96	1996/97
mean specific (annual) net balance:	- 258 mm	- 378 mm	- 478 mm
standard deviation:	± 492 mm	± 533 mm	± 849 mm
minimum value:	- 1193 mm	- 1880 mm	- 2480 mm
maximum value:	+ 811 mm	+ 830 mm	+ 1220 mm
range:	2004 mm	2710 mm	3700 mm
positive balances:	25%	16%	28%

Taking the two reported years together, the mean mass balance was negative by 428 mm, nearing half a meter water equivalent per year. The calculated mean is almost two-thirds higher than the average 1980–1995. The proportion of positive mass balances (22) was less than the average (25) determined during 1980–1995. The rate of glacier melt in the northern hemisphere, thus, clearly accelerated during the two years reported. The mean specific net balance (-306 mm) for the seven years 1990/91–1996/97 is markedly higher than the decadal mean of 1980–1990 (-259 mm). The difference corresponds to an increase in additional energy flux of about 0.5 W/m^2 or 0.05 W/m^2 per year. It should be kept in mind, however, that the annual signal of the mean mass balance is smaller by far than the regional variability. The range of extremes observed on individual glaciers is roughly one order of magnitude higher than the mean value of the sample and reached extreme values in 1996/97 (almost 4 meters water equivalent). The significance of the recorded signal, on the other hand, increases with mass balance values cumulated over extended time periods. Total average loss since 1979/80 is now between 5 and 6 meters water equivalent.

The evolution with time can be described by means of the following graphs:



The mean of all 32 glaciers is strongly influenced by the great number of Alpine and Scandinavian glaciers. A mean value is, therefore, also calculated using only one single (in some places averaged) value for each of the 10 mountain ranges involved:

Year	Cascade Mtns.	Svalbard	Alaska	Scaninavia	Alps	Kamchatka	Altai	Caucasus	Tien Shan	Pamir-Alai	Mean
1980	-972	-475	1400	-1180	418	0	-10	380	-443	-1050	-193
1981	-967	-505	775	194	-16	-1950	-213	-910	-330	70	-385
1982	-337	-10	-245	-185	-887	60	-460	420	-486	-770	-290
1983	-606	-220	15	756	-460	-250	197	-970	-463	-410	-241
1984	-109	-705	-395	194	12	-340	307	210	-968	-1680	-347
1985	-1541	-515	515	-451	-411	2020	200	-380	-818	-810	-219
1986	-1011	-265	-60	-249	-1010	-1660	73	-500	-527	-1010	-622
1987	-1703	230	535	925	-699	-300	183	1540	-399	240	55
1988	-1305	-505	395	-1215	-610	-1940	333	520	-569	-10	-491
1989	-875	-345	-1440	1911	-893	-740	117	40	-248	-220	-269
1990	-834	-585	-1555	1196	-1101	-1280	107	340	-562	-540	-481
1991	-595	115	-260	80	-1227	460	-480	-310	-735	-420	-337
1992	-1400	-120	-210	1162	-1158	-410	-127	-130	-190	400	-218
1993	-1755	-955	-1170	1174	-459	-350	227	1100	129	300	-176
1994	-1225	-140	-660	171	-920	-670	-240	-840	-442	-750	-572
1995	-1588	-785	-785	589	17	-230	60	40	-443	-780	-391
1996	-61	-75	-950	-639	-411	600	-140	-150	-262	-350	-244
1997	-129	-570	-2120	-470	-227	940	-123	270	-989	-1730	-515
Mean	-945	-357	-345	220	-558	-336	1	37	-486	-529	-330

Glaciers:

