GLACIER MASS BALANCE BULLETIN

Bulletin No. 3 (1992 - 1993)

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

Compiled by the World Glacier Monitoring Service

IAHS (ICSI) - UNEP - UNESCO
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Edited by

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The cover page shows Djankuat Glacier in Russia (Caucasus) where detailed and precise mass balance studies have been carried out since the mid-1960s. Photo taken by Ye. A. Zolotaryov and V.V. Popovnin on 22 August 1992.

PREFACE

Exactly 100 years ago, in 1894, the Sixth International Geological Congress at Zurich established an International Glacier Commission with the purpose of coordinating worldwide and long-term glacier observations. The goals of this worldwide glacier monitoring programme were defined by F.-A. Forel from Geneva, the first president of the commission, in a remarkable article entitled "Les variations périodiques des glaciers. Discours préliminaire" published on p. 209-229 of the "Archives des Sciences Physiques et Naturelles" (Geneva, Vol. 34). It was hoped that long-term observation of glaciers would provide answers to a fundamental question in the research of climatology and earth sciences at that time, i.e., "what are the mechanisms of modern variations of climate and glaciers; in particular, are glacier fluctuations globally uniform, synchronous and, hence, caused by some extra-terrestrial influences, or are they regionally variable, asynchronous and therefore brought about by terrestrial conditions?"

Since 1894, the goals of internationally coordinated glacier monitoring have evolved and multiplied. Still today, however, the question of global uniformity in glacier evolution trends is a special focus of interest. Glacier signals are now recognized as a valuable element of early detection strategies in view of possible man-induced climate change. In fact, observed glacier fluctuations contribute important information about ranges of natural variability and rates of change with respect to long-term energy fluxes at the earth 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 is broadly consistent with the estimated anthropogenic greenhouse forcing (a few W/m^2). 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)

- 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)

Vol. 7, Fluctuations of Glaciers 1990 - 1995, will be prepared in 1996/97.

The present Glacier Mass Balance Bulletin (MBB) reporting the results for the balance years 1991/92 and 1992/93 is the third 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 fourth Glacier Mass Balance Bulletin will cover the years 1993/94 and 1994/95. It will be prepared in 1996.

Zurich, December 1994

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 58 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 10 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 (next pages). Some glacier names in the former USSR have changed. The old names are given in brackets.

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	Gulkana	USA (Alaska)	Alaska Range	63° 15' N	145° 28' W
4	Wolverine	USA (Alaska)	Kenai Mtns.	60° 24' N	148° 54' W
5	South Cascade	USA	N Cascades Mtns.	48° 22' N	121° 03' W
6	Chacaltaya	Bolivia	Cordillera Real	16° 21' S	68° 07' W
7	Zongo	Bolivia	Cordillera Real	16° 15' S	68° 10' W
8	Hofsjökull North	Iceland	Central Iceland	64° 57' N	18° 55' W
9	Hofsjökull Southwest	Iceland	Central Iceland	64° 43' N	19° 03' W
10	Hofsjökull East	Iceland	Central Iceland	64° 40' N	18° 35' W
11	Austre Brøggerbreen	Norway (Svalbard)	N-Spitsbergen	78° 53' N	11° 50' E
12	Midtre Lovénbreen	Norway (Svalbard)	N-Spitsbergen	78° 53' N	12° 04' E
13	Kongsvegen	Norway (Svalbard)	N-Spitsbergen	78° 50' N	12° 59' E
14	Hansbreen	Norway (Svalbard)	S-Spitsbergen	77° 05' N	15° 40' E
15	Langfjordjøkulen	Norway	North Norway	70° 07' N	21° 45' E
16	Storsteinsfjellbreen	Norway	North Norway	68° 13' N	17° 55' E
17	Trollbergdalsbreen	Norway	North Norway	66° 43' N	14° 27' E
18	Engabreen	Norway	North Norway	66° 39' N	13° 51' E
19	Svartisheibreen	Norway	North Norway	66° 33' N	13° 46' E
20	Okstindbreen	Norway	North Norway	66° 14' N	14° 22' E
21	Austdalsbreen	Norway	South Norway	61° 48' N	7° 21' E
22	Ålfotbreen	Norway	South Norway	61° 45' N	5° 39' E
23	Nigardsbreen	Norway	South Norway	61° 43' N	7° 08' E
24	Gråsubreen	Norway	South Norway	61° 39' N	8° 36' E
25	Storbreen	Norway	South Norway	61° 34' N	8° 08' E
26	Hellstugubreen	Norway	South Norway	61° 34' N	8° 26' E
27	Hardangerjøkulen	Norway	South Norway	60° 32' N	7° 22' E

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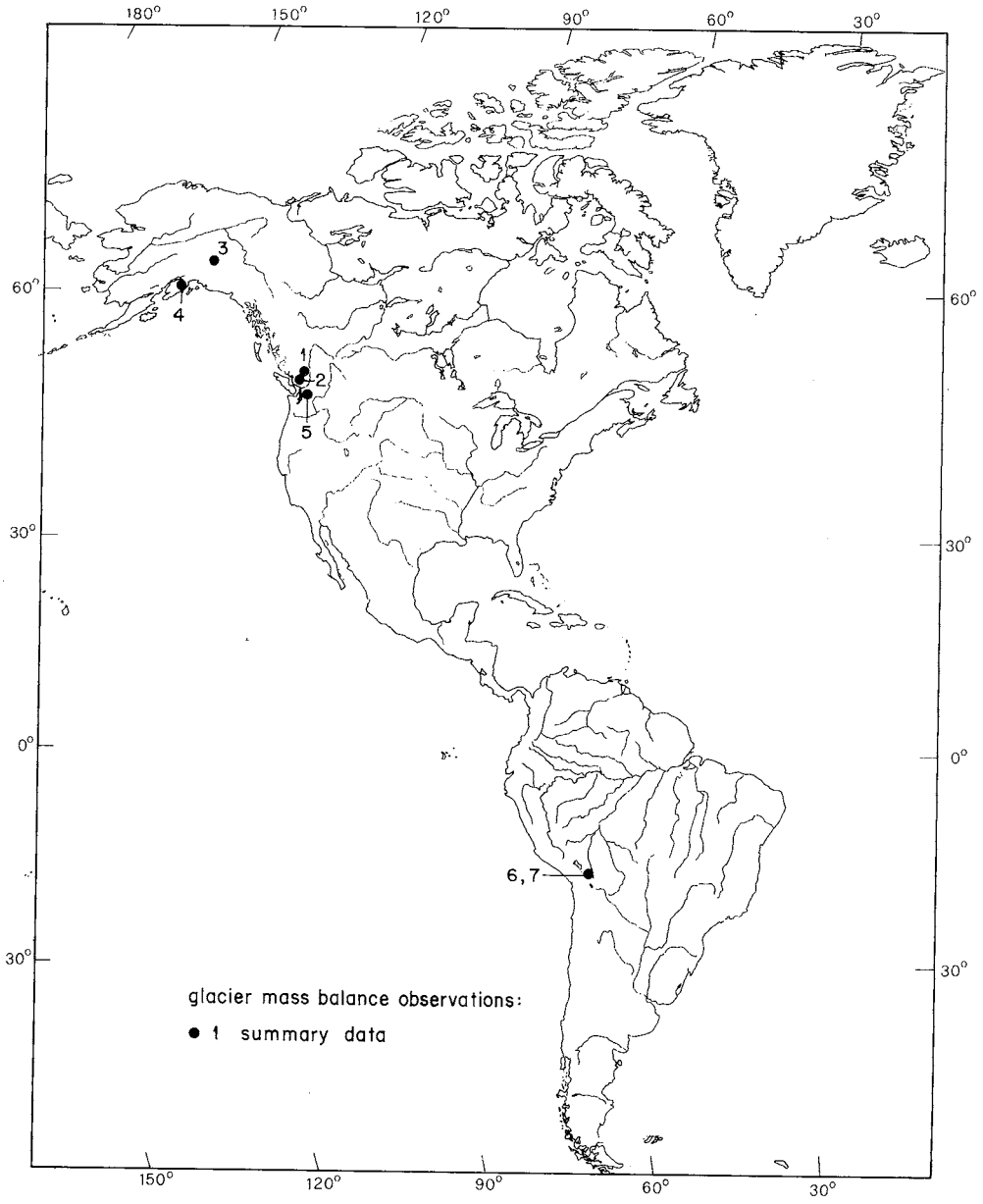
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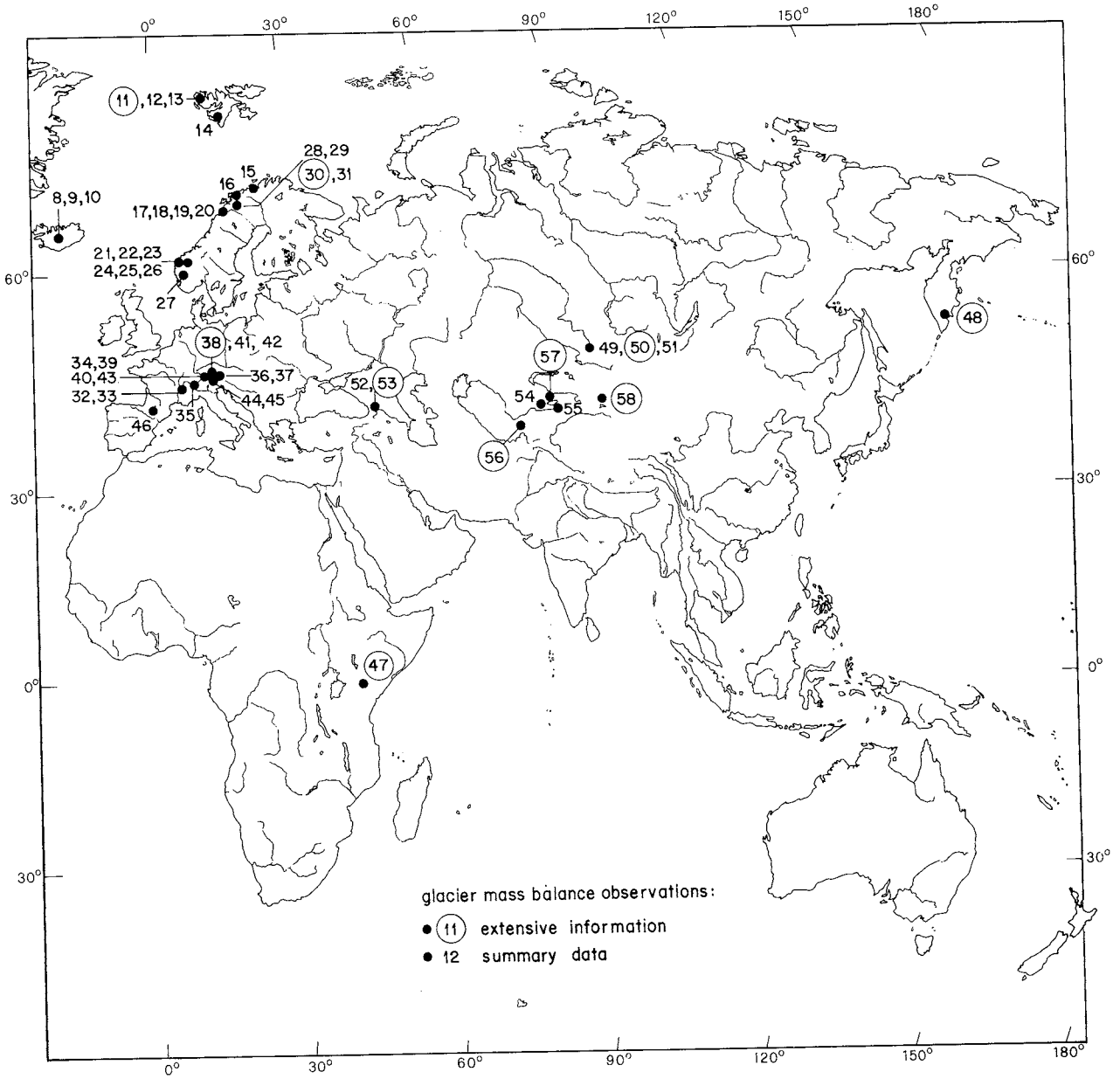
● 1 summary data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glacier mass balance observations:
● (11) extensive information
● 12 summary data

No.	Glacier Name	Country	Location	Coordinates	
28	Riukojietna	Sweden	North Sweden	68° 05' N	18° 05' E
29	Mårmaglaciären	Sweden	North Sweden	68° 05' N	18° 41' E
30	Storglaciären	Sweden	North Sweden	67° 54' N	18° 34' E
31	Rabots glaciär	Sweden	North Sweden	67° 54' N	18° 33' E
32	Saint Sorlin	France	Alps	45° 11' N	6° 10' E
33	Sarennes	France	Alps	45° 07' N	6° 10' E
34	Silvretta	Switzerland	Alps	46° 51' N	10° 05' E
35	Gries	Switzerland	Alps	46° 26' N	8° 20' E
36	Sonnblickkees	Austria	Alps	47° 08' N	12° 36' E
37	Wurtenkees	Austria	Alps	47° 02' N	13° 00' E
38	Vernagtferner	Austria	Alps	46° 53' N	10° 49' E
39	Ochsentalergletscher	Austria	Alps	46° 51' N	10° 06' E
40	Vermuntgletscher	Austria	Alps	46° 51' N	10° 08' E
41	Kesselwandferner	Austria	Alps	46° 50' N	10° 48' E
42	Hintereisferner	Austria	Alps	46° 48' N	10° 46' E
43	Jamtalferner	Austria	Alps	46° 42' N	10° 10' E
44	Fontana Bianca	Italy	Alps	46° 29' N	10° 46' E
45	Careser	Italy	Alps	46° 27' N	10° 42' E
46	Maladeta	Spain	Pyrenees	42° 39 N	0° 38' E
47	Lewis	Kenya	Mount Kenya	00° 09' S	37° 18' E
48	Kozelskiy	Russia	Kamchatka	53° 14' N	158° 49' E
49	No. 125 (Vodopadniy)	Russia	Altai	50° 06' N	87° 42' E
50	Maliy Aktru	Russia	Altai	50° 05' N	87° 45' E
51	Leviy Aktru	Russia	Altai	50° 05' N	87° 41' E
52	Garabashi	Russia	Caucasus	43° 18' N	42° 28' E
53	Djankuat	Russia	Caucasus	43° 12' N	42° 46' E
54	Golubin	Kirghizstan	Tien Shan	42° 27' N	74° 30' E
55	Kara-Batkak (Karabatkak)	Kirghizstan	Tien Shan	42° 08' N	78° 16' E
56	Abramov	Kirghizstan	Pamir-Alai	39° 38' N	71° 34' E
57	Ts. Tuyuksuyskiy (Tuyuksu)	Kazakhstan	Tien Shan	43° 03' N	77° 05' E
58	Urumqihe S. No. 1	China	Tien Shan	43° 05' N	86° 49' E

2. SUMMARY DATA

Specific net balance (b), equilibrium line altitude (ELA) and accumulation area ratio (AAR) of all glaciers from the balance years 1989/90 and 1990/91 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. Reconstructed values were excluded from statistical regression. 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, too, 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.

It is planned to make available in the first issue of a new publication series "World Glacier Monitoring - Updates and Assessments" the complete data set used to calculate the ELA_0/AAR_0 values and which forms the basis of the cumulative specific net balance graphs.

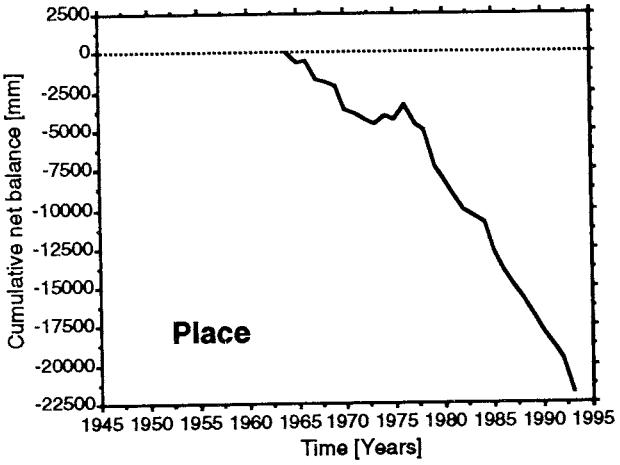
2.1 SUMMARY TABLE (NET BALANCE, ELA, ELA_0, AAR, AAR_0)

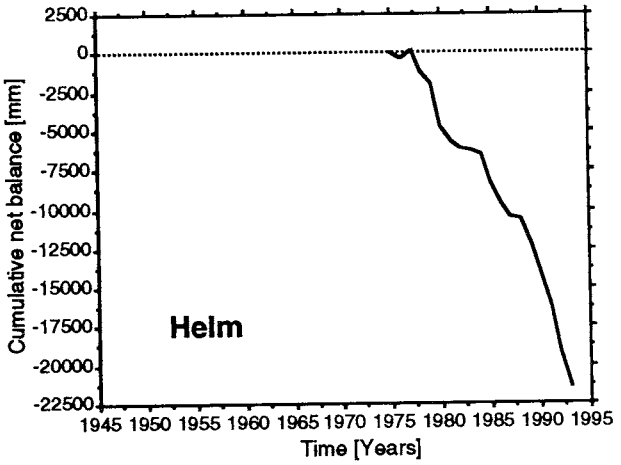
Glacier [1]		Country	b_{92} [mm]	b_{93} [mm]	ELA_{92} [m a.s.l.]	ELA_{93} [m a.s.l.]	ELA_0 [m a.s.l.]	AAR_{92} [%]	AAR_{93} [%]	AAR_0 [%]
Place	(1965)	Canada	- -790	- 2280	2250	2460	2084	25	2	49
Helm	(1975)	Canada	- 2798	- 2342	>2179[2]	>2179[2]	2014	0	0	35
Gulkana	(1966)	USA	- 250	- 1540	1760	1880	1728	60	45	62
Wolverine	(1966)	USA	- 170	- 800	1210	1250	1159	60	57	61
South Cascade	(1953)	USA	- 2010	- 1230	2070	1986		8	17	
Chacaltaya	(1992)	Bolivia	- 1160	+ 231	>5350[2]	5150		0	72	
Zongo	(1992)	Bolivia	- 1380	+ 20	5300	5100		58	86	
Hofjökull North	(1988)	Iceland	+1060	+ 910	1160	1165	1274	67	64	48
Hofsjökull Southwest	(1990)	Iceland	+1190	+ 130	1190	1235		52	45	
Hofsjökull East	(1989)	Iceland	+1610	+1110	1000	1070		72	63	
Austre Brøggerbreen	(1967)	Norway	- 100	- 1030	340	>600[2]	276	39	0	55
Midtre Lovenbreen	(1968)	Norway	- 140	- 880	375	>600[2]	298	40	0	59
Kongsvegen	(1987)	Norway	+ 320	- 380	475	670	538	68	22	56
Hansbreen	(1989)	Norway	- 31	- 243	330	370		45	31	
Langfjordjøkulen	(1989)	Norway	+ 280	+ 80	690	700		68	64	
Storsteinsfjellbreen	(1991)	Norway	+1040	+ 950	1210	1190		86	88	
Trollbergdalsbreen	(1990)	Norway	+ 600	+ 210	<900[3]	1060		100	44	
Engabreen	(1970)	Norway	+2340	+1040	875	990	1165	94	87	57
Svartisheibreen	(1988)	Norway	+1210	+ 910	900	880	1007	81	81	58
Okstindbreen	(1987)	Norway	+1230	+ 190	1260	1290	1295	73	65	64
Austdalsbreen	(1988)	Norway	+ 540	+ 910	1375	1320	1434	80	87	59
Ålfotbreen	(1963)	Norway	+2290	+2180	1050	<870	1199	92	100	55
Nigardsbreen	(1962)	Norway	+1600	+1850	1360	1310	1564	89	92	59
Gråsubreen	(1962)	Norway	- 90	+ 420	2150	<1850[3]	2128	21	100	33
Storbreen	(1949)	Norway	+ 150	+ 690	1690	1620	1708	68	80	60
Hellstugubreen	(1962)	Norway	+ 140	+ 300	1850	1670	1831	62	83	58
Hardangerjøkulen	(1963)	Norway	+1990	+1910	1525	1450	1669	88	92	66
Riukojietna	(1986)	Sweden	+ 586	+ 350	<1150[3]	1300		82	87	
Mårmaglaciären	(1990)	Sweden	+ 90	+ 270	1539	1533		51	54	
Storglaciären	(1946)	Sweden	+ 880	+1000	1393	1397	1462	58	58	46
Rabots glaciär	(1982)	Sweden	+ 110	+ 510	1283	1347	1368	71	57	52
Saint Sorlin	(1959)	France	- 1713	- 1116						
Sarennes	(1949)	France	- 1310	- 1200						
Silvretta	(1960)	Switzerland	- 780	- 50	2942	2778	2765	18	52	53
Gries	(1962)	Switzerland	- 930	- 230	3107	2872	2836	8	56	58
Sonnblickkees	(1959)	Austria	- 2100	- 310	2975	2780	2738	3	44	60
Wurtenkees	(1983)	Austria	- 1250	- 480	>3120[2]	3010		7	15	
Vernagtferner	(1965)	Austria	- 860	- 470	3270	3225	3082	22	37	67
Ochsentalergletscher	(1991)	Austria	- 1120	- 190	>3160[2]	2865		0	60	
Vermuntgletscher	(1991)	Austria	- 1350	- 570	>3140[2]	2950		0	20	
Kesselwandferner	(1953)	Austria	- 410	+ 120	3160	3095	3101	51	73	71
Hintereisferner	(1953)	Austria	- 1120	- 570	3155	3050	2920	24	48	66
Jamtalferner	(1989)	Austria	- 1230	- 370	>3160[2]	2860		7	44	
Fontana Bianca	(1984)	Italy	- 1091	- 556	>3440[2]	>3440[2]		10	13	
Careser	(1967)	Italy	- 1200	- 300	3315	3148	3094	0	14	48
Maladeta	(1992)	Spain	- 327	- 32	3090	3066		26	35	
Lewis[4]	(1979)	Kenya	- 1750	- 480	>5000[2]	4790	4792	0	44	58
Kozelskiy	(1973)	Russia	- 410	- 350	1635	1620	1435	45	47	52
No. 125 (Vodopadniy)	(1977)	Russia	- 20	+ 100	3220	3170	3217	72	80	64
Maliy Aktru	(1962)	Russia	- 170	+ 340	3230	3180	3136	67	76	70
Leviy Aktru	(1977)	Russia	- 190	+ 240	3240	3070	3154	56	72	60
Garabashi	(1987)	Russia	+ 140	+ 310	3780	3630	3847	66	80	59
Djankuat	(1968)	Russia	- 130	+1100	3220	3020	3190	60	79	60
Golubin	(1969)	Kirghizstan	- 454	- 276	3830	3810	3804	63	63	74
Kara-Batkak	(1957)	Kirghizstan	- 352	- 185	3820	3750	3831	61	68	57
Abramov	(1968)	Kirghizstan	+ 400	+ 300	4110	4120	4154	68	66	59
Ts. Tuyuksuyskiy	(1957)	Kazakhstan	- 240	+ 602	3800	3632	3742	38	80	53
Urumqihe S. No. 1	(1959)	China	+ 23	- 29	3975	3984	4021	68	69	56

1) Numbers in brackets behind the glacier names indicate the beginning of continuous mass balance records.
2) Above glacier maximum elevation.
3) Below glacier minimum elevation.
4) Note that the balance year here starts in March of the year indicated.