Cascade Mtns.:	Place, South Cascade
Svalbard:	Austre Brøggerbreen, Midtre Lovénbreen
Alaska:	Gulkana, Wolverine
Scandinavia:	Engabreen, Ålfotbreen, Nigardsbreen, Gråsubreen, Storbreen, Hellstugubreen, Hardangerjøkulen, Storglaciären
Alps:	Saint Sorlin, Sarennes, Silvretta, Gries, Sonnblickkees, Vernagtferner, Kesselwandferner, Hintereisferner, Caresèr
Kamchatka:	Kozelskiy
Altai:	No. 125, Maliy Aktru, Leviy Aktru
Caucasus:	Djankuat
Tien Shan:	Kara-Batkak, Ts. Tuyuksuyskiy, Urumqihe S. No. 1
Pamir-Alai:	Abramov

The mean specific net balance of the 10 mountain ranges involved is -350 mm for the seven-year period of 1990/91–1996/97 and thus, clearly higher than the decadal mean of 1980–1990 (-317 mm) and the corresponding value for all 32 glaciers.

Further analysis requires detailed consideration of such aspects 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 influenced by maritime-type glaciers such as the glaciers on the coast mountains of Norway or USA/Alaska, where effects of atmospheric warming may be compensated by effects from
increased precipitation.

Rising snowlines and cumulative mass losses lead to changes in average albedo and 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 as combined with albedo effects. The cumulative length change of glaciers is the result of all effects combined and constitutes the key to global intercomparison of secular mass losses. Attempts are presently being made to estimate dynamic response times and to derive long-term average mass balances from cumulative length changes. Another new possibility is to dynamically fit mass balance histories to present-day geometries and historical length change measurements of long-observed glaciers using time-dependent flow models. It is hoped that the corresponding backward extension of mass balance records will be useful for investigating the question about secular rates of change and possible acceleration trends.

Completion of the present Glacier Mass Balance Bulletin was made possible through the cooperation of the national correspondents to WGMS and the principal investigators on the various glaciers, as listed in the final chapter 5. Thanks are also due to the other staff members of WGMS for their assistance, especially to Eva Kraetzer at VAW/ETHZ for drawing the maps. Funding was mainly through IHP/UNESCO, FAGS / ICSU, the Glaciology Commission of the Swiss Academy of Sciences, the Geography Department at the University of Zurich and VAW/ETH Zurich.

5. PRINCIPAL INVESTIGATORS AND NATIONAL CORRESPONDENTS

5.1 PRINCIPAL INVESTIGATORS

CANADA	Place Helm Place	M. N. Demuth Geological Survey of Canada Terrain Sciences Division – Glaciology 601 Booth Street **CANADA – Ottawa, ON K1A 0E8**
	White	G. Cogley Trent University Department of Geography 1600, West Bank Drive **CANADA – Peterborough, ON K9J 7B8**
USA	South Cascade	R. M. Krimmel US Geological Survey University of Puget Sound **USA – Tacoma, WA 98416**
	Wolverine	D. Trabant US Geological Survey Water Resources Division 800 Yukon Drive **USA – Fairbanks, AK 99775**
	Gulkana	R. March US Geological Survey Water Resources Division 800 Yukon Drive **USA – Fairbanks, AK 99775**
ECUADOR	Antizana 15 alpha	B. Francou Centre de Géomorpholgie du CRNS Mission ORSTOM P.O. Box 1712 857 **ECUADOR – Quito**
BOLIVIA	Chacaltaya Zongo	B. Francou Centre de Géomorpholgie du CRNS Mission ORSTOM P.O. Box 1712 857 **ECUADOR – Quito**

ARGENTINA	Glaciar de los Tres	V.V. Popovnin Moscow State University Geographical Faculty Leninskiye Gory **RUSSIA – 119 899 Moscow**
ICELAND	Hofsjökull North Hofsjökull East Hofsjökull Southwest Thrándarjökull	O. Sigurdsson National Energy Authority Hydrological Survey Orkustofnun Grensásvegur 9 **ICELAND – 108 Reykjavik**
	Brúarjökull Dyngjujökull Eyjabakkajökull Koldukvíslarjökull	H. Björnsson Science Institute University of Iceland **ICELAND – 107 Reykjavik**
NORWAY	Austre Brøggerbreen Midtre Lovénbreen Kongsvegen	Elisabeth Isaksson Norwegian Polar Institute P.O. Box 399 **NORWAY – 9005 Tromsø**
	Ålfotbreen Austdalsbreen Engabreen Gråsubreen Hansebreen Hardangerjøkulen Hellstugubreen Jostefonn Langfjordjøkelen Nigardsbreen Okstindbreen Storbreen	Erik Roland Norwegian Water Resources and Energy Administration (NVE) Glacier Division P.O. Box 5091, Majorstua **NORWAY – 0301 Oslo**
SWEDEN	Mårmaglaciären Rabots glaciär Riukojietna Storglaciären	P. Holmlund and W. Karlén Department of Physical Geography University of Stockholm **SWEDEN – 106 91 Stockholm**
FRANCE	Sarennes	F. Valla CEMAGREF-NIVOLOGY B.P. 76 **FRANCE – 38402 St. Martin d’Hères Cedex**

	Saint Sorlin	L. Reynaud, M. Vallon and C. Vincent Laboratory of Glaciology and Environmental Geophysics (CNRS) Domaine Universitaire C.P. 96 **FRANCE – 38402 St. Martin d'Hères Cedex**
SWITZERLAND	Gries Silvretta	M. Funk Laboratory of Hydraulics, Hydrology and Glaciology (VAW) Federal Institute of Technology ETH-Zentrum **SWITZERLAND – 8092 Zurich**
ITALY	Caresèr	G. Zanon Department of Geography University of Padua Via del Santo, 26 **ITALY – 35123 Padua**
	Fontana Bianca	G. Kaser Institute of Geography University of Innsbruck Innrain 52 **AUSTRIA – 6020 Innsbruck**
		M. Munari Hydrographical Office Autonom Province of Bozen Mendelstrasse 24 **Italy – 39100 Bozen**
AUSTRIA	Hintereisferner Jamtalferner Kesselwandferner Ochsentalergletscher Vermuntgletscher	G. Markl and M. Kuhn Institute of Meteorology and Geophysics University of Innsbruck Innrain 52 **AUSTRIA – 6020 Innsbruck**
	Sonnblickkees	H. Slupetzky Geographical Institute University of Salzburg Hellbrunnerstrasse 34 / III **AUSTRIA – 5020 Salzburg**
	Vernagtferner	L.N. Braun Commission for Glaciology Bavarian Academy of Sciences Marstallplatz 8 **GERMANY – 80539 München**

	Wurtenkees	R. Böhm Central Institute for Meteorology Hohe Warte 38 **AUSTRIA – 1190 Wien**
SPAIN	Maladeta	AMINSA C/Guardia Civil, 23, Esc-2, PT-3 **SPAIN – Valencia (46020)**
KENYA	Lewis	S. Hastenrath Department of Meteorology University of Wisconsin-Madison 1225 West Dayton Street **USA – Madison, Wisconsin 53706**
RUSSIA	Garabashi	A.B. Bazhev, O.V. Rototayeva and I.F. Khmelevskoy Russian Academy of Sciences Institute of Geography Staromonetniy, 29 **RUSSIA – 109 017 Moscow**
	Djankuat	V.V. Popovnin Moscow State University Geographical Faculty Leninskiye Gory **RUSSIA – 119 899 Moscow**
	Leviy Aktru Maliy Aktru No. 125	Yu. K. Narozhniy Tomsk State University Lenin Str., 36 **RUSSIA – 634 010 Tomsk**
	Kozelskiy	Ya. D. Muravyov Russian Academy of Sciences Far East Research Center Institute of Volcanology Piyp Boulevard, 9 **RUSSIA – 683 006 Petropavlovsk Kamchatskiy**
KAZAKHSTAN	Ts. Tuyuksuyskiy	P.A. Cherkasov National Kazakh Academy of Sciences Institute of Geography Pushkin Str., 99 **KAZAKHSTAN – 480 100 Alma Ata**