2.2 CUMULATIVE SPECIFIC NET BALANCES

CANADA:





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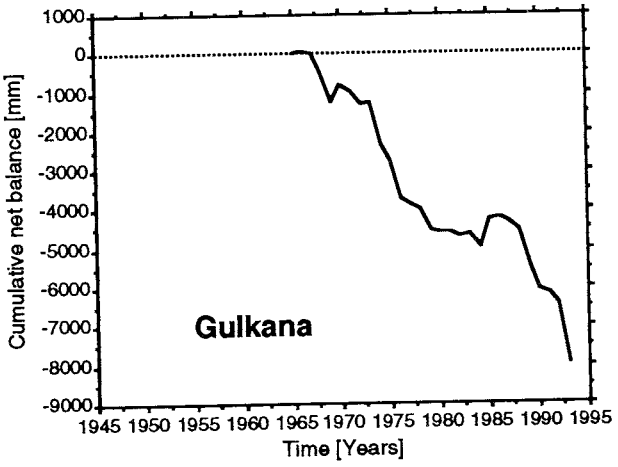

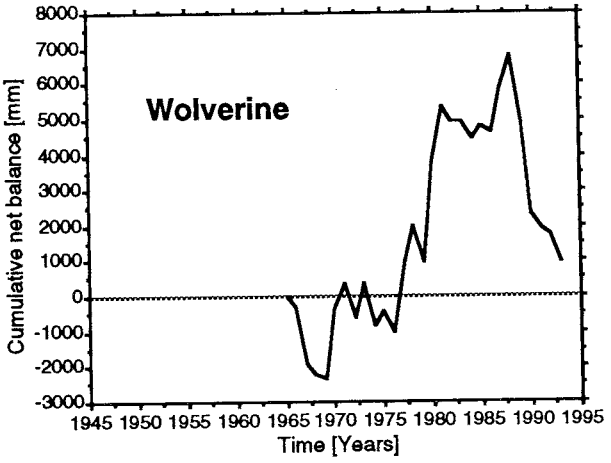

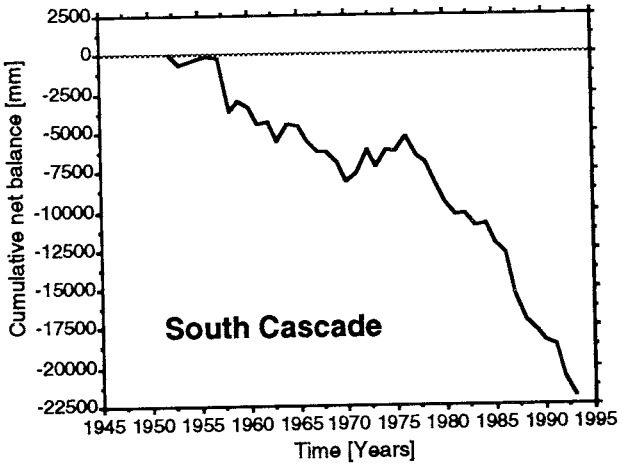

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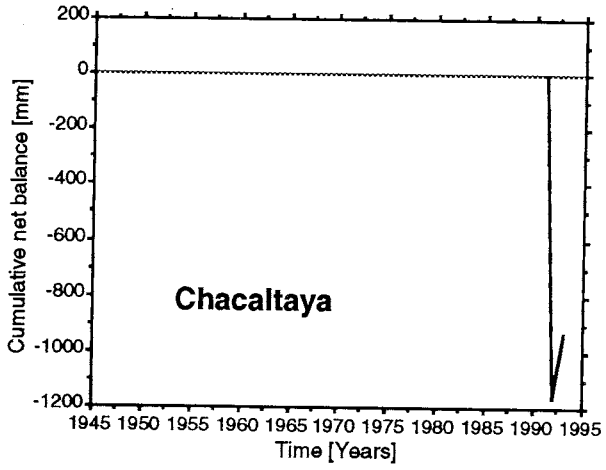

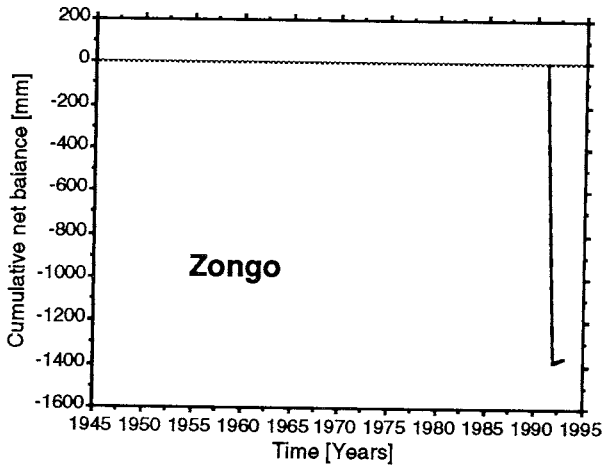

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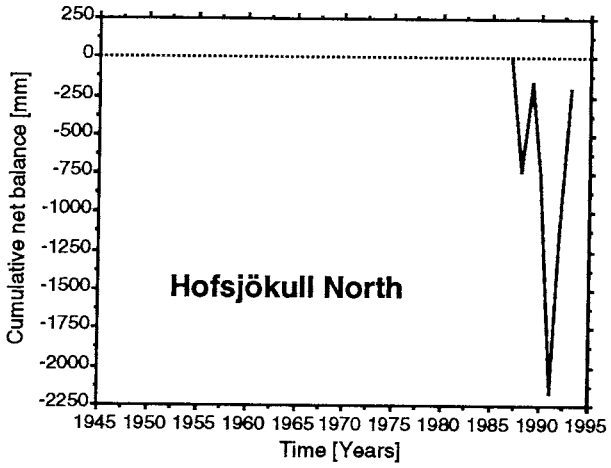

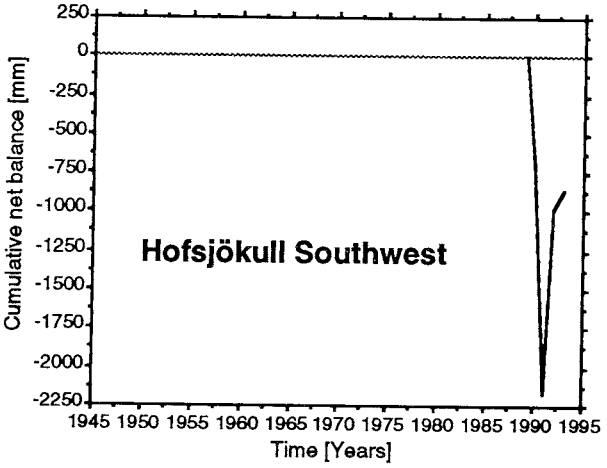

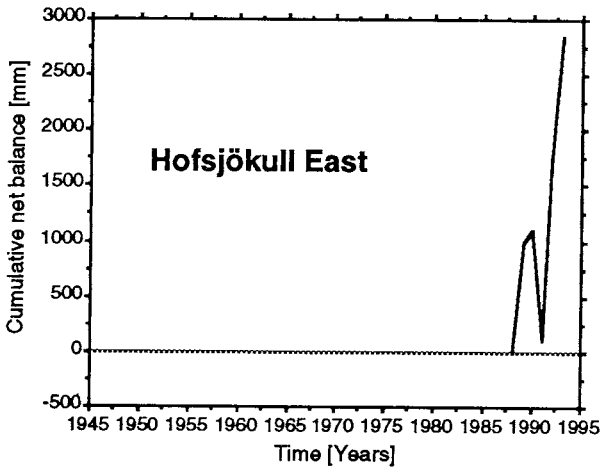

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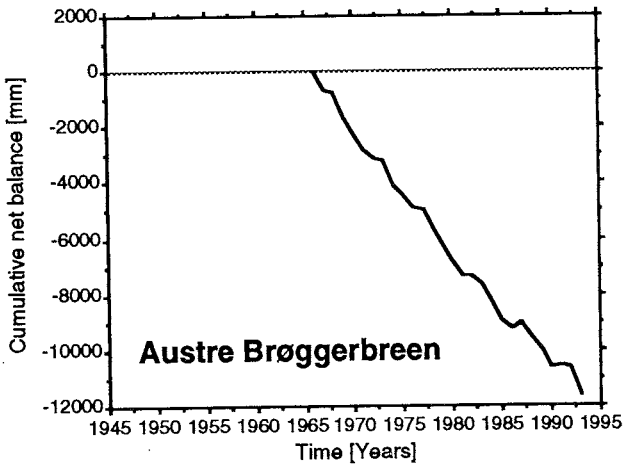

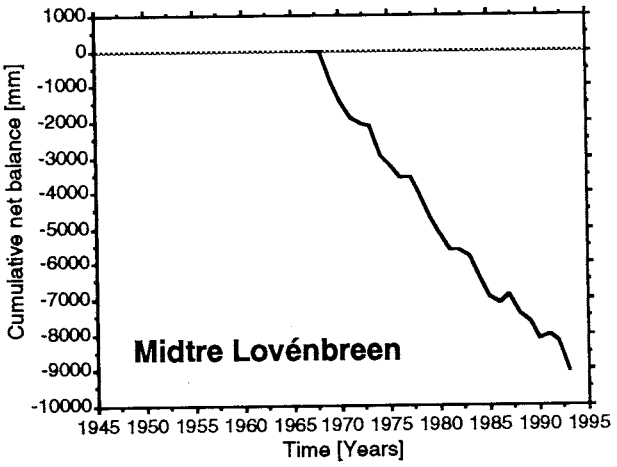

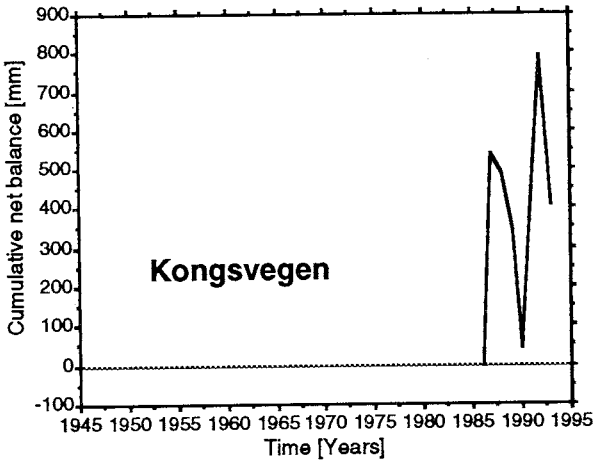

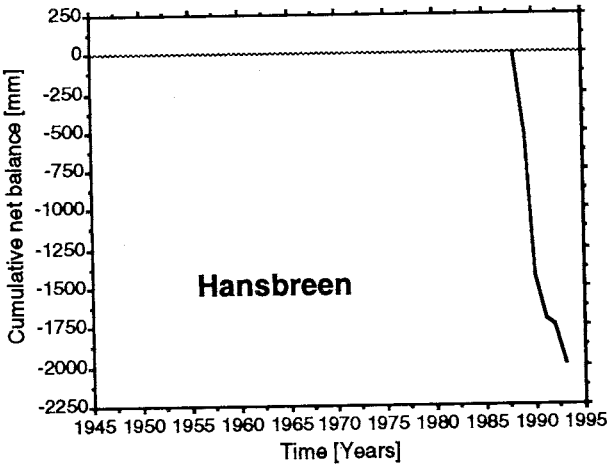

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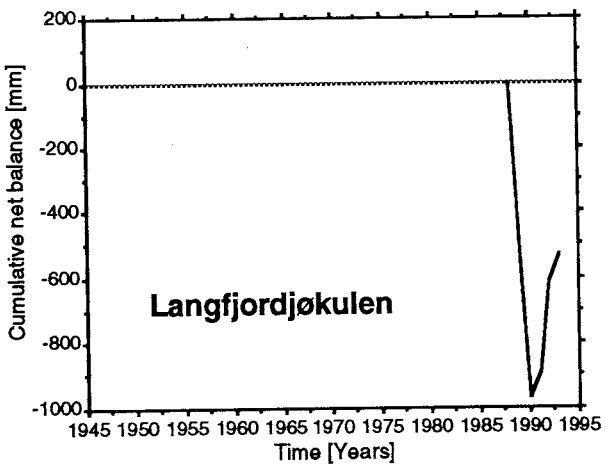

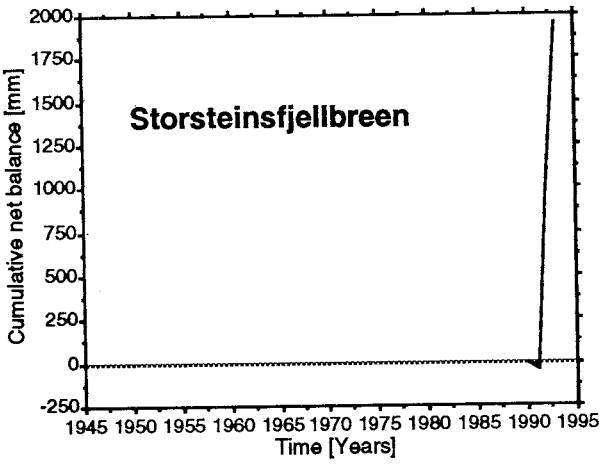

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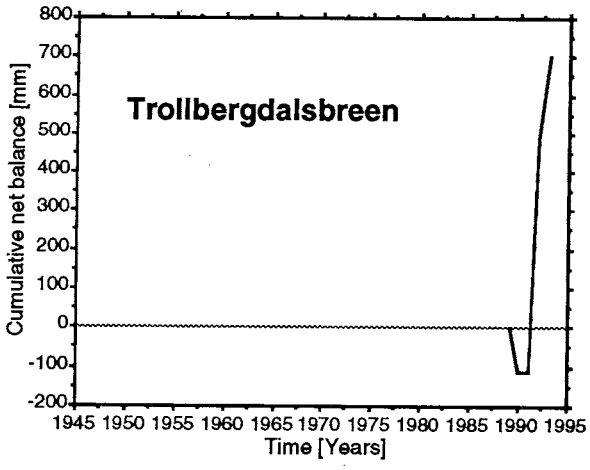
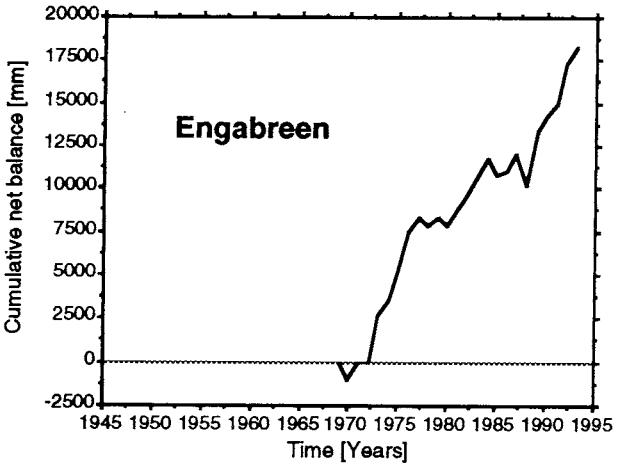
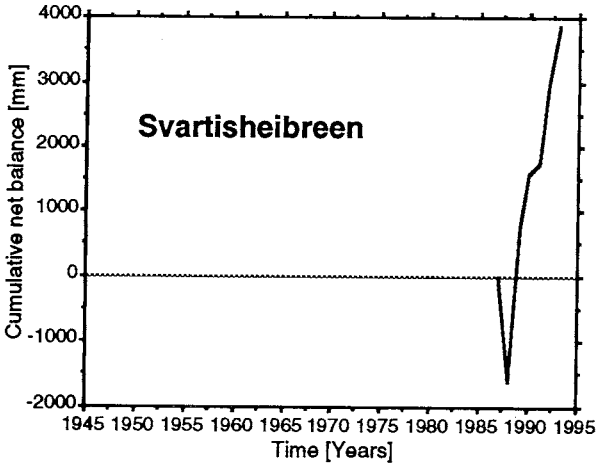
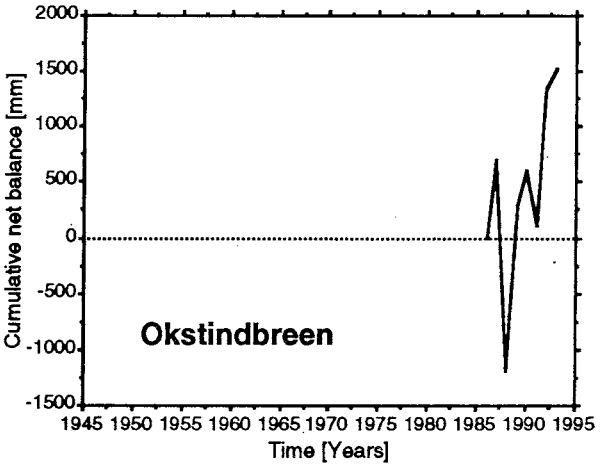
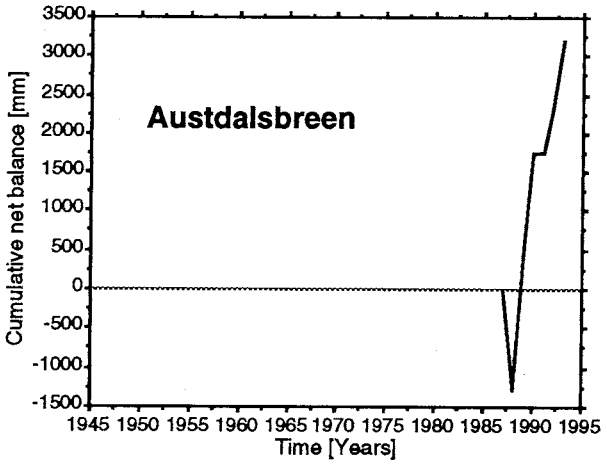
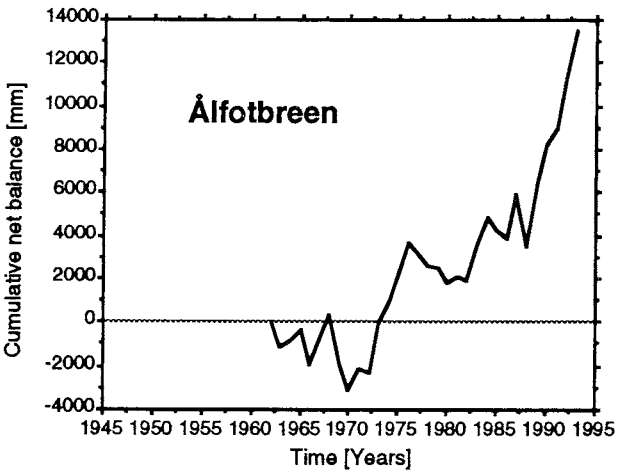

Trollbergdalsbreen
Cumulative net balance [mm]
800
700
600
500
400
300
200
100
0
-100
-200
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]


Engabreen
Cumulative net balance [mm]
20000
17500
15000
12500
10000
7500
5000
2500
0
-2500
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

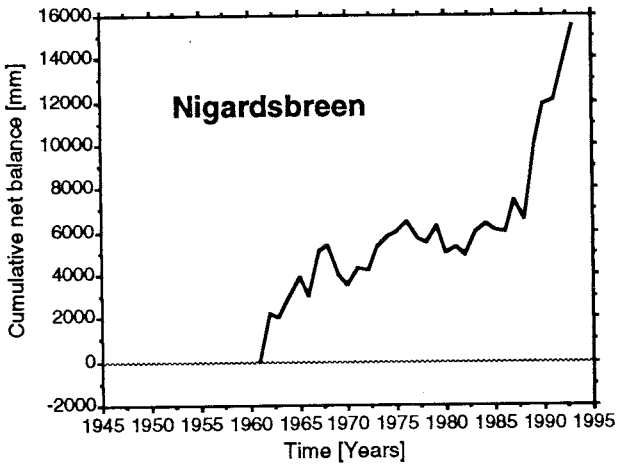

Svartisheibreen
Cumulative net balance [mm]
4000
3000
2000
1000
0
-1000
-2000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

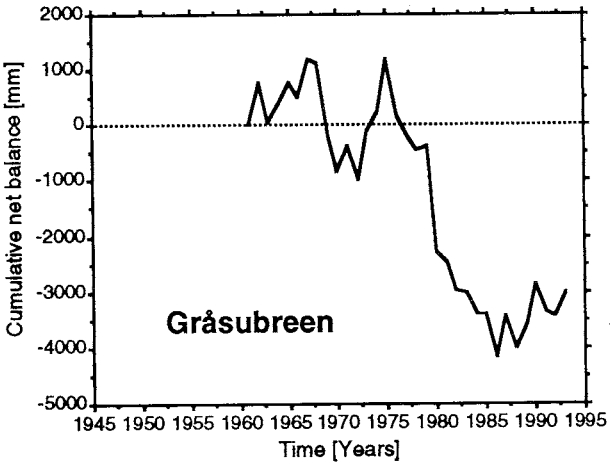

Okstindbreen
Cumulative net balance [mm]
2000
1500
1000
500
0
-500
-1000
-1500
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

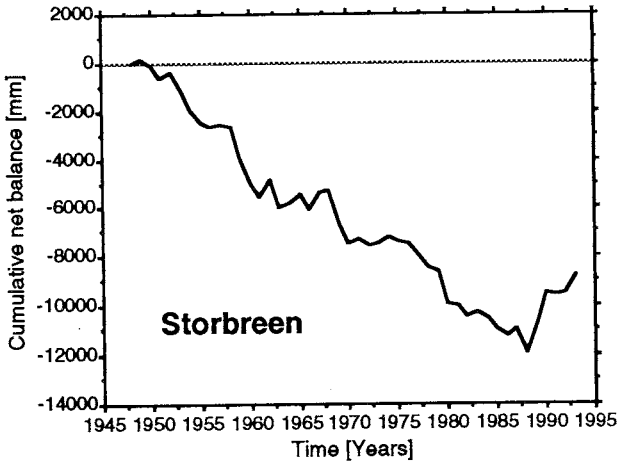

Austdalsbreen
Cumulative net balance [mm]
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

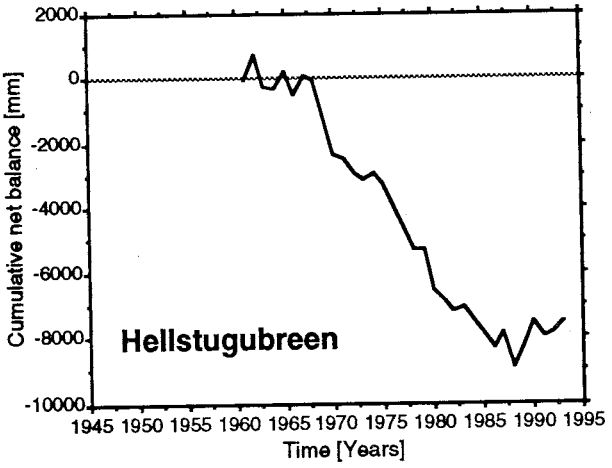

Ålfotbreen
Cumulative net balance [mm]
14000
12000
10000
8000
6000
4000
2000
0
-2000
-4000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

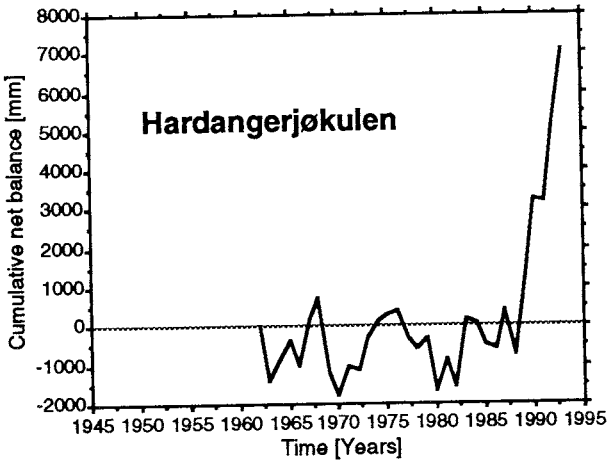
NORWAY:


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

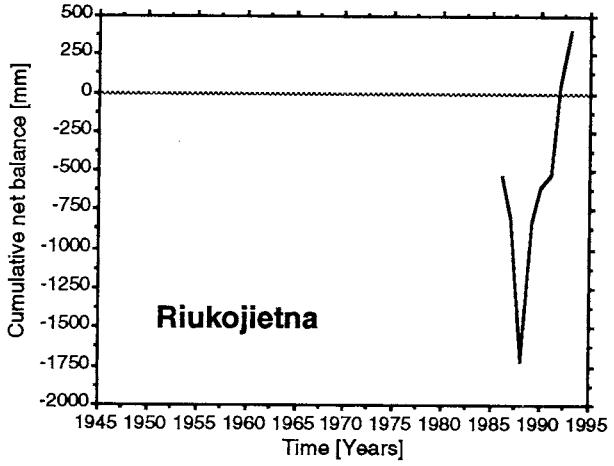

Gråsubreen
Cumulative net balance [mm]
Time [Years]
2000
1000
0
-1000
-2000
-3000
-4000
-5000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

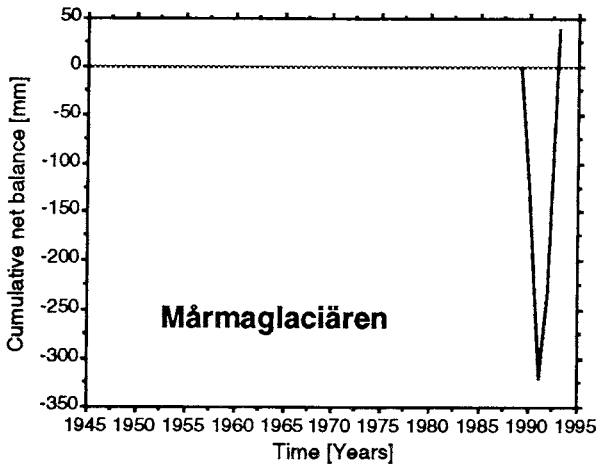

Storbreen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
-14000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

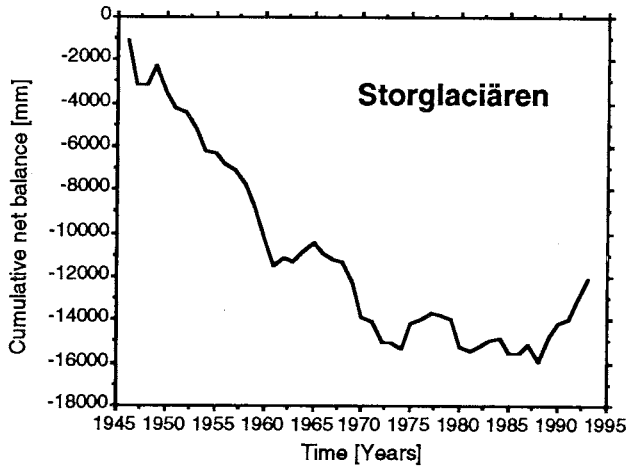

Hellstugubreen
Cumulative net balance [mm]
Time [Years]
2000
0
-2000
-4000
-6000
-8000
-10000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