KIRGHIZSTAN	Abramov	G.M. Kamnyanskiy Main Administration of Hydrometeorology (GLAVGIDROMET) Cabinet of Ministers Observatorskaya Str., 72 **UZBEKISTAN – 700 052 Tashkent**
	Kara-Batkak	A.N. Dikikh National Kirghiz Academy of Sciences Institute of Geology Erkin-Dik Boulevard, 30 **KIRGHIZSTAN – 720 481 Bishkek**
CHINA	Urumqihe S. No. 1	Chaohai Liu Lanzhou Institute of Glaciology and Geocryology Chinese Academy of Sciences **CHINA – Lanzhou**
NEPAL	AX010	Y. Ageta Institute for Hydrospheric-Atmospheric Sciences (IHAS) Nagoya University Chikusa-Ku **JAPAN – Nagoya 464 8601**

5.2 NATIONAL CORRESPONDENTS OF WGMS

ARGENTINA

L. Espizua
Instituto Argentino de Nivología y Glaciología
CONICET (IANIGLA)
Casilla de Correo, 330
ARGENTINA – 5500 Mendoza
E-mail: lespizua@lab.cricyt.edu.ar

AUSTRALIA

A. Ruddel
Antarctic CRC and Antarctic Division Glaciology
G.P.O. Box 252 80
AUSTRALIA – Hobart 7001
E-mail: andrew_rud@antdiv.gov.au

AUSTRIA

M. Kuhn
Institute of Meteorology and Geophysics
University of Innsbruck
Innrain 52
AUSTRIA – 6020 Innsbruck
E-mail: Michael.Kuhn@uibk.ac.at

BOLIVIA

B. Francou
Centre de Géomorpholgie du CRNS
Mission ORSTOM
P.O. Box 1712 857
ECUADOR – Quito
E-mail: francou@glace.com.ec

CANADA

M. N. Demuth
Geological Survey of Canada
Terrain Sciences Division – Glaciology
601 Booth Street
CANADA – Ottawa, ON K1A 0E8
E-mail: mdemuth@nrcan.gc.ca

CHILE

G. Casassa
Centro Austral Antárctico
Universidad de Magellanes
Casilla 113 D
CHILE – Puntas Arenas
E-mail: gcasassa@yagan.fh.umag.cl

CHINA	Liu Shiyin Lanzhou Institute of Glaciology and Cryopedology Chinese Academy of Sciences West Dongyang Road 260 **CHINA – 730 000 Lanzhou** E-mail: liusy@ns.lzb.ac.cn
C.I.S.	D.G. Tsvetkov Russian Academy of Sciences Institute of Geography Department of Glaciology Staromonetny 29 **RUSSIA – 109 0l7 Moscow** E-mail: geography@glas.apc.org
COLOMBIA	L. Guarnizo INGEOMINAS Observatorío Vulcanológico Colombia Deformation and Glaciology Group Av. 12 de Octubre No. 15–47 **COLOMBIA – Manizales** E-mail: ov_ruiz@mafalda.univalle.edu.co
ECUADOR	R.H. Galárraga Escuela Politécnica Nacional Facultad de Ingeniería Nacional Departamento de Hydráulica y Rercursos Hídricos P.O. Box 17 01 2759 **ECUADOR – Quito** E-mail: glaciar@mail.epn.edu.ec
FRANCE	L. Reynaud Laboratory of Glaciology and Environmental Geophysics (CNRS) Domaine Universitaire C.P. 96 **FRANCE – 38402 St. Martin d'Hères Cedex** E-mail: Reynaud@glaciog.ujf-grenoble.fr
GERMANY	L. Braun Commission for Glaciology Bavarian Academy of Sciences Marstallplatz 8 **GERMANY – 80539 München** E-mail: Ludwig.Braun@Lrz.badw-muenchen.de