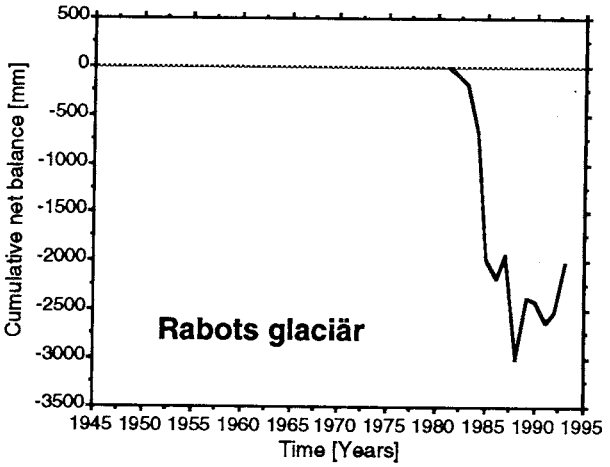

Hardangerjøkulen
Cumulative net balance [mm]
Time [Years]
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995

SWEDEN:

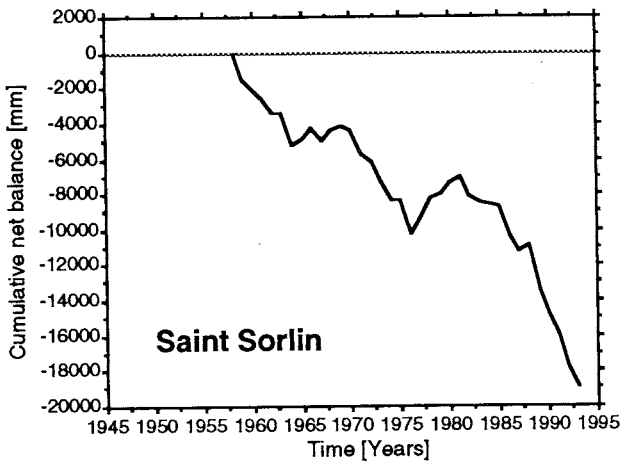

Riukojietna
Cumulative net balance [mm]
500
250
0
-250
-500
-750
-1000
-1250
-1500
-1750
-2000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

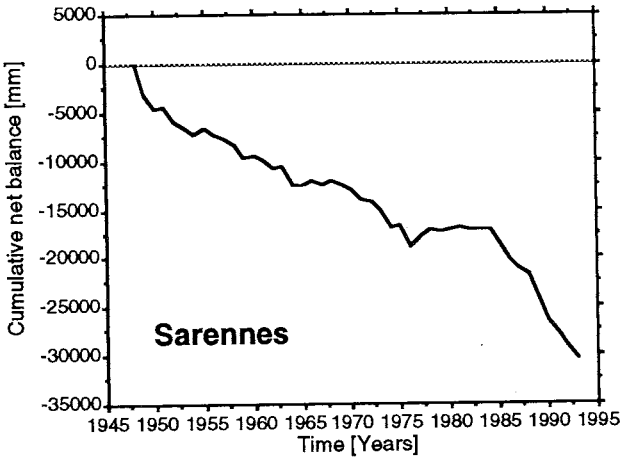

Mårmaglaciären
Cumulative net balance [mm]
50
0
-50
-100
-150
-200
-250
-300
-350
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]


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


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

FRANCE:





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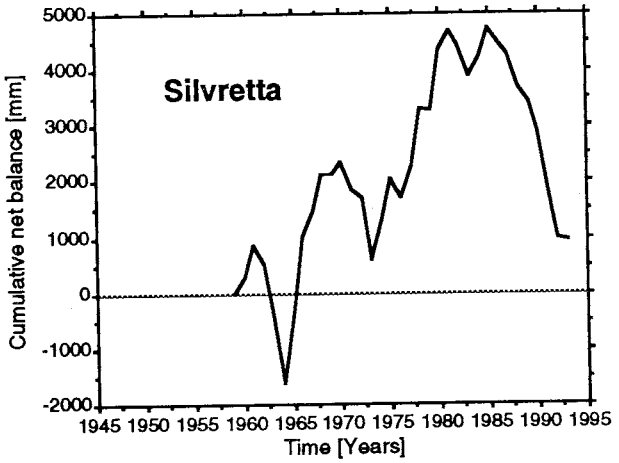

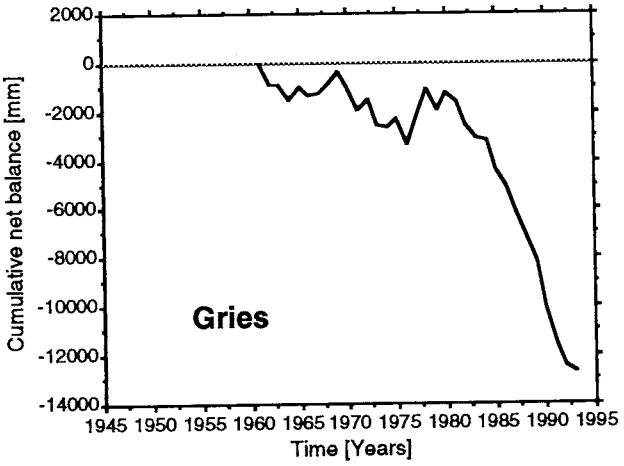

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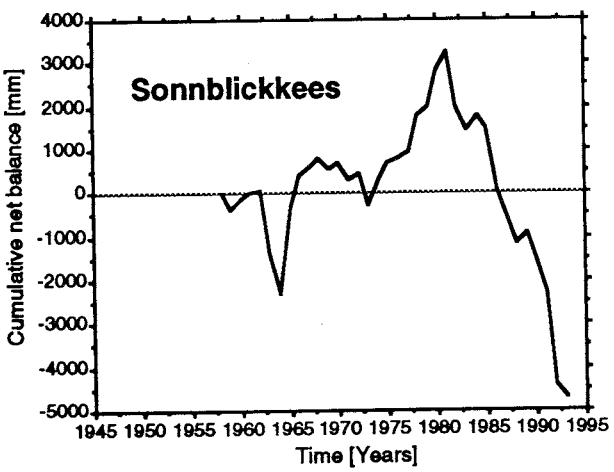

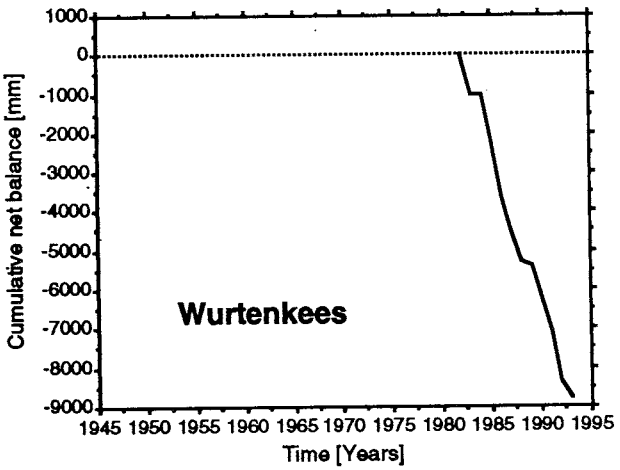

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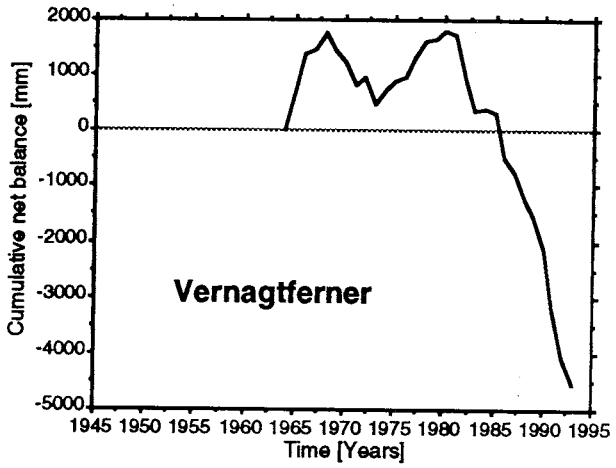
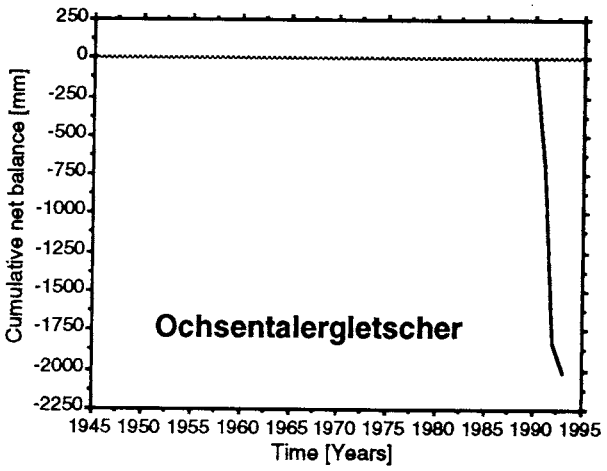
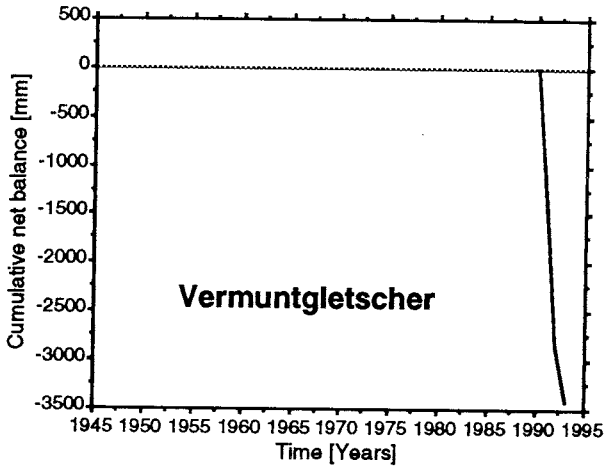
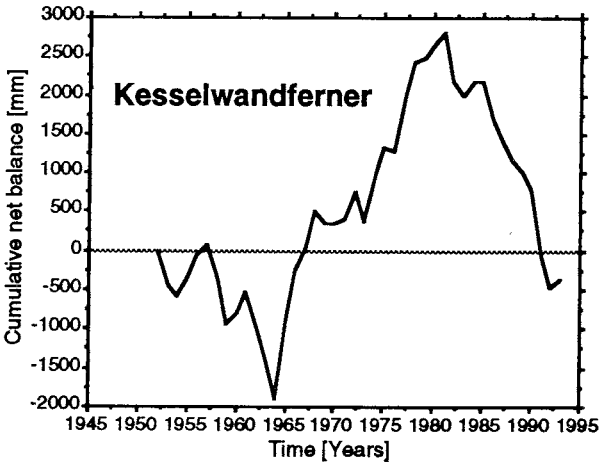
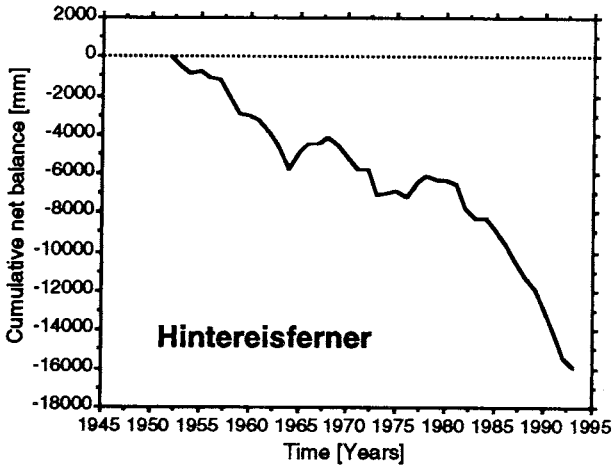
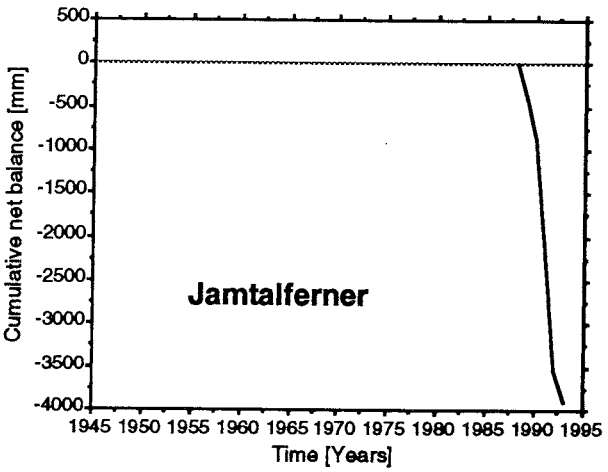

Vernagtferner
Cumulative net balance [mm]
2000
1000
0
-1000
-2000
-3000
-4000
-5000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]


Ochsentalergletscher
Cumulative net balance [mm]
250
0
-250
-500
-750
-1000
-1250
-1500
-1750
-2000
-2250
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

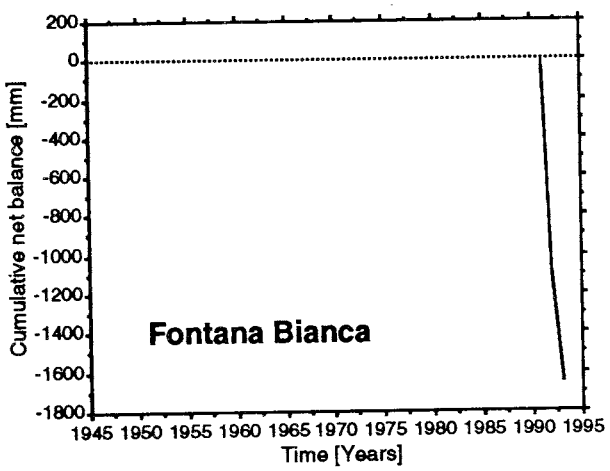

Vermuntgletscher
Cumulative net balance [mm]
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]

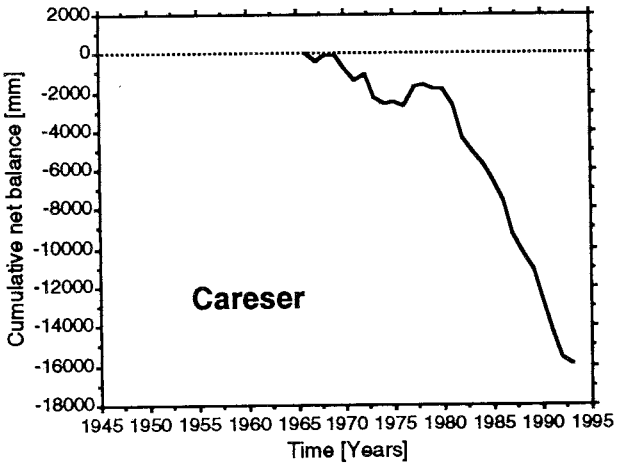

Kesselwandferner
Cumulative net balance [mm]
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Time [Years]


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


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

ITALY:





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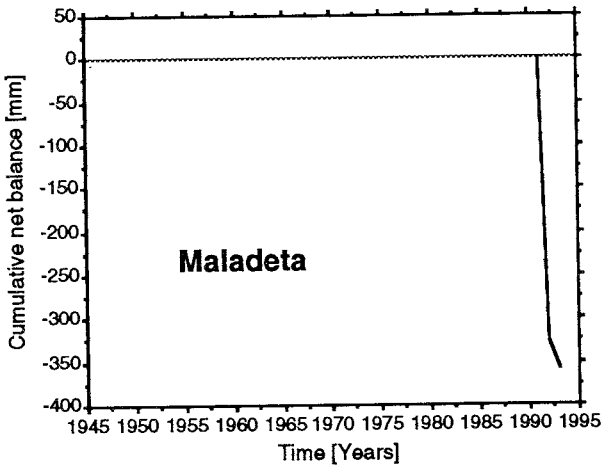
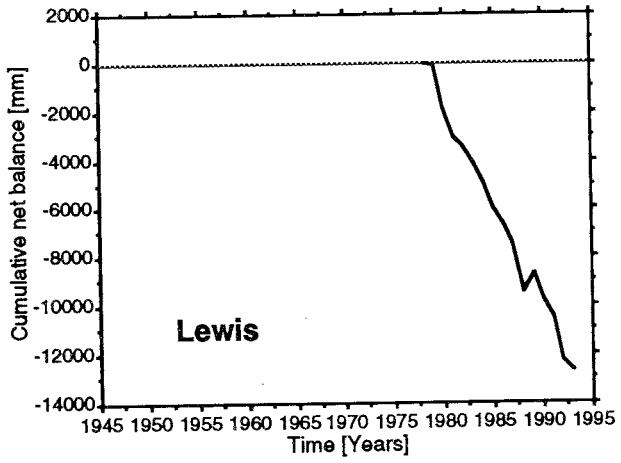


KENYA:



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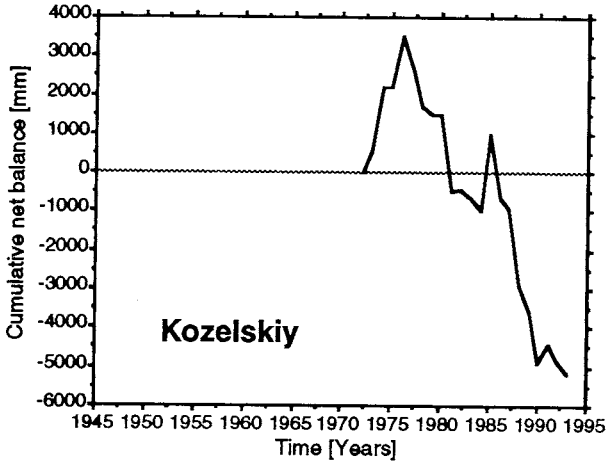
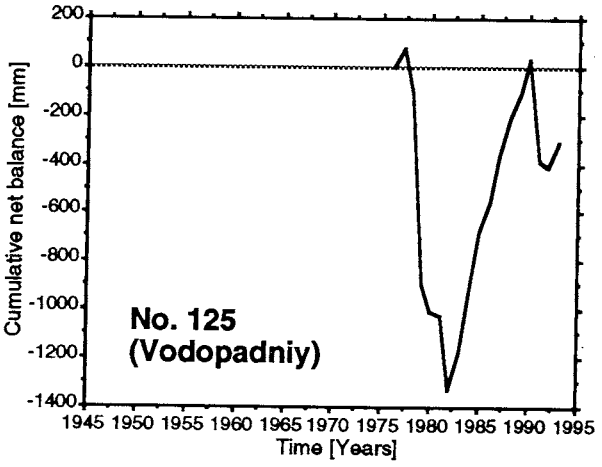
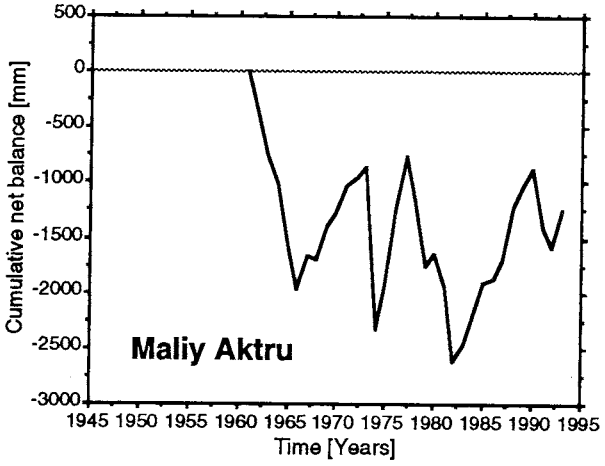
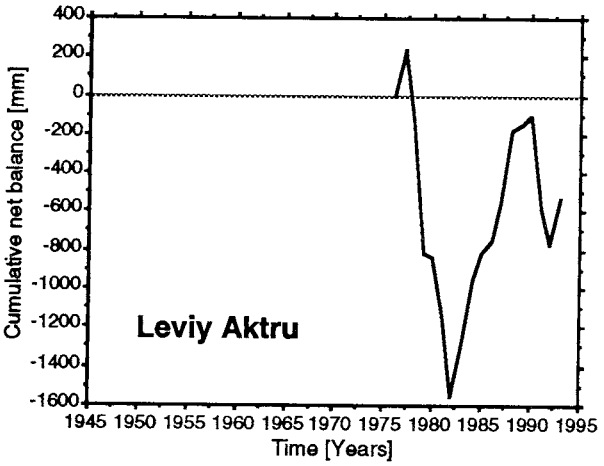
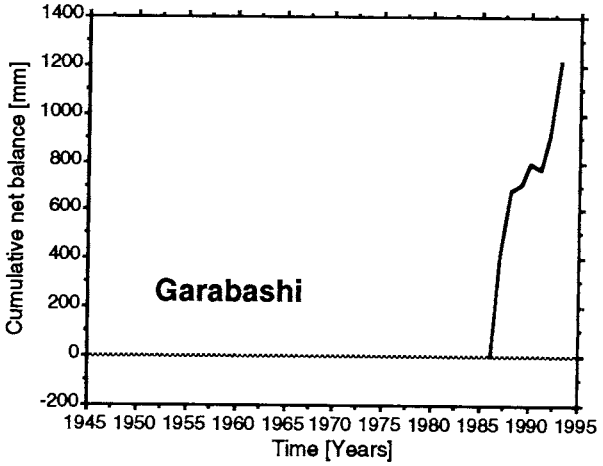
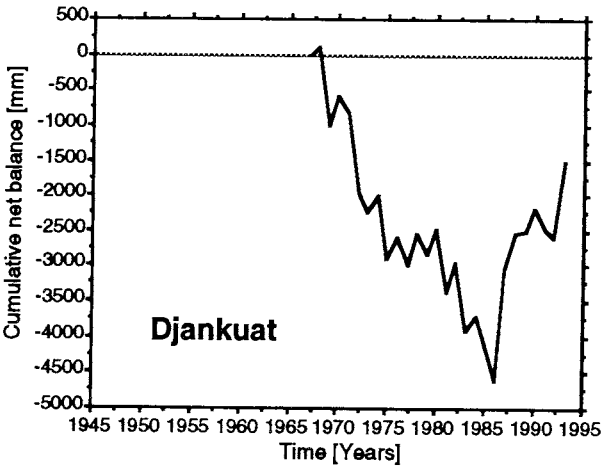

Kozelskiy
Cumulative net balance [mm]
Time [Years]


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

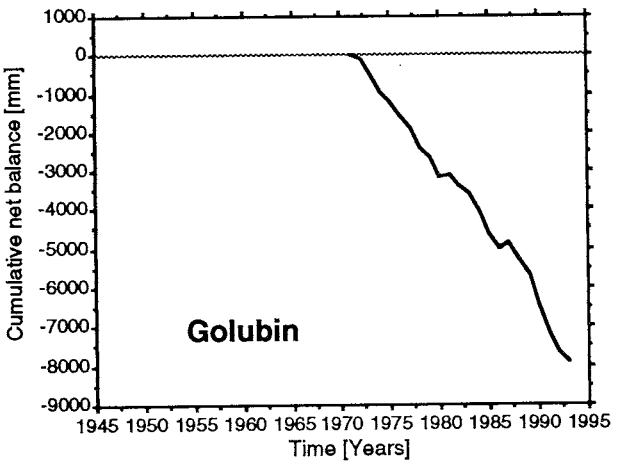

Maliy Aktru
Cumulative net balance [mm]
Time [Years]

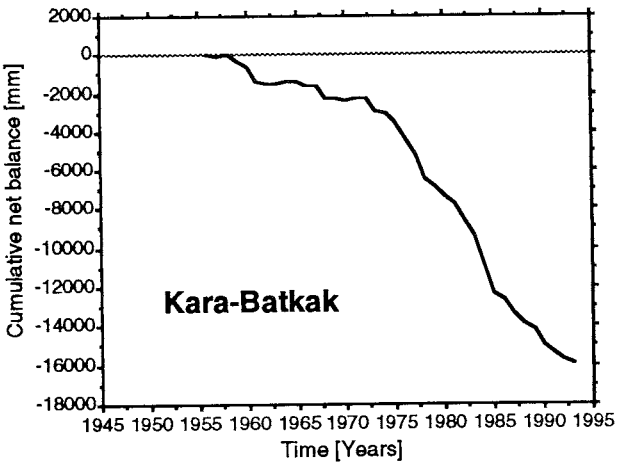

Leviy Aktru
Cumulative net balance [mm]
Time [Years]

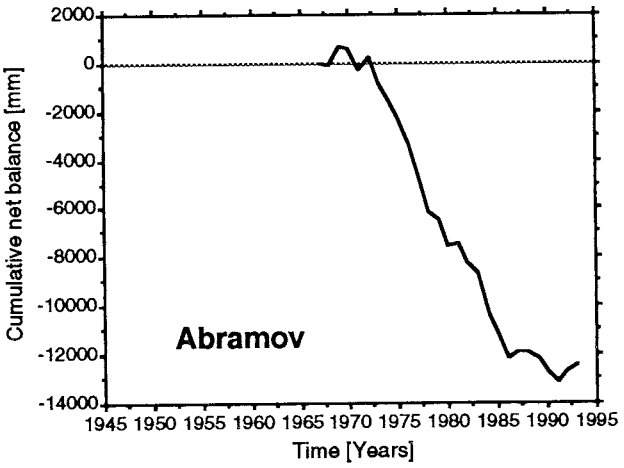

Garabashi
Cumulative net balance [mm]
Time [Years]


Djankuat
Cumulative net balance [mm]
Time [Years]

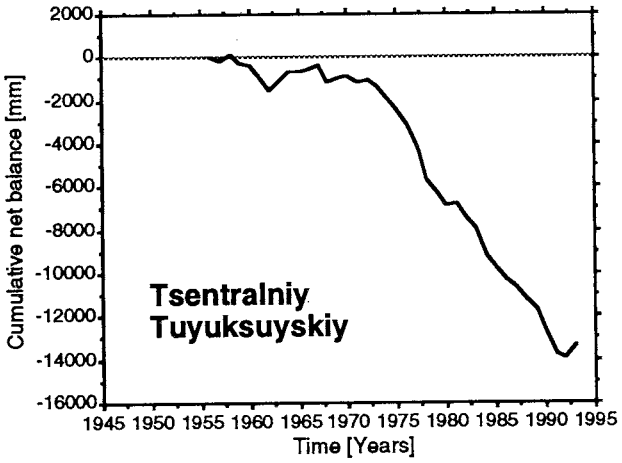
KIRGHIZSTAN:



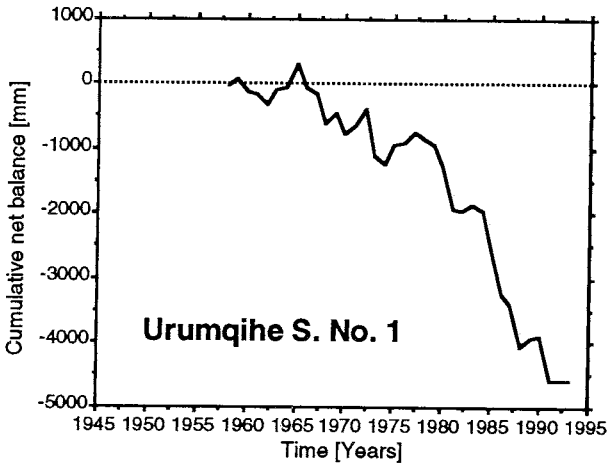




KAZAKHSTAN:



CHINA:


1000
0
-1000
-2000
-3000
-4000
-5000
Cumulative net balance [mm]
Urumqihe S. No. 1
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
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 final version of the data presentation was then revised by the national correspondents again.

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 1992/93. The second and third maps are balance maps from the years 1991/92 and 1992/93 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 (1991/92, 1992/93) are specially marked in the plots.

With Austre Brøggerbreen (Svalbard) an arctic glacier could be included. On the other hand, no extensive information could be obtained on Place glacier. New programmes have been started in the Pyrenees and in the Bolivian Andes. It is hoped that corresponding information can be published in forthcoming issues of the Bulletin.

3.1 AUSTRE BRØGGERBREEN (NORWAY/SVALBARD)

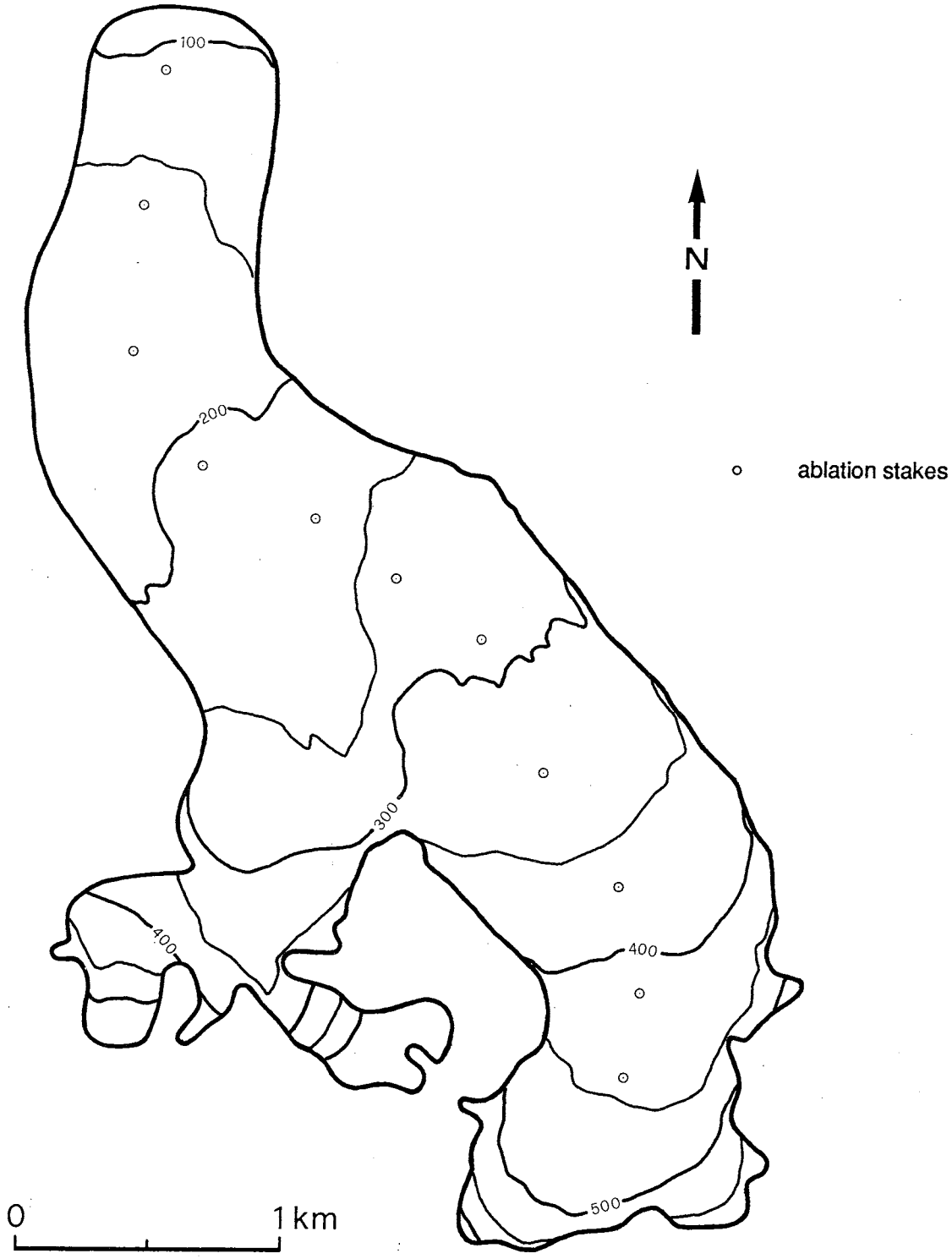
COORDINATES: 78°53' N / 11°50' E

Photo taken by Jon Tolgensbakk (University of Oslo, in August 1989

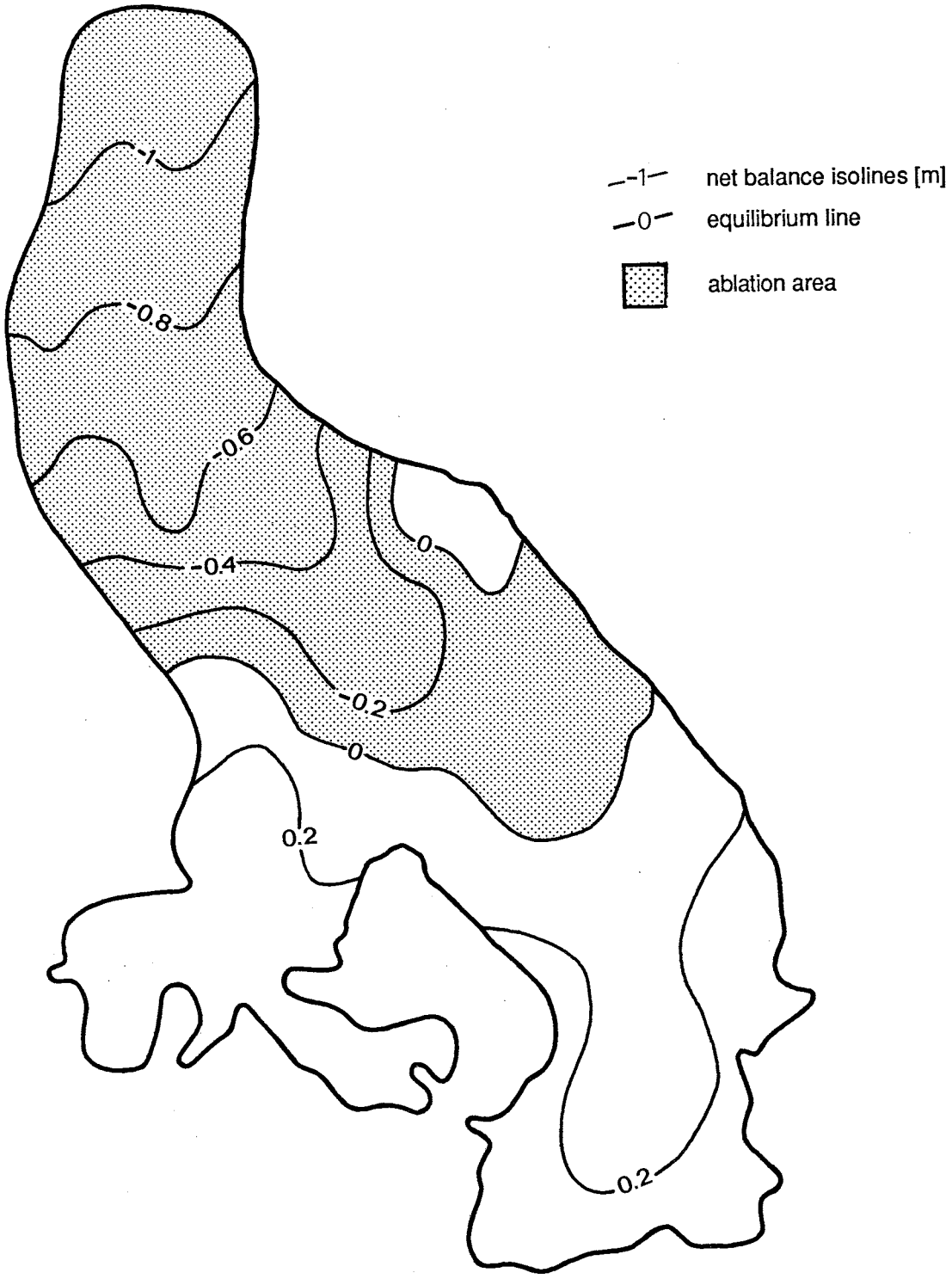
Austre Brøggerbreen in the north-western part of Spitsbergen (Svalbard) is a valley or cirque-type glacier extending from 600 to 50 m a.s.l. Its surface has an area of 11.8 km^2 and is mainly exposed to the north. The glacier is composed of more than one firn area but the mass balance measurements are carried out on the well-defined eastern part of it, covering 6.1 km^2. Annual mean air temperature at the equilibrium line (around 300 m a.s.l.) is about -8°C and the glacier is predominantly cold, with only the deepest part being temperate. Average annual precipitation at the nearby meteorological station at Ny-Ålesund (40 m a.s.l.) is just below 400 mm. Periglacial permafrost is continuous.

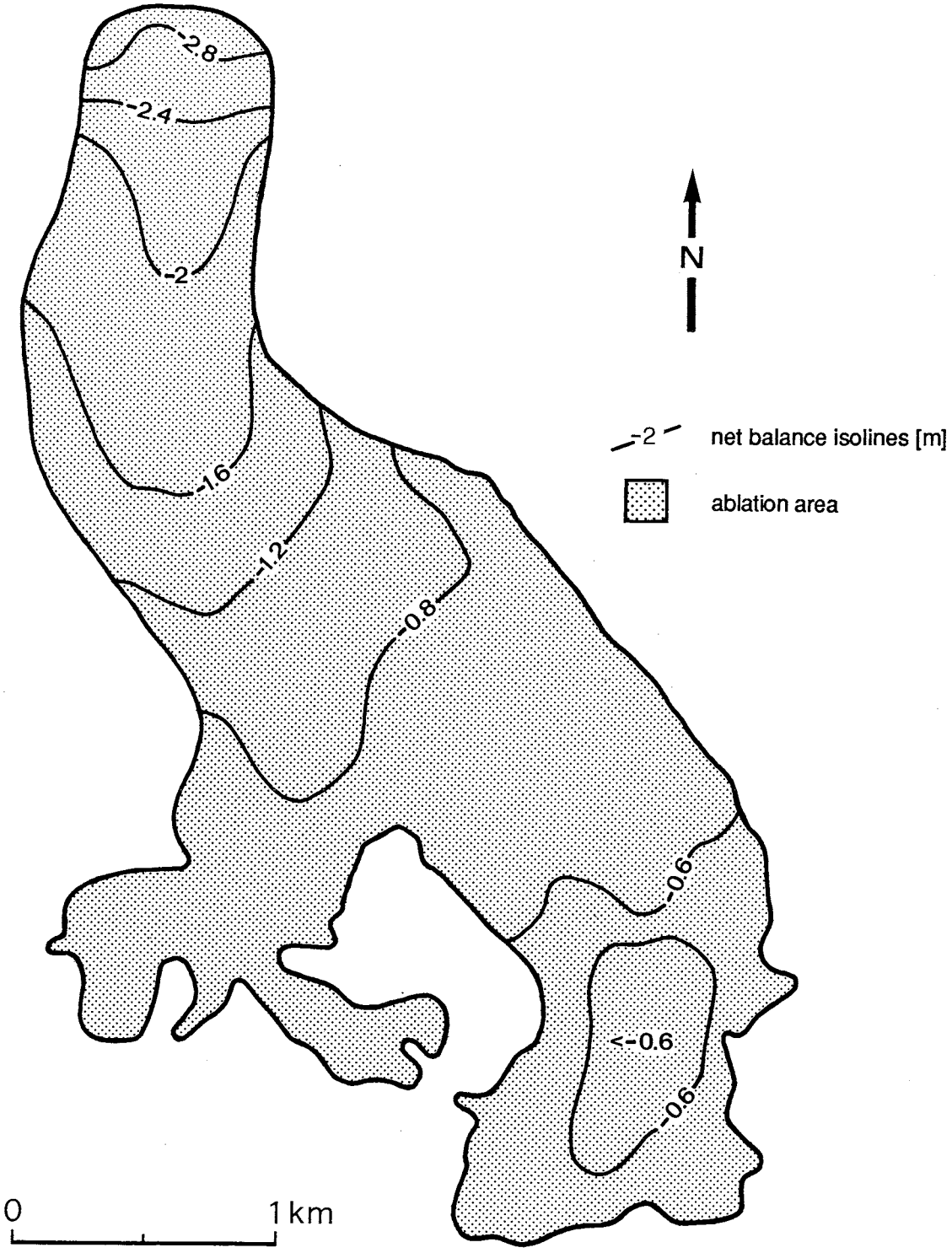
The balance year 1991/92 gave a net mass loss of -0.10 m water equivalent. This value is less negative than the average of -0.43 m water equivalent for the observation period 1967 - 1993. The accumulation was close to normal while summer ablation was slightly below average. With a mass loss of -1.03 m water equivalent, on the other hand, the balance year 1992/93 was the most negative year since the beginning of the measurements. This is due to a low winter accumulation (0.54 m water equivalent or 75% of the average) and an extremely high ablation (1.57 m water equivalent or 137% of the average) during summer. The equilibrium line was above the highest point of the glacier.

3.1.1 Topography and observational network

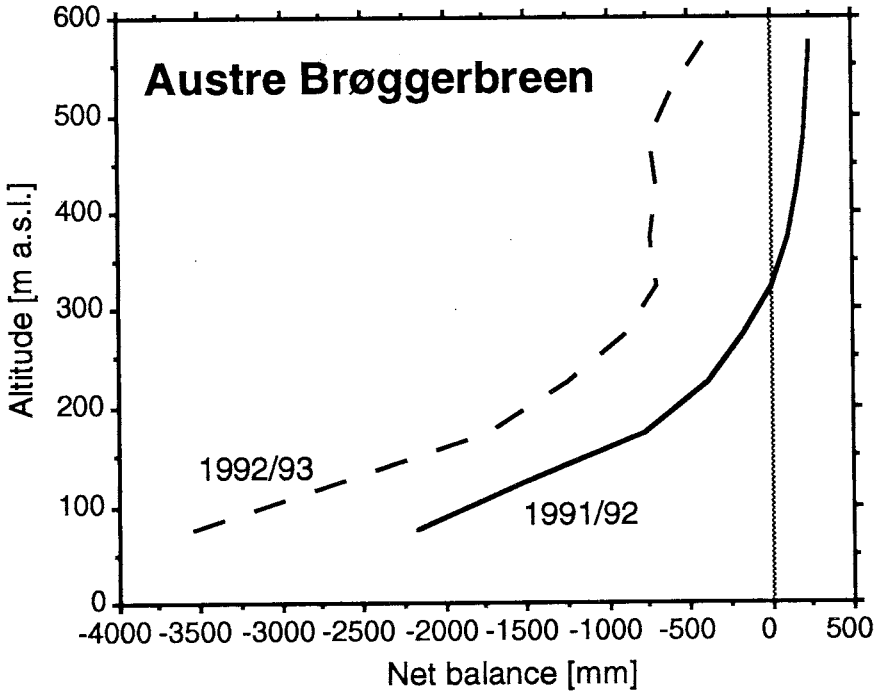


3.1.2 Net balance maps 1991/92 and 1992/93

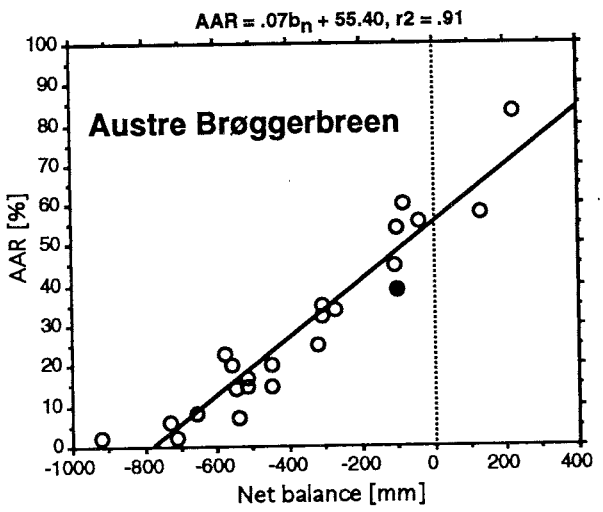


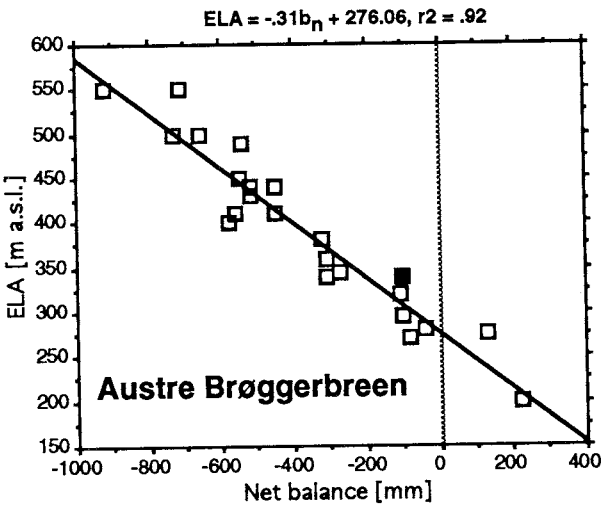

-2.8
-2.4
-2
-1.6
-1.2
-0.8
-0.6
<-0.6
-0.6
N
-2
net balance isolines [m]
ablation area
0
1 km

3.1.3 Net balance versus altitude (1991/92 and 1992/93)



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





3.2 STORGLACIÄREN (SWEDEN)

COORDINATES: 67° 54' N / 18° 34' E

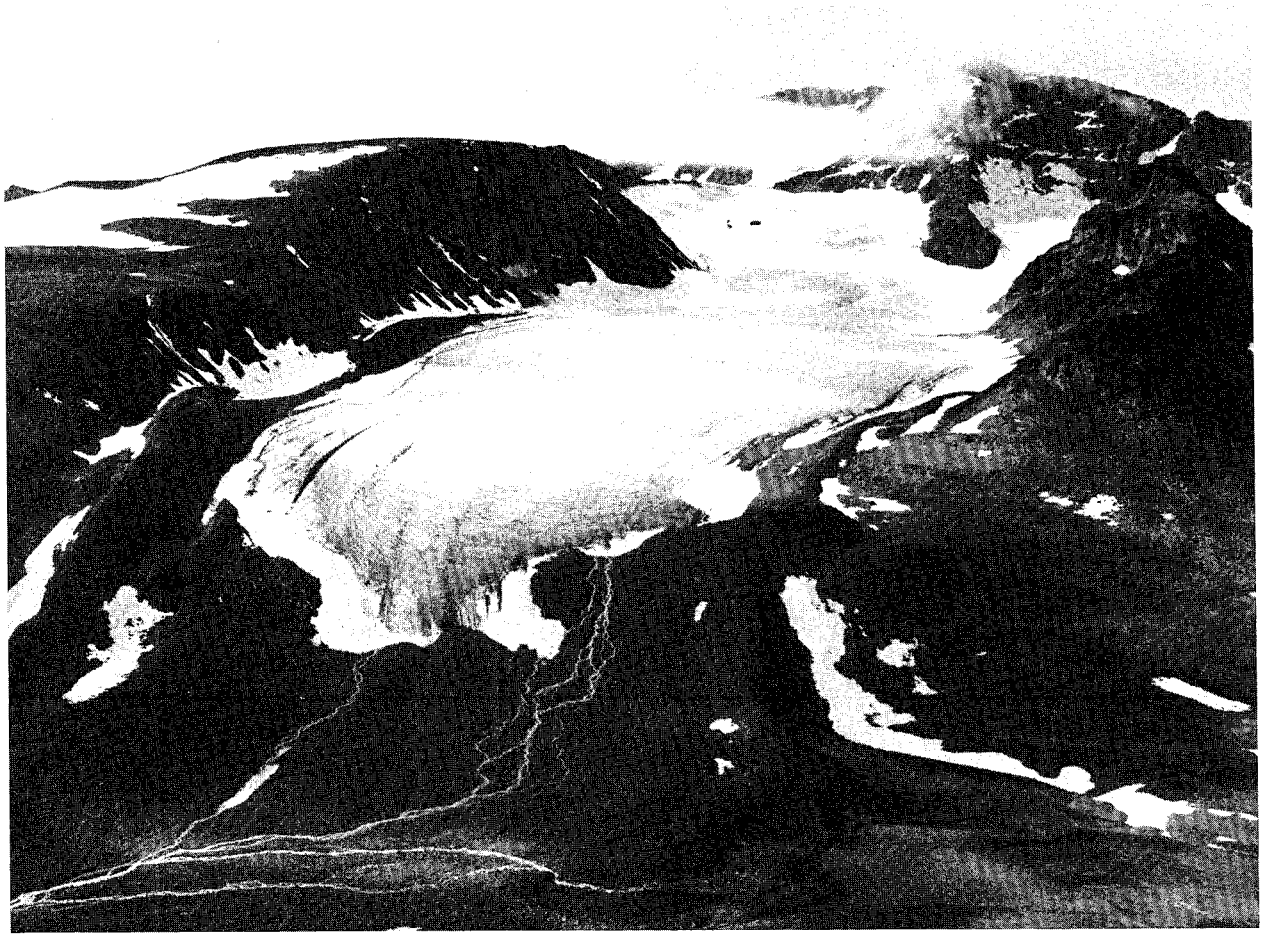
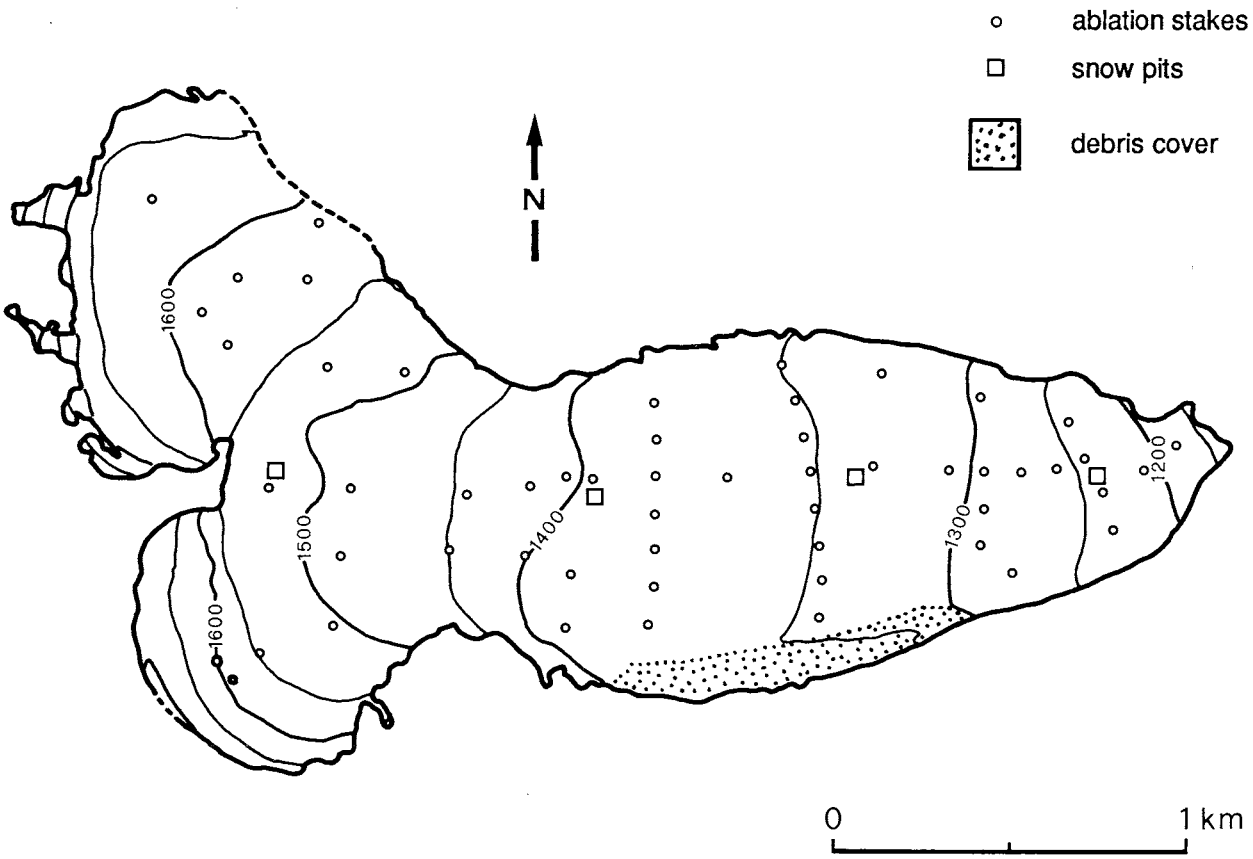


Photo taken by P. Holmlund in August 1987.