GREENLAND	C.E. Bøggild Department of Hydrology and Glaciology (GEUS) Thoravej 8 **DENMARK – 2400 København N** E-mail: ceb@geus.dk
ICELAND	O. Sigurdsson National Energy Authority Hydrological Survey Orkustofnun Grensásvegur 9 **ICELAND – 108 Reykjavik** E-mail: osig@os.is
INDIA	K.V. Krishnamurthy Geological Survey of India 27, Jawaharlal Nehru Road **INDIA – 700 0l6 Calcutta**
INDONESIA	see Australia
ITALY	G. Zanon Department of Geography University of Padua Via del Santo 26 **ITALY – 35l00 Padua**
JAPAN	Y. Ageta Institute for Hydrospheric-Atmospheric Sciences (IHAS) Nagoya University Chikusa-Ku **JAPAN – Nagoya 464 8601** E-mail: ageta@ihas.nagoya-u.ac.jp
KENYA	S. Hastenrath Department of Atmospheric and Oceanic Sciences University of Wisconsin 1225 West Dayton Street **USA – Madison, WI 53706** E-mail: barafu@macc.wisc.edu
MEXICO	H. Delgado-Granados Instituto de Geofísica Universidad Nacional Autónoma de Mexico Circuito Cientifico **MEXICO – Coyoacan 04510 D.F.** E-mail: hugo@tonatiuh.igeofcu.unam.mx

MONGOLIA

P. Baast
Institute of Water Policy
Surface Water Section
Ministry of Nature and Environment
Baruun Selbe 13
MONGOLIA – Ulaanbataar 211 238
E-mail: puba@picub.edu.mn

NEPAL

see Japan

NEW ZEALAND

T.J. Chinn
National Institute of Water and Atmosphere (NIWA)
P.O. Box 6414
NEW ZEALAND – Dunedin
E-mail: T.Chinn@gns.cri.nz

NORWAY

J.O. Hagen
Department of Physical Geography
University of Oslo
P.O. Box 1042, Blindern
NORWAY – 0316 Oslo
E-mail: J.O. Hagen@geografi.uio.no

PAKISTAN

K. Hewitt
Cold Regions Research Center
Wilfried Laurier University
100 University Avenue
CANADA – Waterloo, ON N2L 3C5
E-mail: khewitt@mach1.wlu.ca

PERU

M. Zamora C.
Section of Glaciology and Lake Safety
Electroperú
Jr. Huaylas No. 143
PERU – Huaraz / Ancash

POLAND

B. Gadek
University of Silesia
Department of Geomorphology
ul. Bedzinska 60
POLAND – 41 200 Sosnowiec
E-mail: jgadek@usctoux1.cto.us.edu.pl

SPAIN

E. Martinez de Pisón
Miguel Arenillas Parra
Ingeniería 75, S.A.
Velázquez 87–4° derecha
SPAIN – 28006 Madrid
E-mail: i75@mad.servicom.ex

SWEDEN

P. Holmlund
Department of Physical Geography
Glaciological Section
University of Stockholm
SWEDEN – 106 91 Stockholm
E-mail: Pelle@natgeo.su.se

SWITZERLAND

M. Hoelzle
Laboratory of Hydraulics, Hydrology and Glaciology (VAW)
Federal Institute of Technology
ETH-Zentrum
SWITZERLAND – 8092 Zurich
E-mail: hoelzle@vaw.baum.ethz.ch

UNITED KINGDOM

D. N. Collins
Alpine Glacier Project
School of Geography
University of Oxford
UNITED KINGDOM – Oxford OX1 3TB
E-mail: David.Collins@geog.ox.ac.uk

USA

A. Fountain
Department of Geology
Portland State University
P.O. Box 751
USA – Portland, OR 97207
E-mail: fountaina@pdx.edu

UZBEKISTAN

G.M. Kamnyanskiy
Main Administration of Hydrometeorology
Cabinet of Ministers
Observatorskaya 72
UZBEKISTAN – 700 052 Tashkent

VENEZUELA

R. Quintana
Unversidad de los Llanos Ezequiel Zamora (UNELLEZ)
Barinas
VENEZUELA – Edo. Barinas 5201
E-mail: rquint@SAMAN.unellez.edu.ve