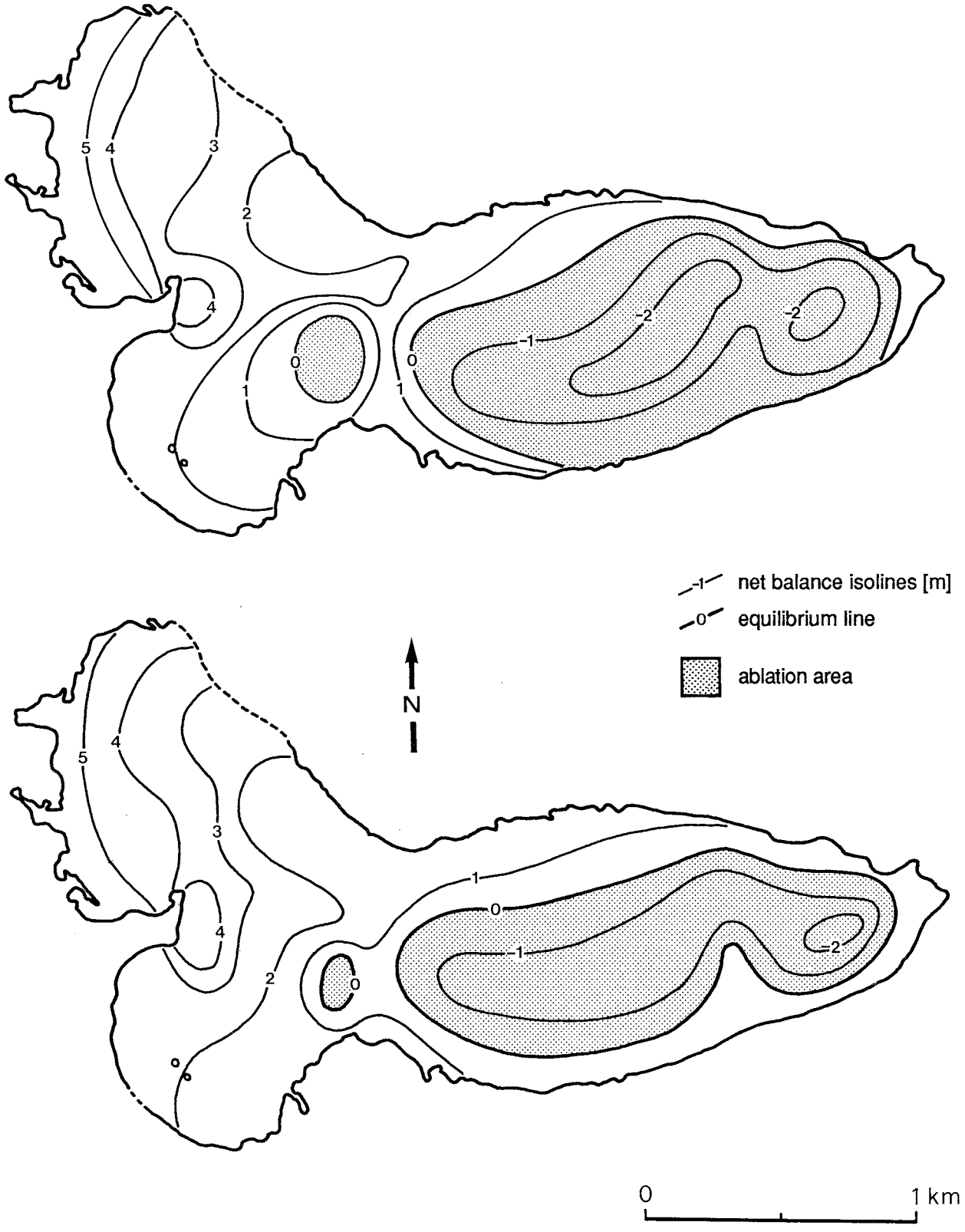
Storglaciären in the Kebnekaise Mountains, northern Sweden, is a small valley-type glacier with a divided accumulation area and a smooth longitudinal profile. It is exposed to the E, maximum and minimum elevations are 1,750 and 1,130 m a.s.l. and its surface area is 3.12 km^2. Annual mean air temperature at the equilibrium line of the glacier (around 1,500 m a.s.l.) is about -6 °C. The glacier is mainly temperate with a cold surface layer in its lower parts and ends in discontinuous permafrost. Average annual precipitation is about 1,000 mm at the nearby Tarfala Research Station.

The budget years of 1991/92 and 1992/93 showed the same pattern as the previous years with very high accumulation rates and about average ablation rates. Steeper than normal balance gradients indicate a maritime influence. Mass gain amounted to 0.88 m water equivalent in 1991/92 and to 1.0 m water equivalent in 1992/93. A snow radar was successfully used in addition to manual probing in order to determine snow accumulation in spring 1993. Rather extreme wind speeds (up to a peak of 81 m/s) were recorded during the stormy winter of 1992/93. Three houses at the Tarfala Research Station were damaged and had to be rebuilt in the summer of 1993.

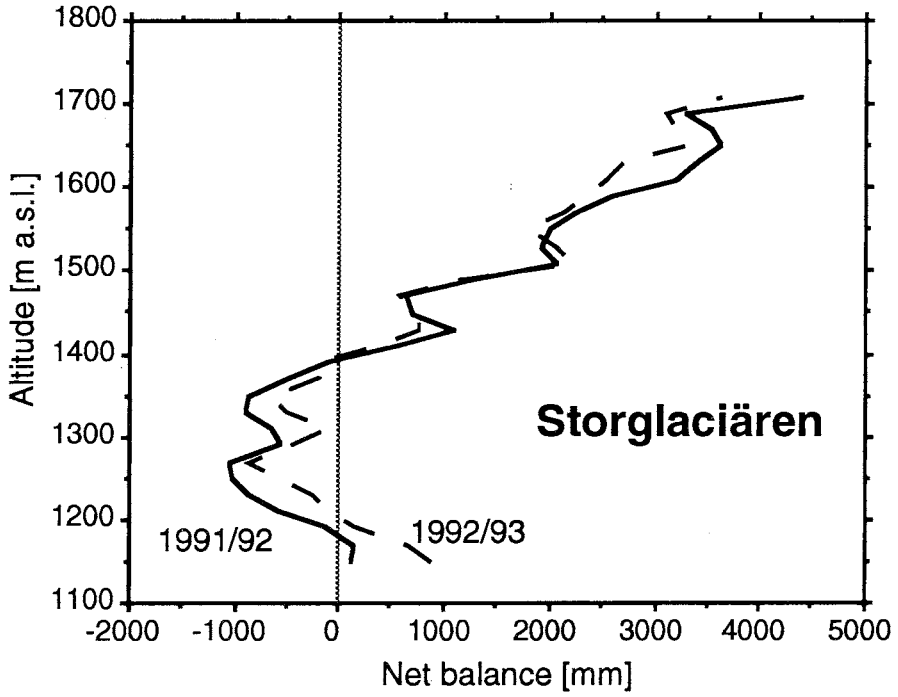
3.2.1 Topography and observational network



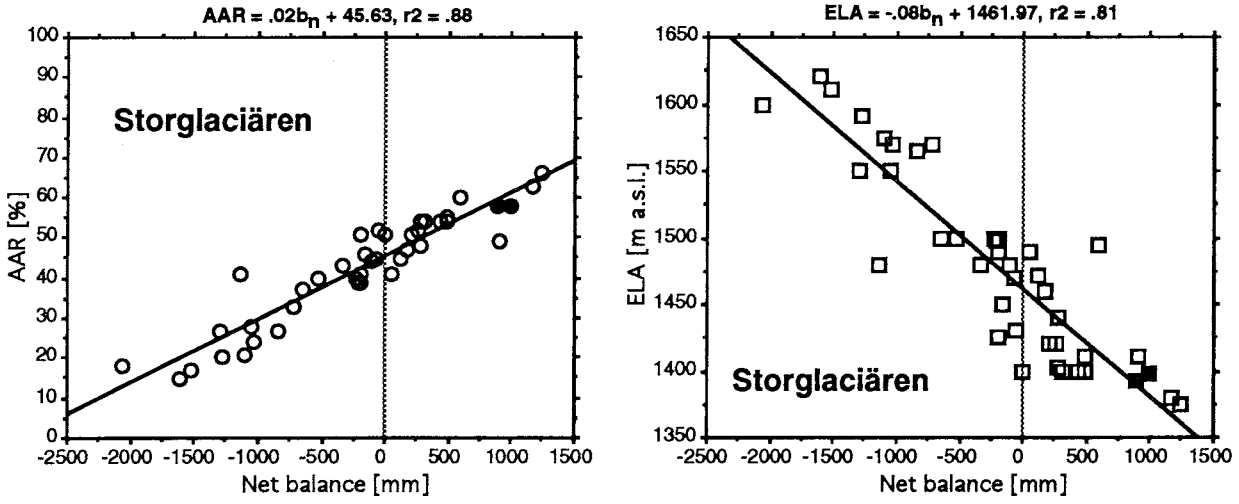
3.2.2 Net balance maps 1991/92 and 1992/93



3.2.3 Net balance versus altitude (1991/92 and 1992/93)



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)

COORDINATES 46° 53' N / 10° 49' E

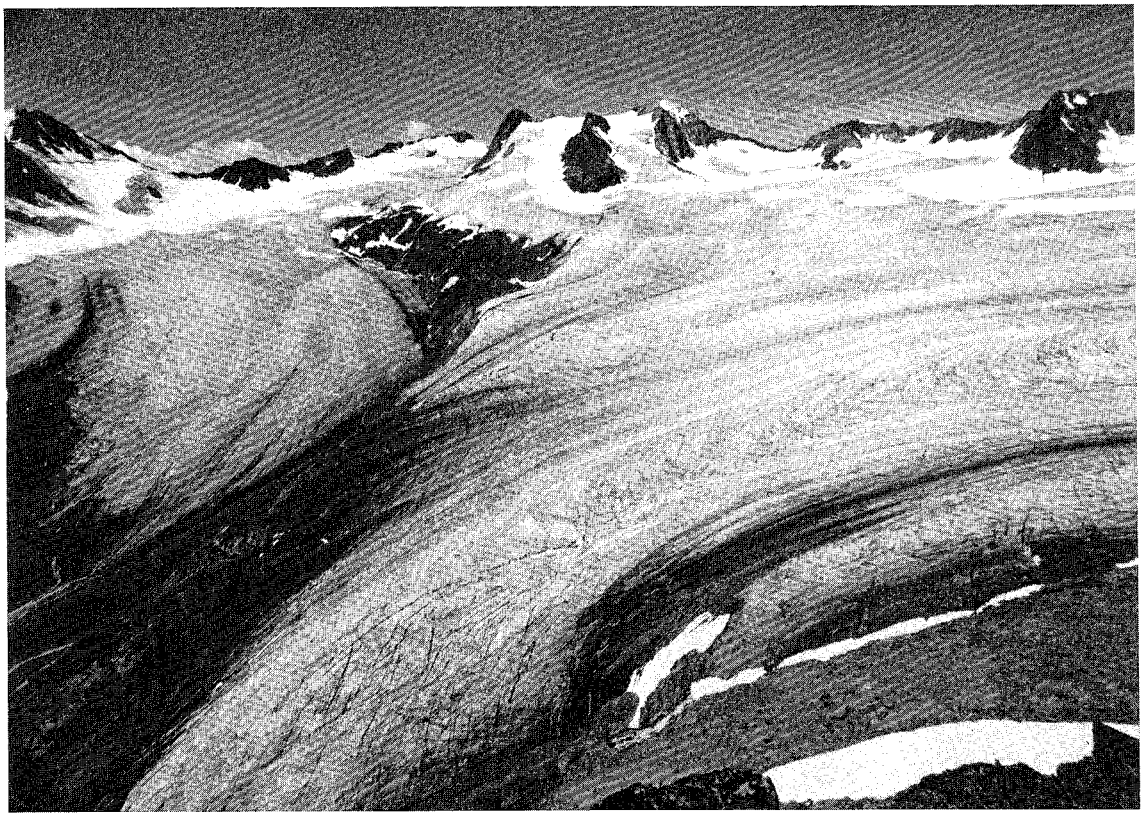
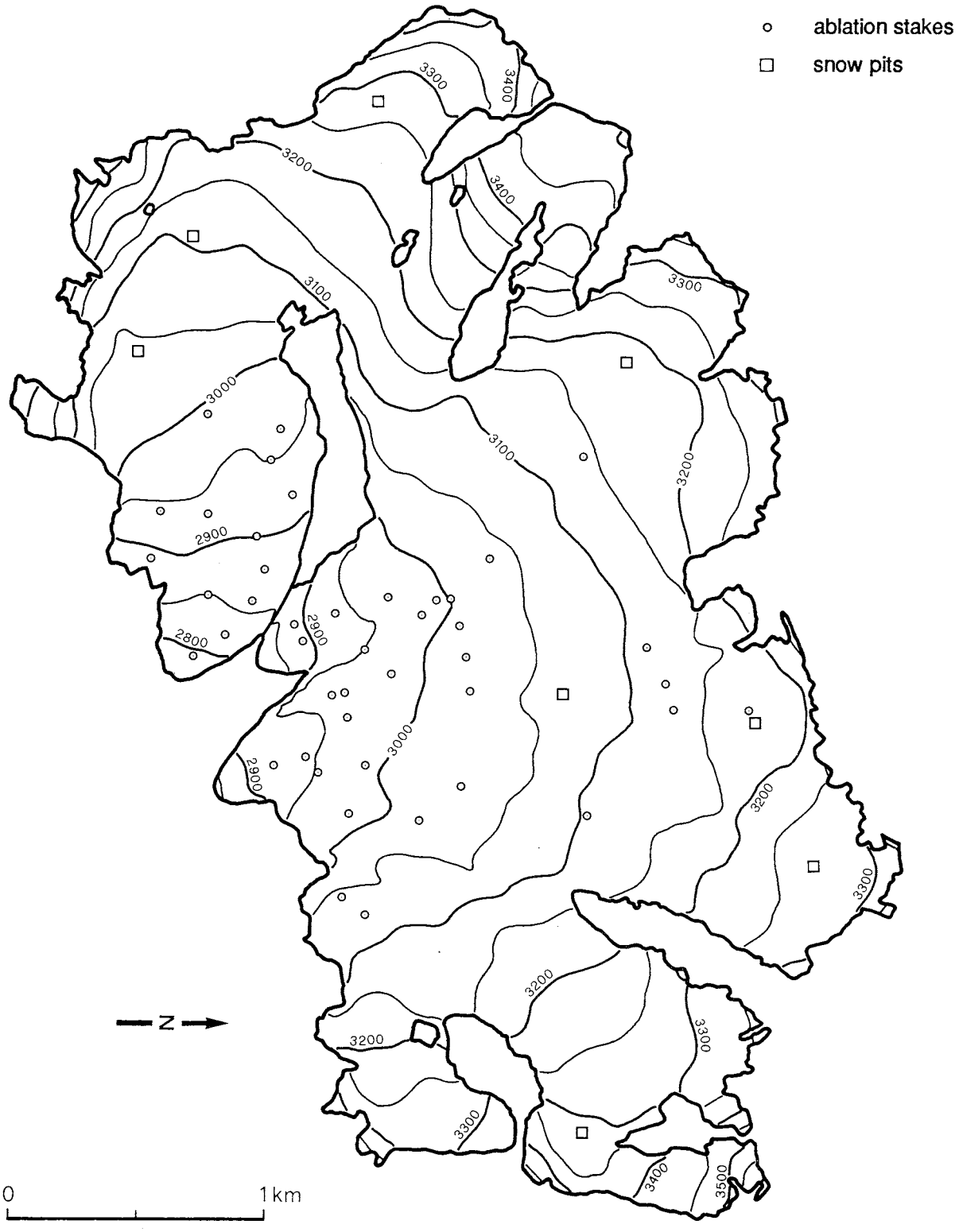


Photo taken by automatic camera situated on Schwarzkögele, 3070 m a.s.l., on 5 August 1994.

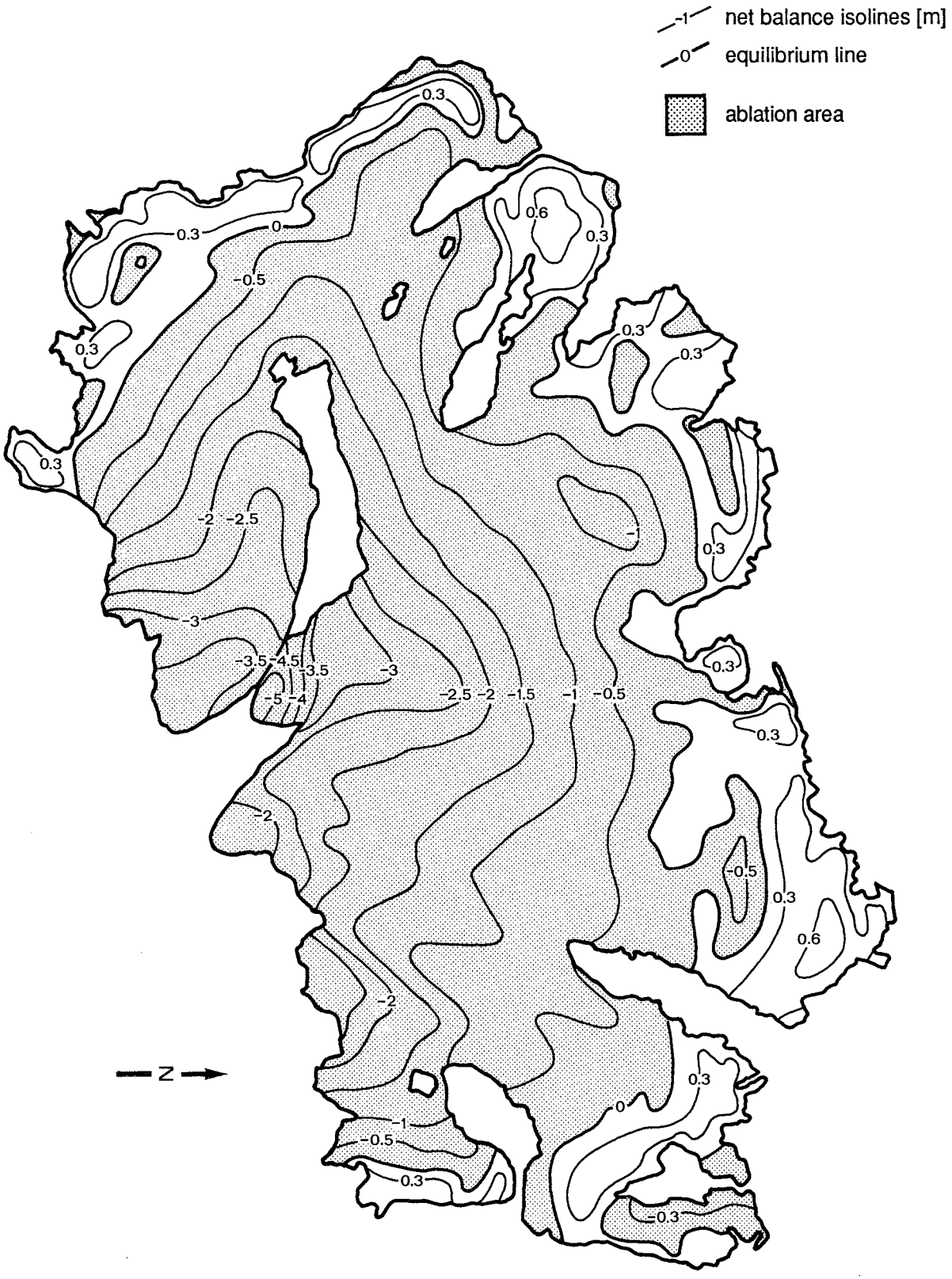
The rather flat mountain glacier in the southern part of the Oetztal Alps is located not far from Hintereisferner. The surface area of 9.0 km^2 is unevenly distributed between 2,740 and 3,630 m a.s.l. with 80% in the altitude interval between 3,100 and 3,300 m a.s.l. Mean annual air temperature at the 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.

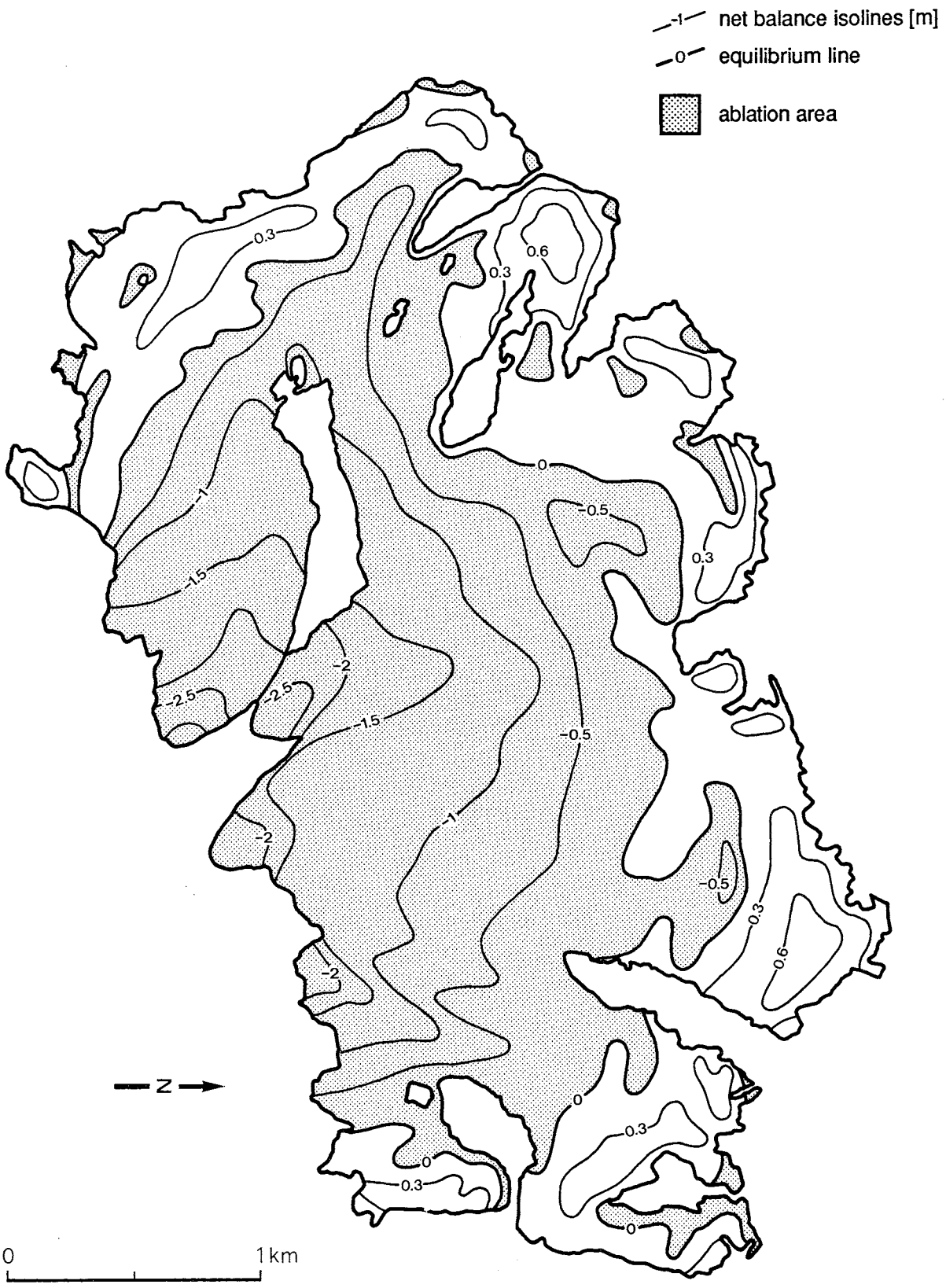
As in previous years very small amounts of net accumulation are characteristic for the negative mass balances 1991/92 and 1992/93. Whereas ELA and AAR differ only slightly in both years because ablation areas were of nearly similar extent, net balance in 1992/93 is considerably less negative due to reduced ablation caused by repeated fresh snow cover and an early end of the ablation season. These conditions are demonstrated by the deviating net balance/altitude-relation below 3,100 m a.s.l.

3.3.1 Topography and observational network

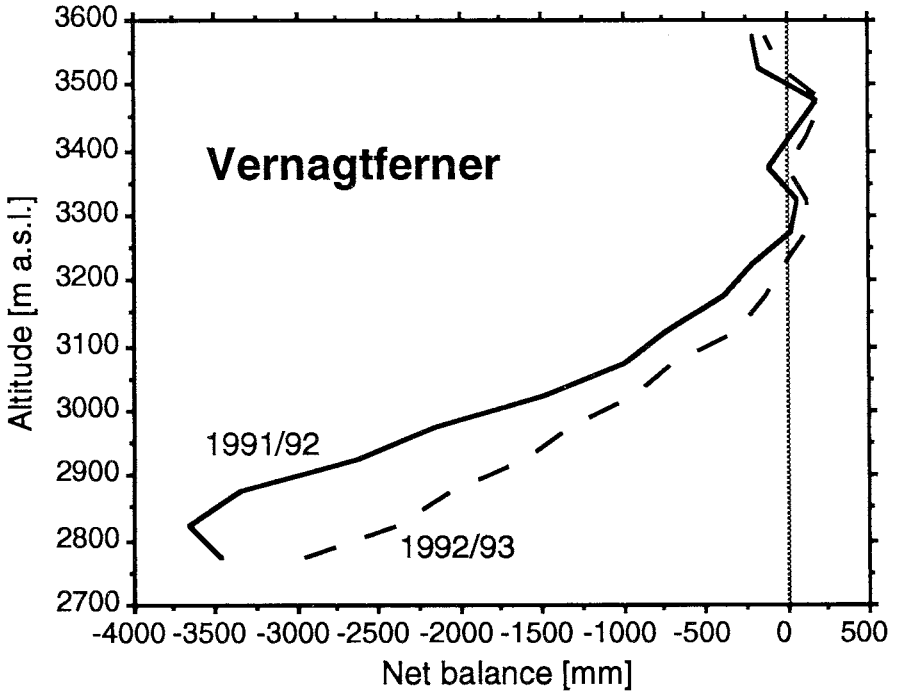


3.3.2 Net balance maps 1991/92 and 1992/93

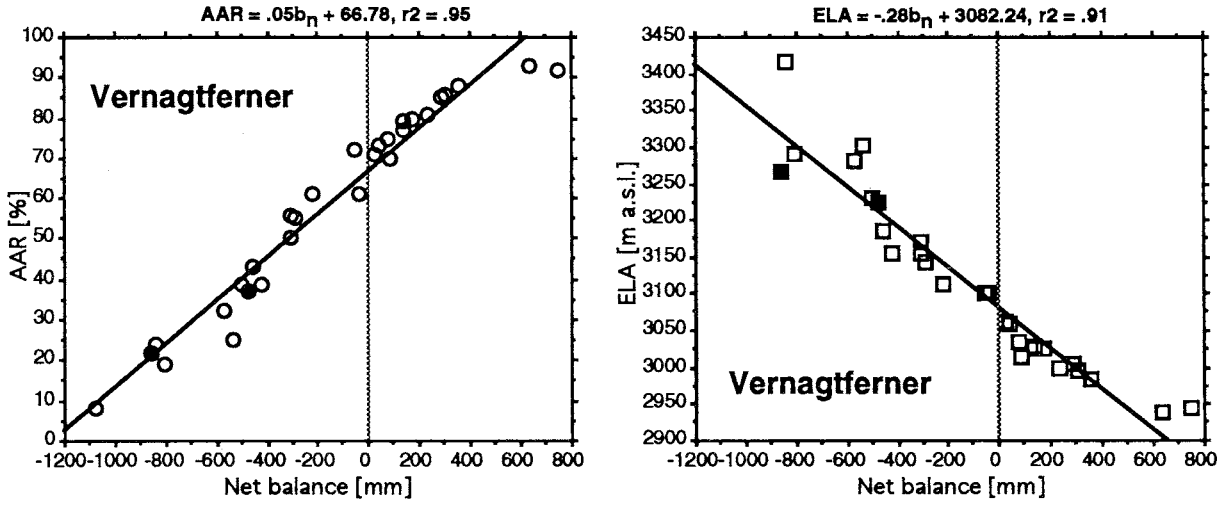



-1 net balance isolines [m]
0 equilibrium line
ablation area
0.3
0.6
0.3
0
-0.5
0.3
-1
-1.5
-2
-2.5
-2.5
-1.5
-0.5
-1
-2
-0.5
0.3
0.6
-2
0
0.3
0
0.3
0
Z
0
1 km

3.3.3 Net balance versus altitude (1991/92 and 1992/93)



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



3.4 LEWIS (KENYA)

COORDINATES: 00° 09' S / 37° 18' E

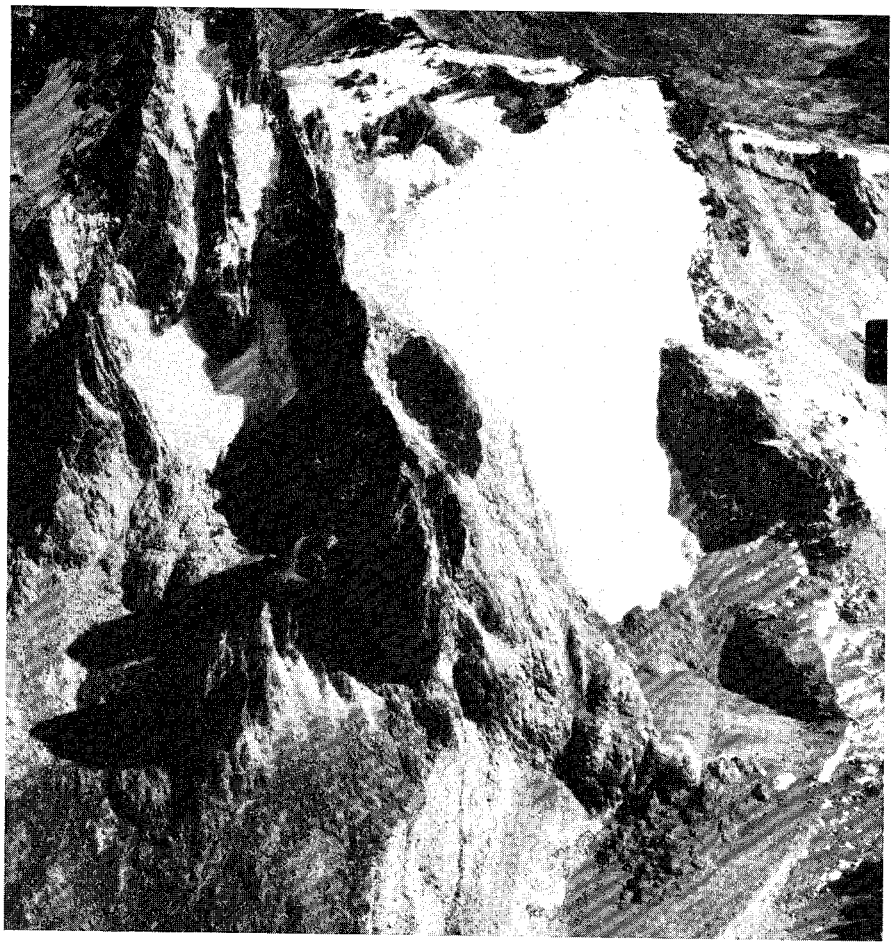
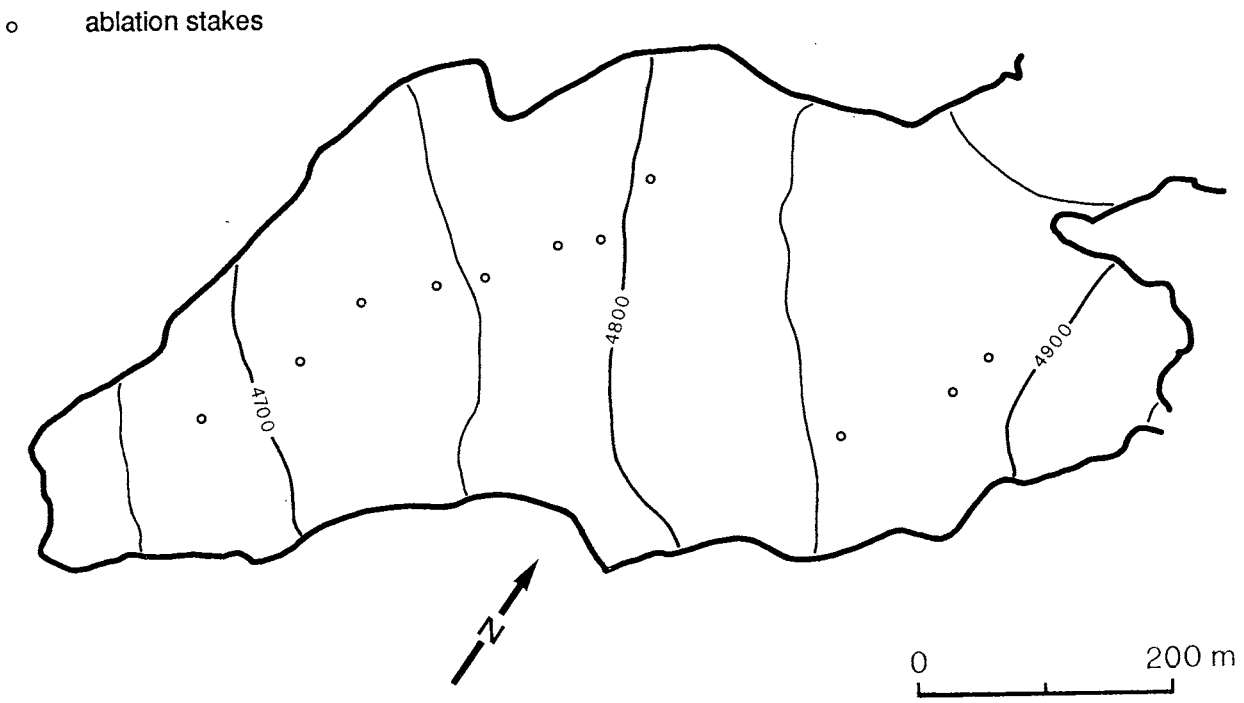


Photo taken in the mid-1980s; courtesy of Photomap (K) Ltd.

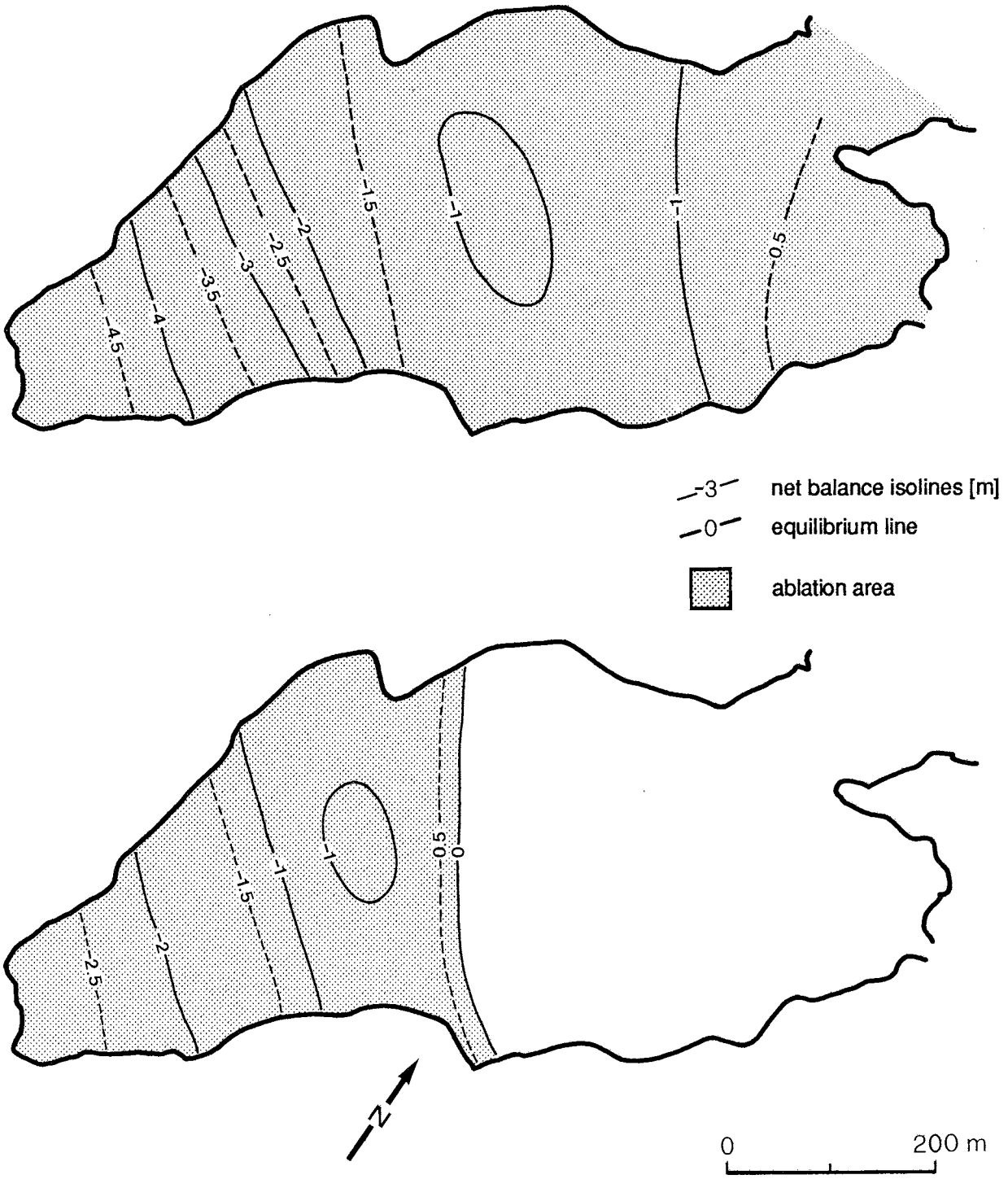
This largest glacier on Mount Kenya is located less than 20 km to the south of the Equator at elevations between 5,000 and 4,600 m a.s.l. It has a surface area of 0.25 km^2 and is exposed to the SW. Annual mean air temperature at the equilibrium line of the glacier (around 4,700 to 4,800 m a.s.l.) is 0 to -1 °C. The glacier is assumed to be temperate, and periglacial areas to be free of permafrost. Average annual precipitation measured on a rock ridge ("Austrian Hut") next to the glacier was about 700 mm during the last 12 years of predominantly negative balances. However, years of zero balance are characterized by annual precipitation of about 1,000 mm. Ablation is substantial throughout the year and the seasons of minimum precipitation are January/February and July/August. The applicability of mid-latitude glaciological terminology to this tropical glacier is limited: for instance, start of the balance year is in March rather than in boreal autumn. For various of the years monitored since 1978, the entire glacier acted as an "ablation area". Topographic maps of the glacier in 1987 and 1990 can be found in Vol. 6 of the Fluctuations of Glaciers.

Both March 1991 to March 1992 and March 1992 to March 1993 were again years with net mass losses of 1.75 and 0.48 m water equivalent, respectively. The ELA of the year 1991/92 was again above the highest point of the glacier.

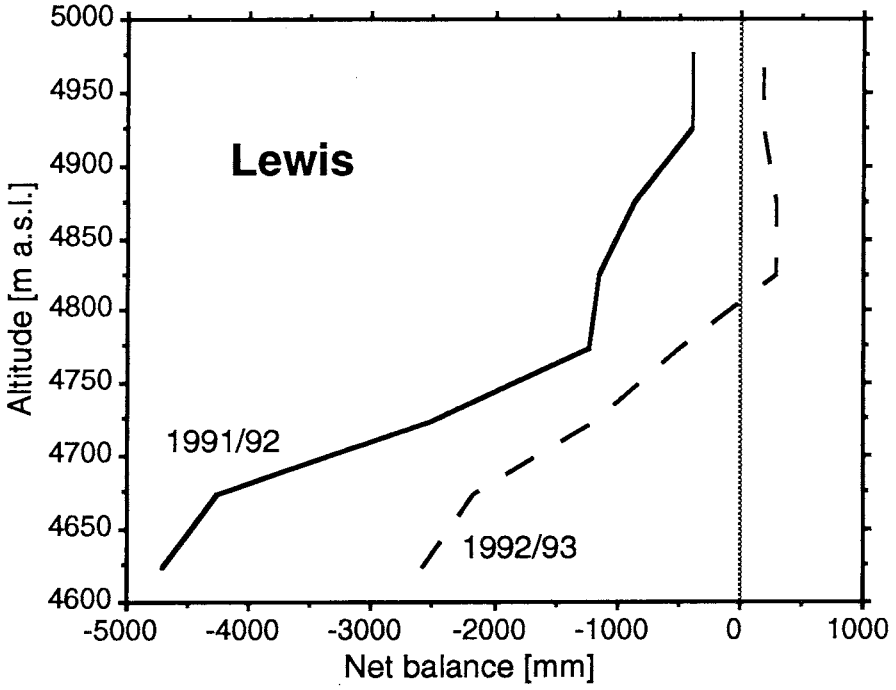
3.4.1 Topography and observational network



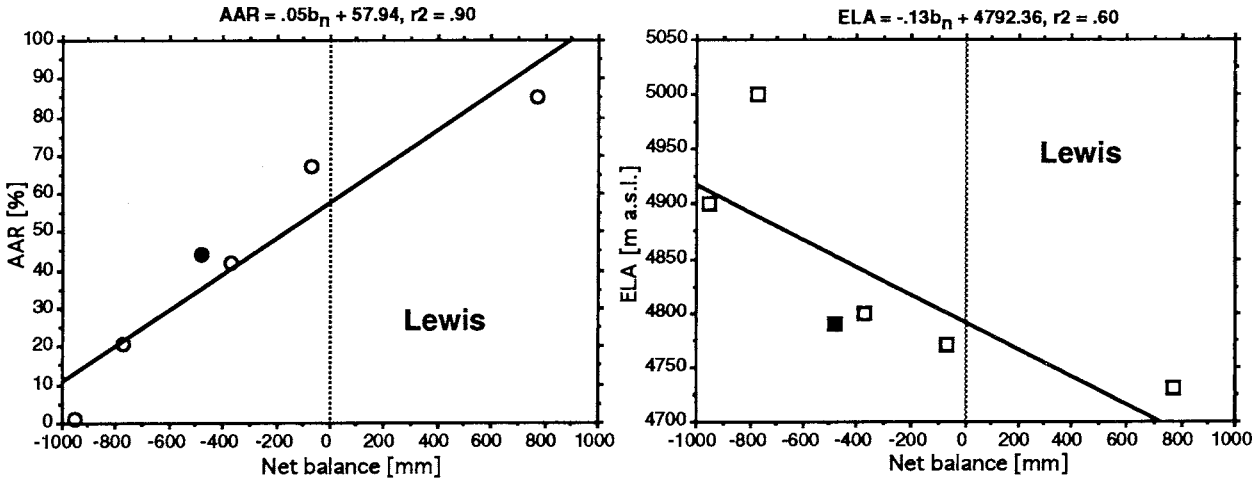
3.4.2 Net balance maps 1991/92 and 1992/93



3.4.3 Net balance versus altitude (1991/92 and 1992/93)



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



3.5 DJANKUAT (RUSSIA)

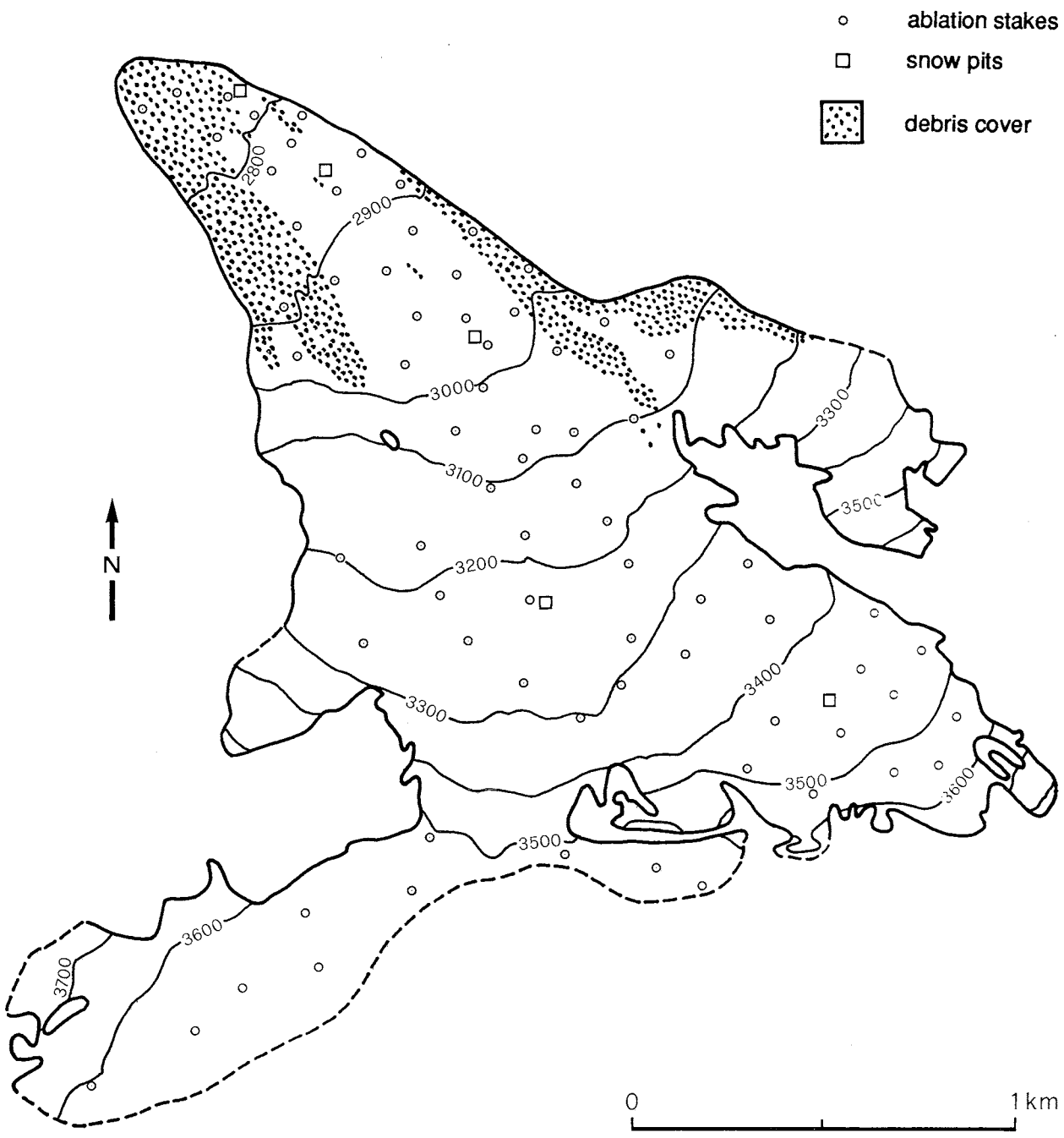
COORDINATES: 43° 12' N / 42° 46' E

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

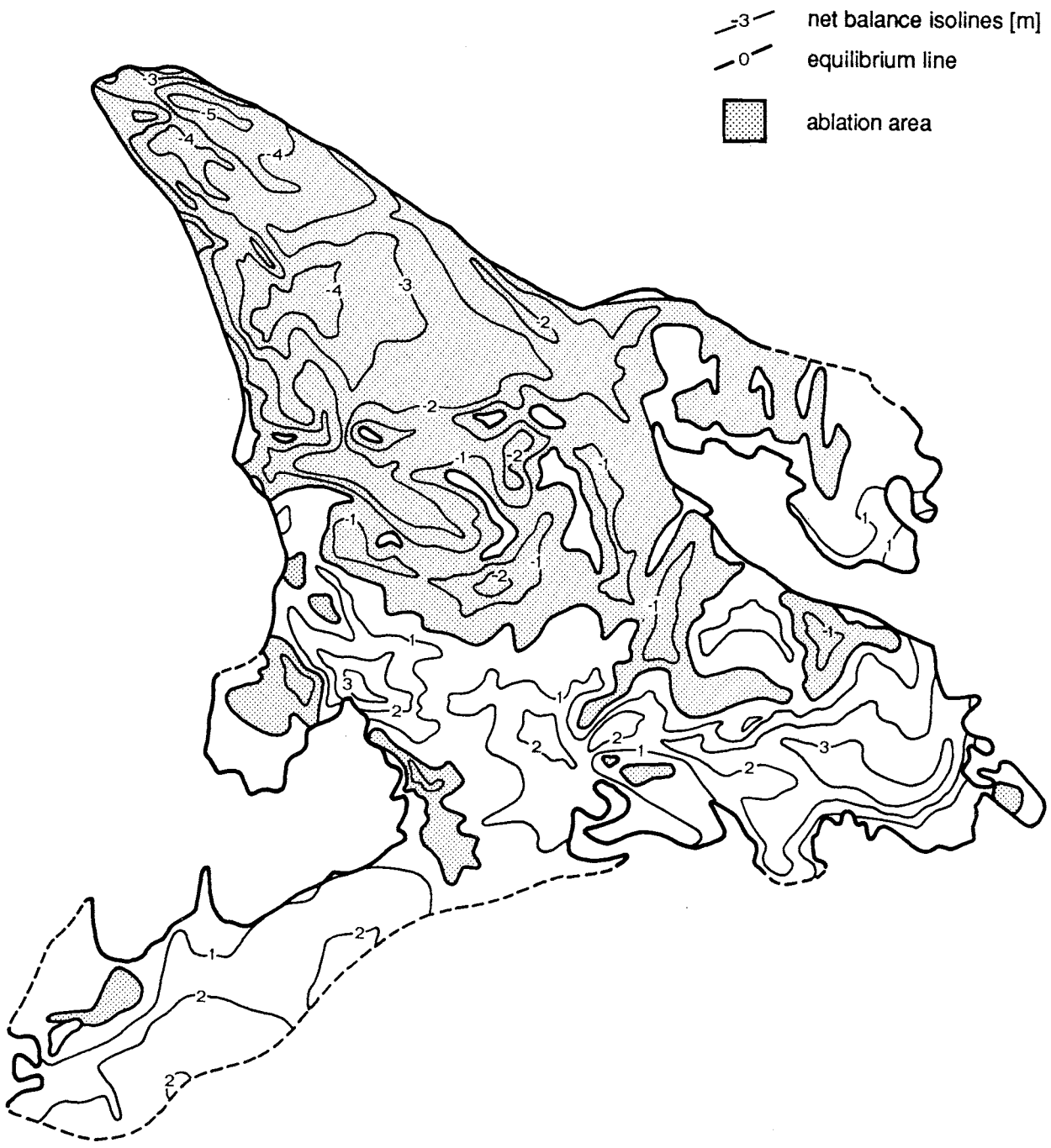
The valley-type glacier is located on the northern slope of the central section of the main Caucasus Ridge and extends from 3,830 to 2,700 m a.s.l. Its surface area is 3.10 km^2 and the exposure is NW. Mean annual air temperature at the equilibrium line of the glacier at about 3,200 m a.s.l. is -3 to -4.5 °C and the glacier is temperate. Periglacial permafrost is highly discontinuous. Average annual precipitation as measured near the snout is about 1,100 to 1,200 mm but roughly three times that amount at the equilibrium line. Four 1:10,000 topographic maps (1968, 1974, 1984 and 1992) exist at the Moscow State University but have not yet been 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.

The balance year 1991/92 was characterized by reduced mass exchange: both winter accumulation (17%) and summer ablation (15%) were below average. Abundant snowfalls in the uppermost reaches kept the mass loss to 0.13 m water equivalent. Severe winter weather conditions in 1992/93 with much snow, cold temperatures and strong winds resulted in anomalously high spring snow densities and 33% above average accumulation. Huge avalanches essentially distorted the commonly observed snow distribution patterns. Ablation was 16% below the norm despite warm summer air temperatures. The resulting mass gain (1.13 m water equivalent) is the second-highest ince the beginning of direct observations in 1968.

3.5.1 Topography and observational network

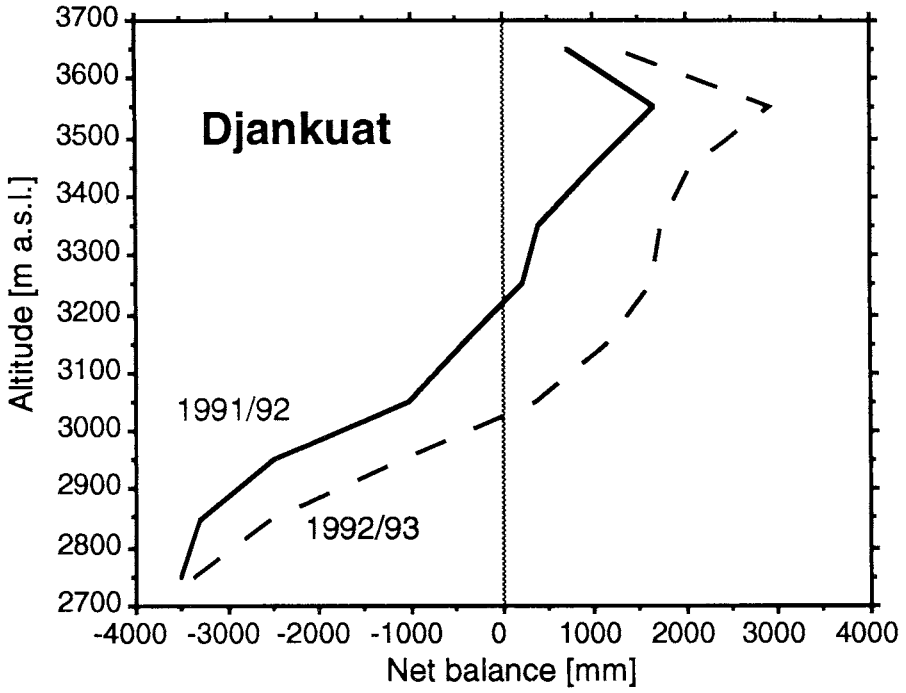


3.5.2 Net balance maps 1991/92 and 1992/93

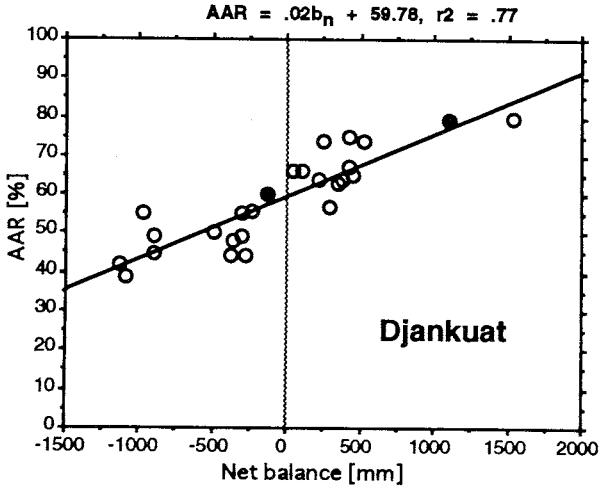


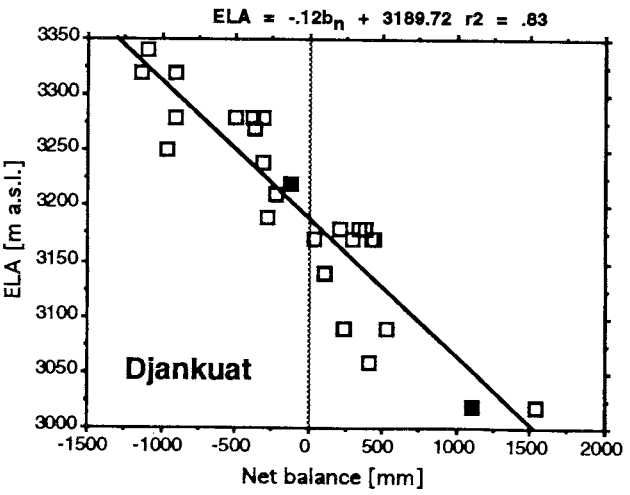
-2
net balance isolines [m]
0
equilibrium line
ablation area
N
0
1 km

3.5.3 Net balance versus altitude (1991/92 and 1992/93)



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





3.6 ABRAMOV (KIRGHIZSTAN)

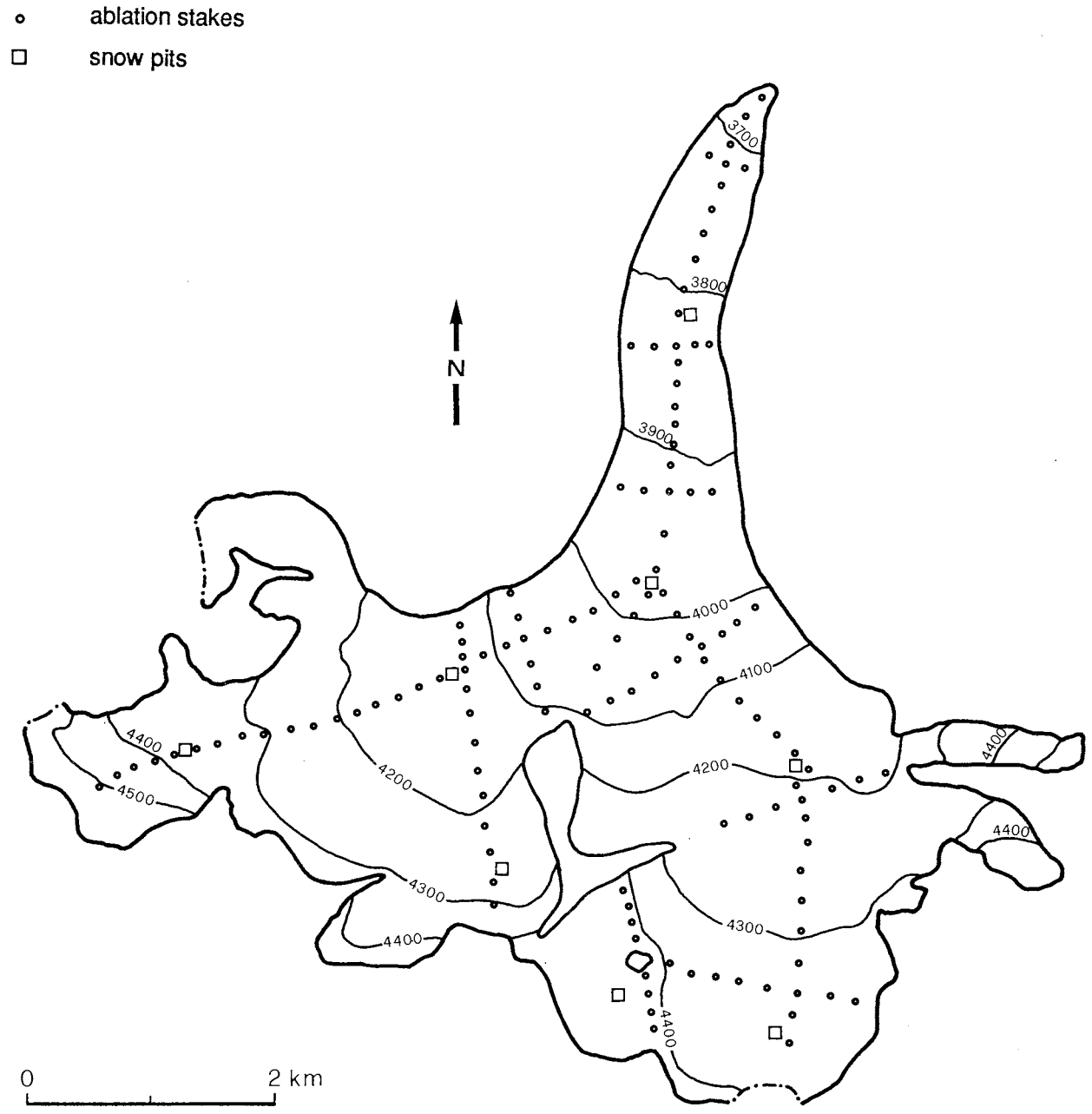
COORDINATES: 39° 38' N / 71° 34' E

Photo taken by G.M. Kamnyanskiy in 1978.

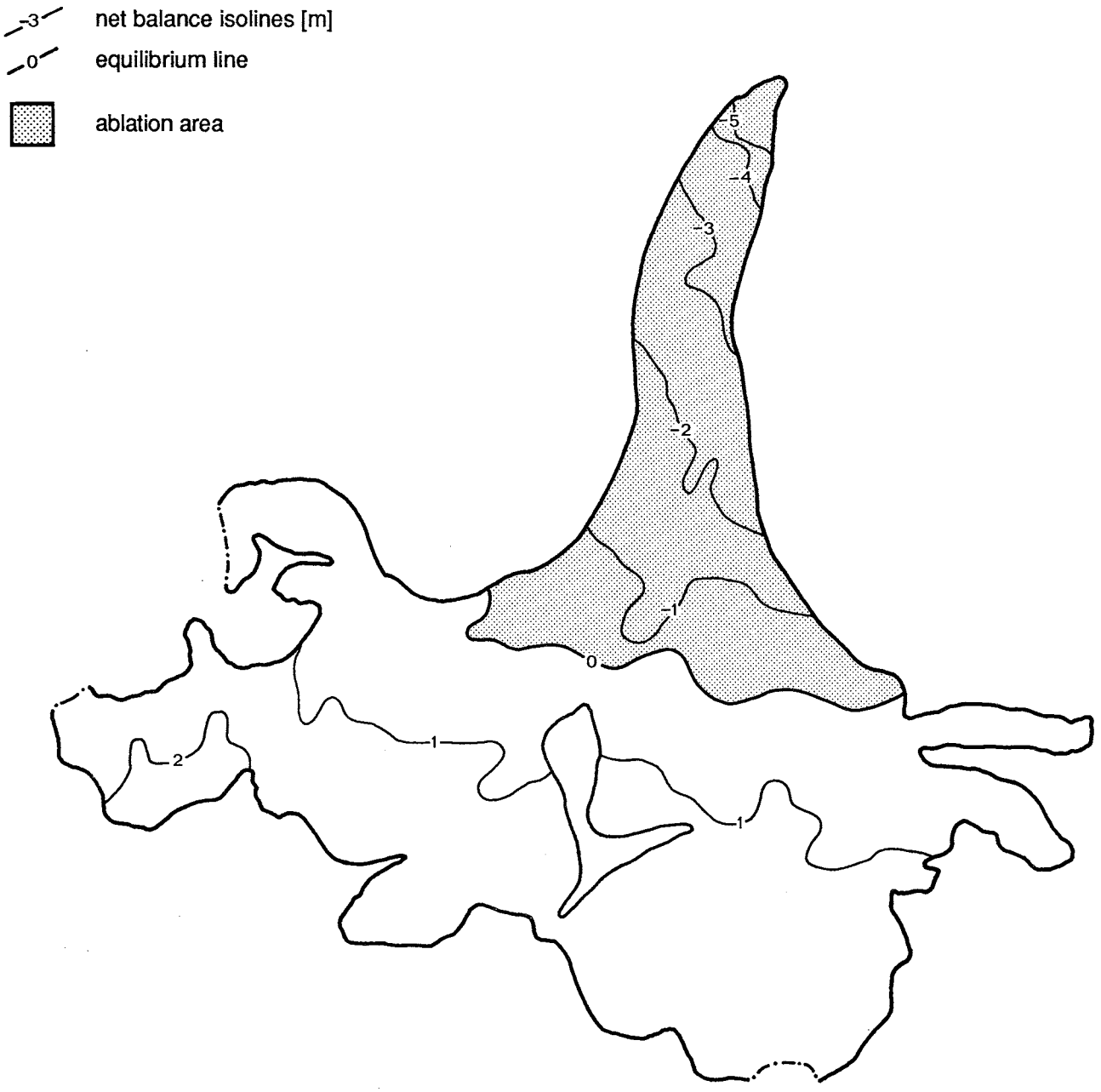
The valley-type glacier of the Amudarya river basin is located in the Southern Alai Range and extends from 4,960 to 3,625 m a.s.l. Its surface area is 26.21 km^2 and the exposure is N. Annual mean air temperature at the equilibrium line of the glacier (around 4,200 m a.s.l.) is -6.5 to -8 °C. The glacier 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.

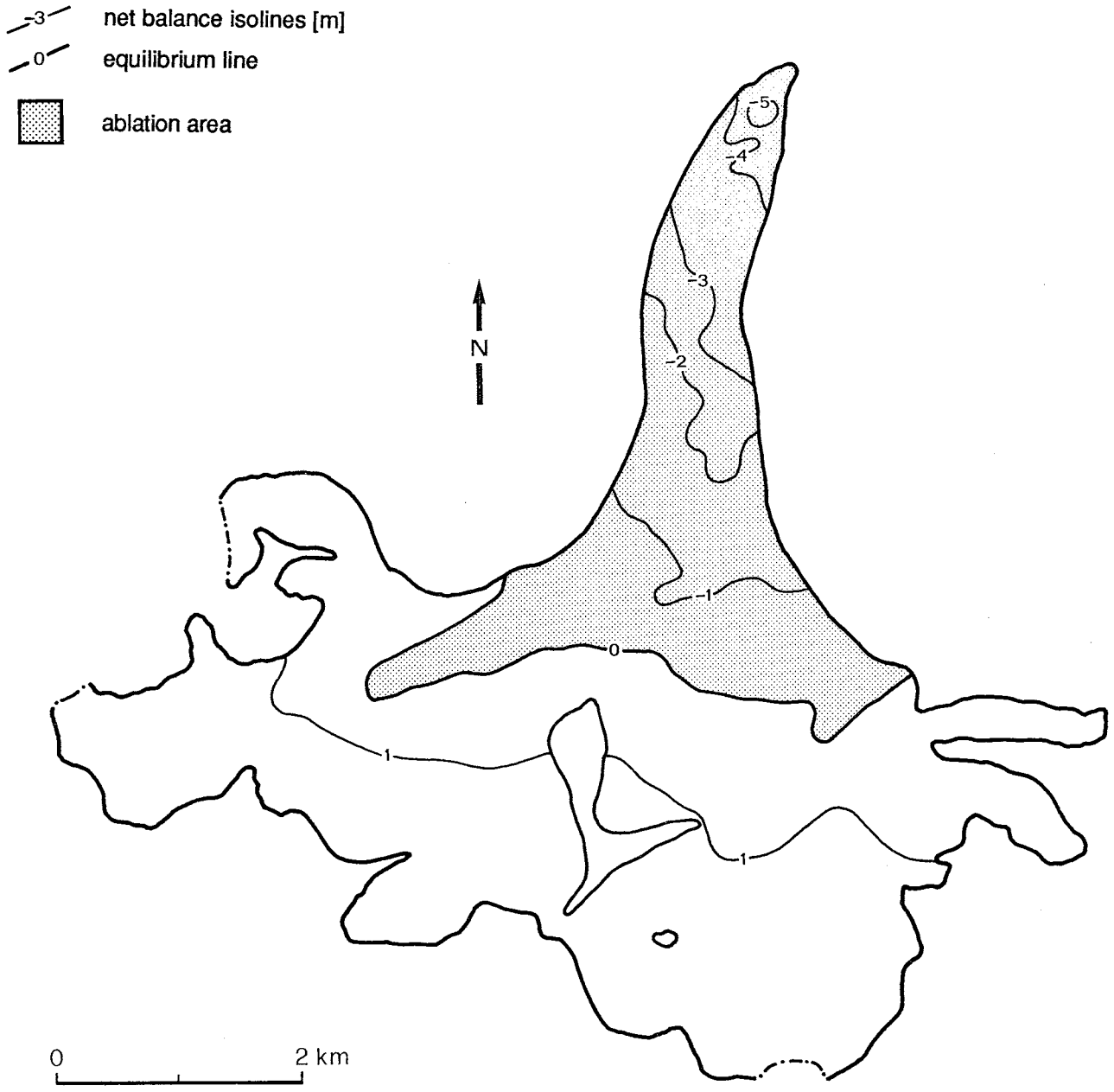
For the first time in the 26-year observation period, the mass balance was positive during two consecutive years. The 1991/92 balance year was characterized by a 25%-excess in summer precipitation and lower than normal mean annual air temperatures. Delayed melting in the lower reaches due to above-normal June snowfalls led to a positive balance of 0.4 m water equivalent. The year 1992/93 with a 30%-excess of winter snow and again lower than normal summer temperatures, especially during July and August, caused a mass gain of 0.3 m water equivalent. Equilibrium line altitude in both years was slightly above 4,100 m a.s.l.

3.6.1 Topography and observational network

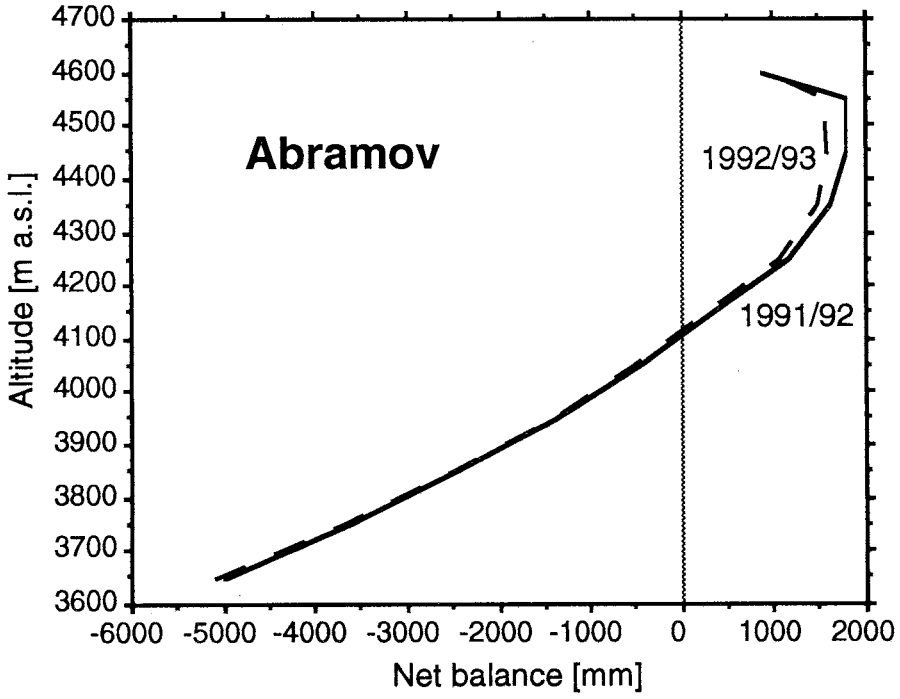


3.6.2 Net balance maps 1991/92 and 1992/93

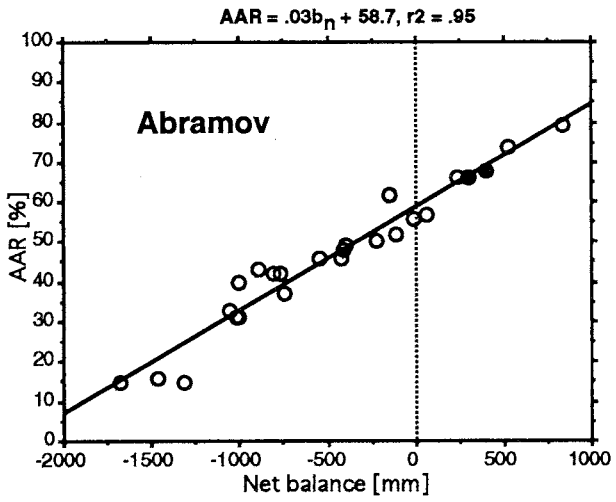


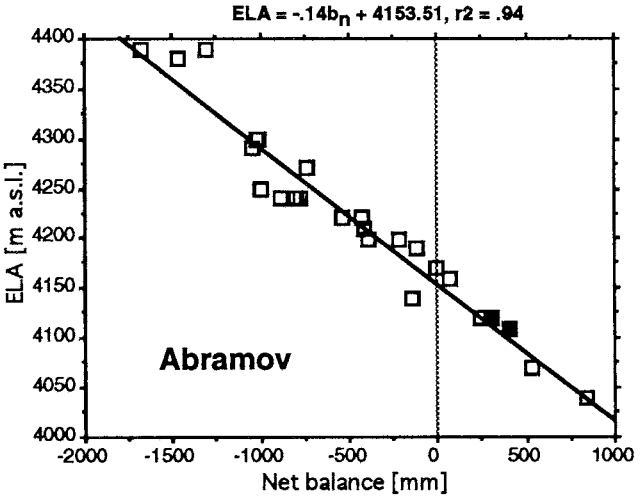

-3
net balance isolines [m]
0
equilibrium line
ablation area
N
-5
-4
-3
-2
-1
0
1
1
0
2 km

3.6.3 Net balance versus altitude (1991/92 and 1992/93)



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





3.7 TSENTRALNIY TUYUKSUYSKIY (KAZAKHSTAN)

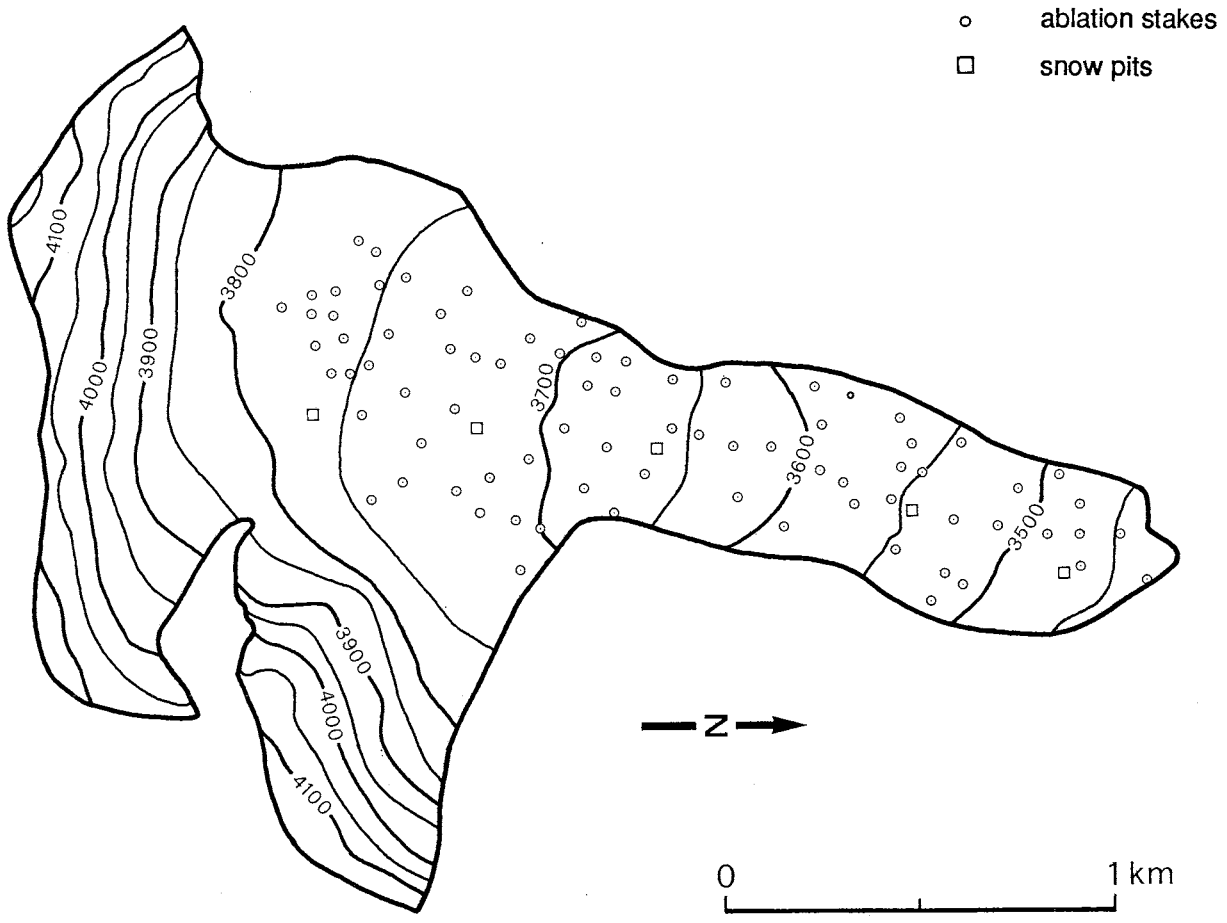
COORDINATES: 43° 03' N / 77° 05' E

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

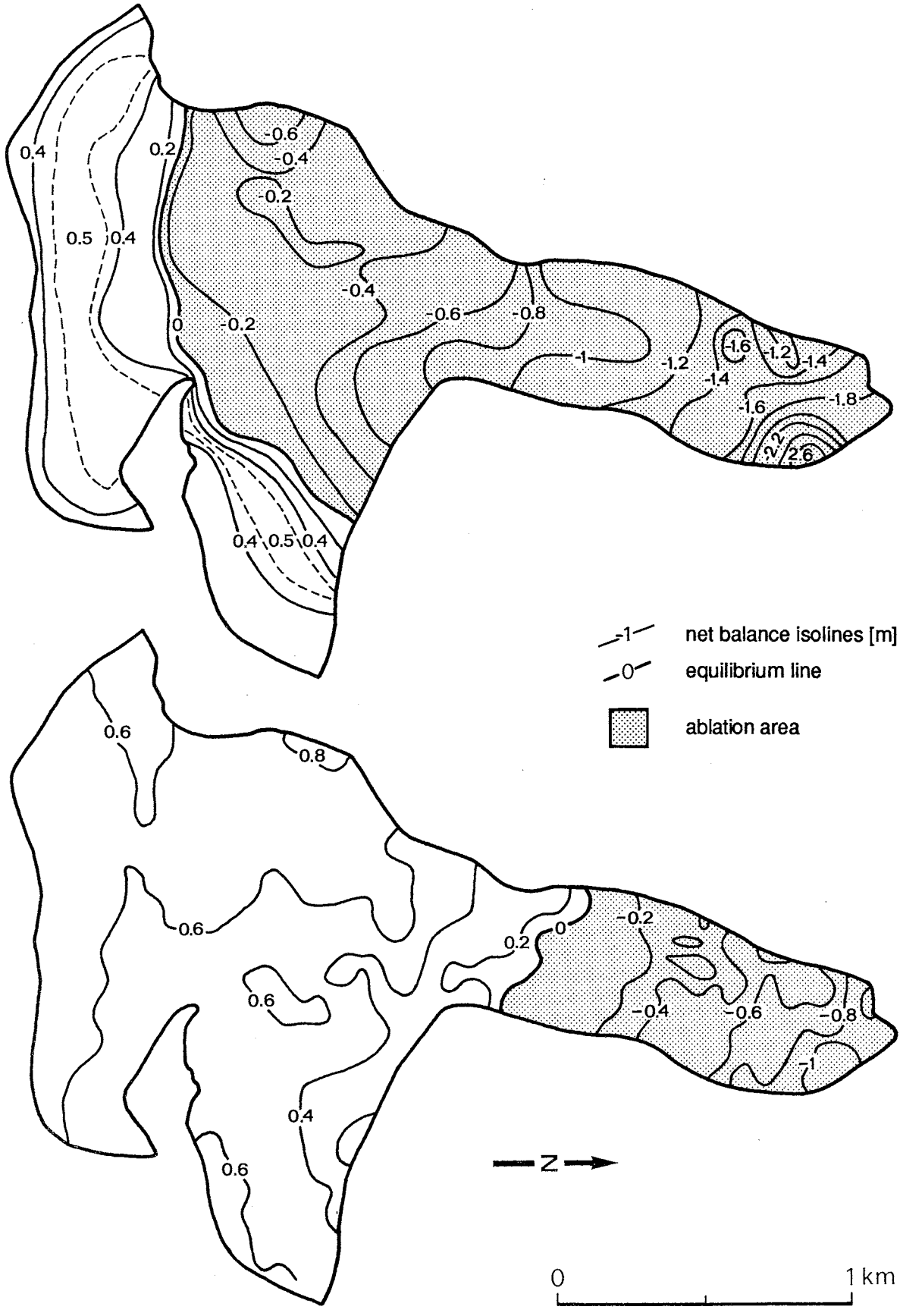
The valley-type glacier in the Zailiyskiy Alatau Range of the Kazakh Tien Shan is also called Tuyuksu Glacier. It extends from 4,220 to 3,400 m a.s.l and has a surface area of 2.88 km^2 (including debris-covered ice) with the exposure being to the N. Annual mean air temperature at the equilibrium line 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 a great number of precipitation gauges is about 1,000 mm in the glacier belt. Characteristic features of the highly continental climatic conditions are stable winter anticyclones, low air temperatures, a summer peak of precipitation and the co-existence of accumulation and ablation processes during the warm season, ablation playing the key role for the mass balance.

While the balance year 1991/92 with a mass loss of 0.24 m water equivalent remained close to average, abundant precipitation and cool summer temperatures in 1992/93 for the first time since 1963/64 caused an essential mass gain (0.6 m water equivalent). Equilibrium line altitude remained below average by 12 m in 1991/92 and by 170 m in 1992/93.

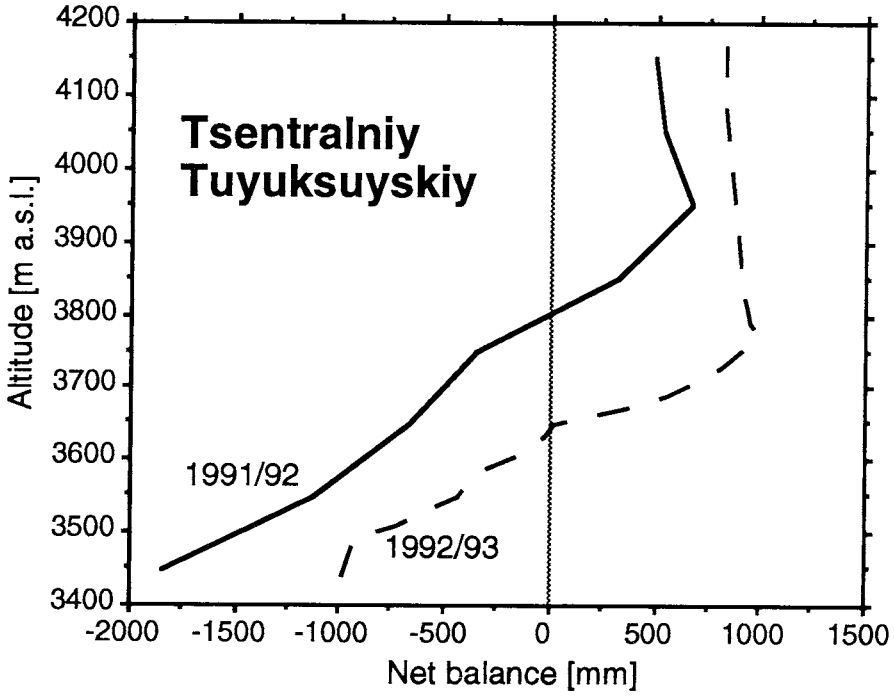
3.7.1 Topography and observational network



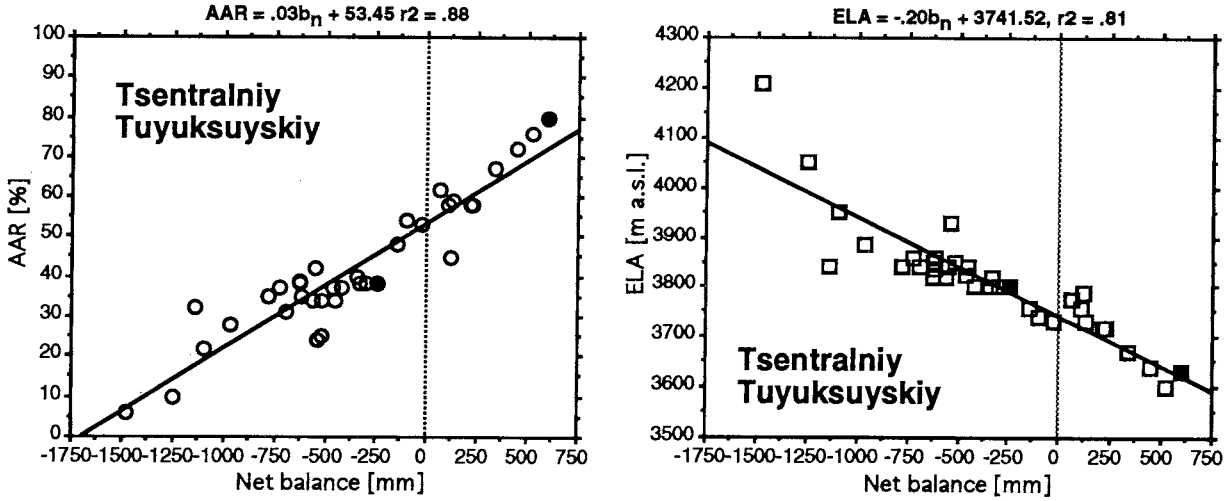
3.7.2 Net balance maps 1991/92 and 1992/93



3.7.3 Net balance versus altitude (1991/92 and 1992/93)



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



3.8 MALIY AKTRU (RUSSIA)

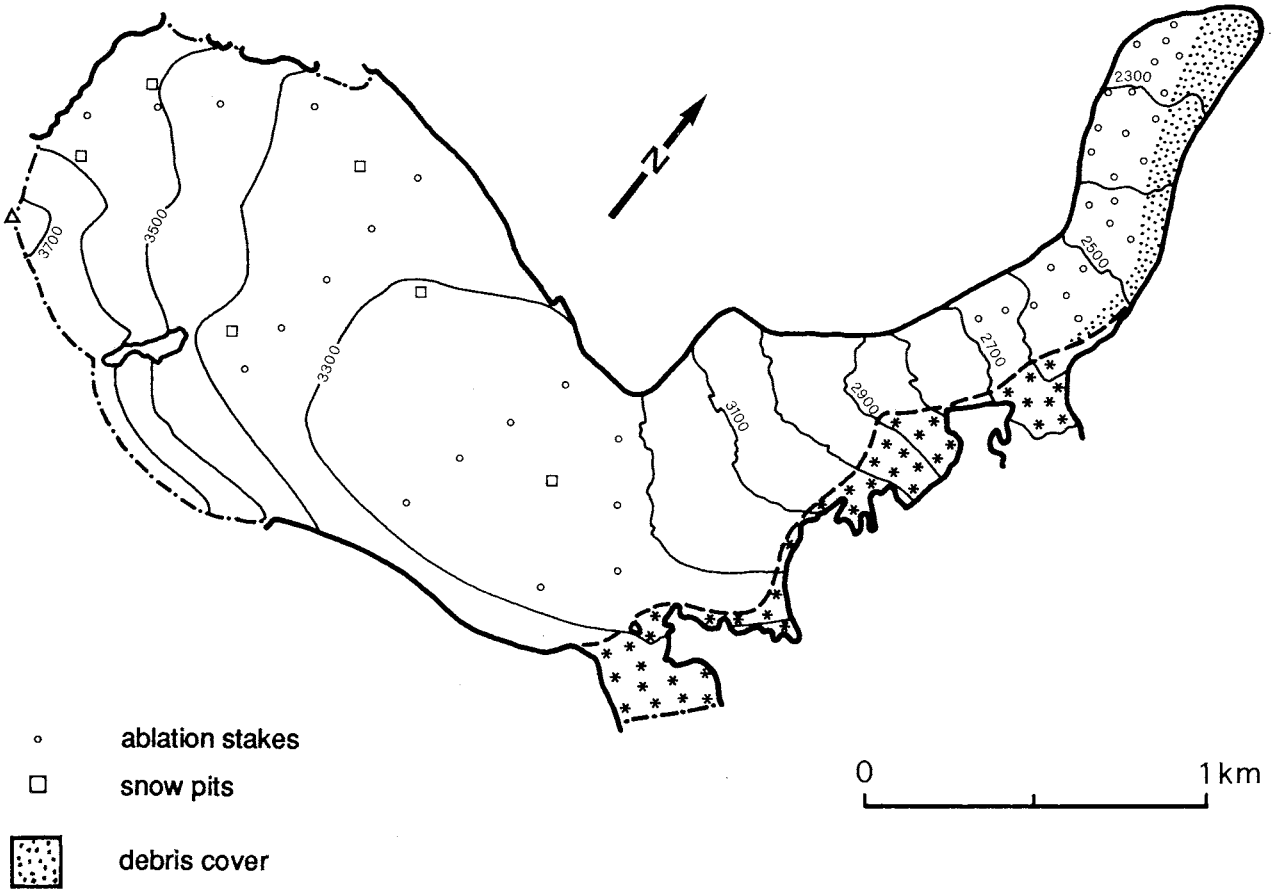
COORDINATES: 50° 05' N / 87° 45' E

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 Russian Altai Mountains. It extends from 3,714 to 2,224 m a.s.l, its surface is 2.73 km^2 and the exposure is E to N. Annual mean air temperature at the equilibrium line of the glacier (around 3,130 m a.s.l for balanced years) 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 three other glaciers within the same drainage basin are being monitored as well.

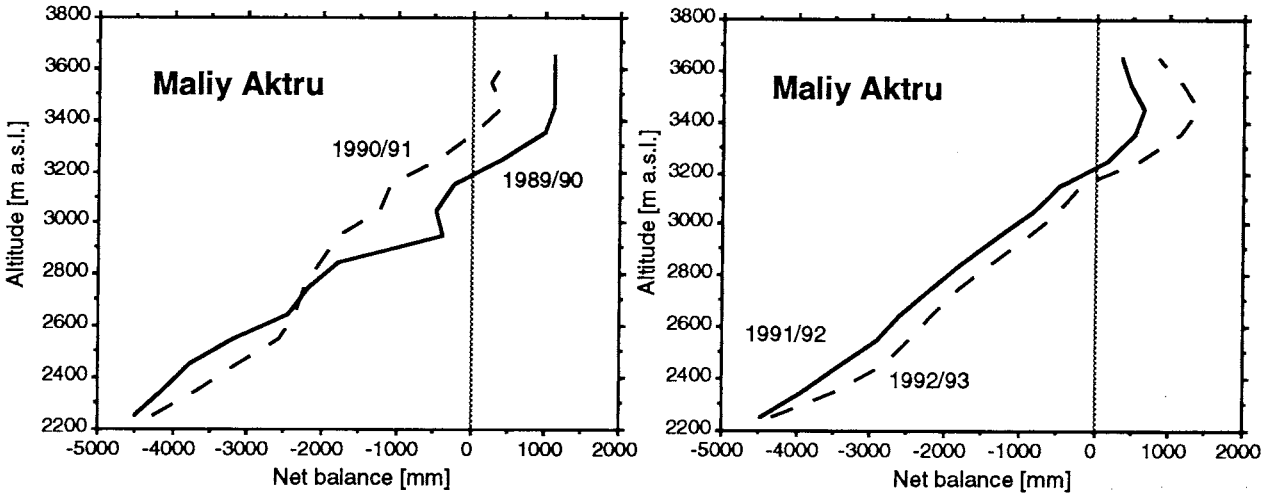
The balance year 1991/92 was characterized by 15% below-average snow accumulation and strong summer melting (20% above average), resulting in a mass loss of 0.17 m water equivalent. In 1992/93, more favourable conditions enabled a mass gain of 0.34 m water equivalent. The general mass accretion of the glacier since 1983 led to accelerated flow velocities in the middle and lower reaches as well as to a recent advance tendency of the glacier front.

3.8.1 Topography and observational network

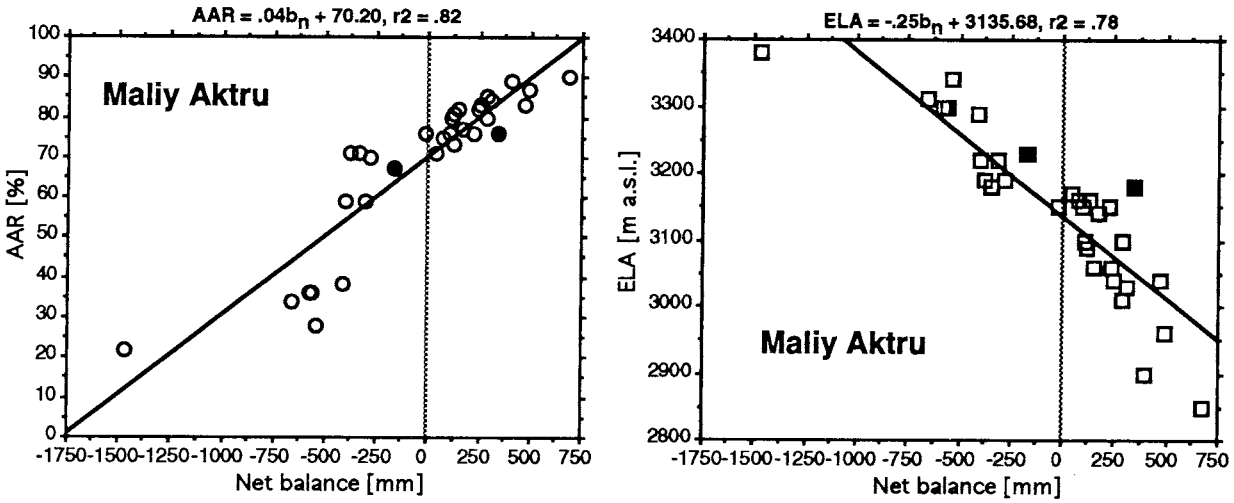


3.8.2 Net balance maps 1991/92 and 1992/93

3.8.3 Net balance versus altitude (1989/90, 1990/91 and 1991/92, 1992/93)



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



3.9 KOZELSKIY (RUSSIA)

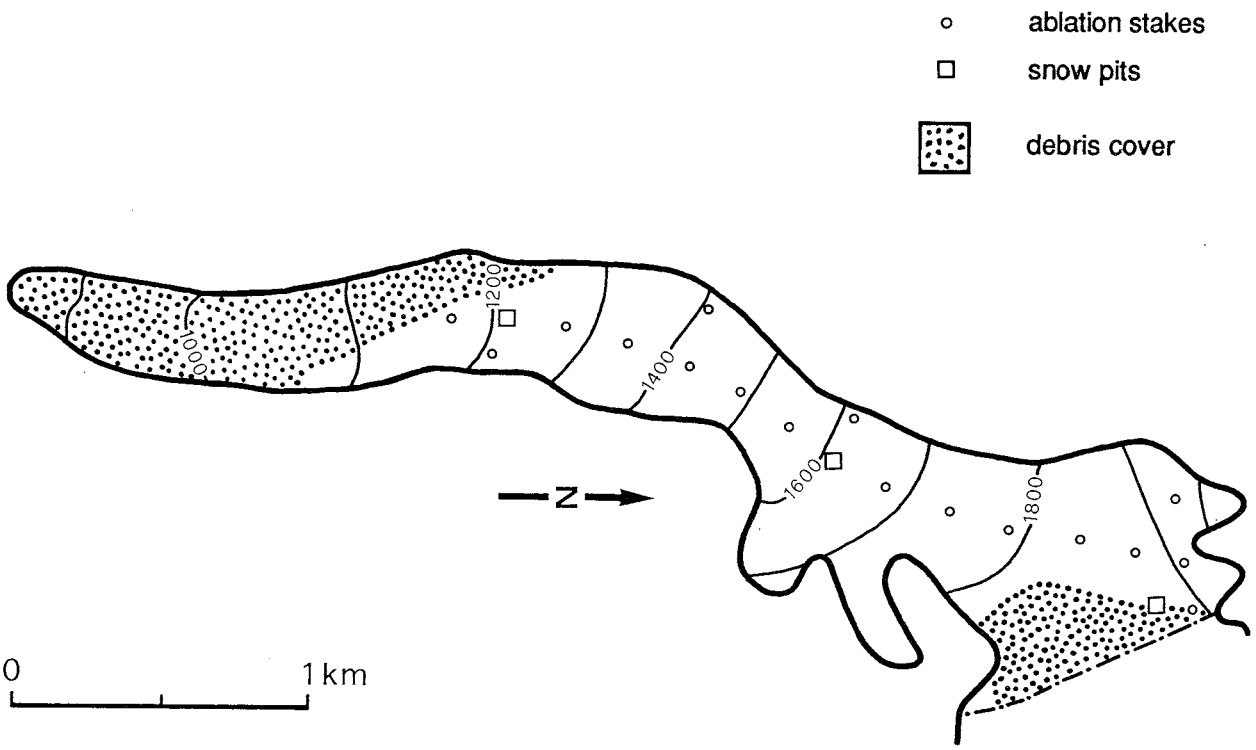
COORDINATES: 53° 14' N / 158° 49' E

Photo taken by Ya. D. Muravyov in September 1984.

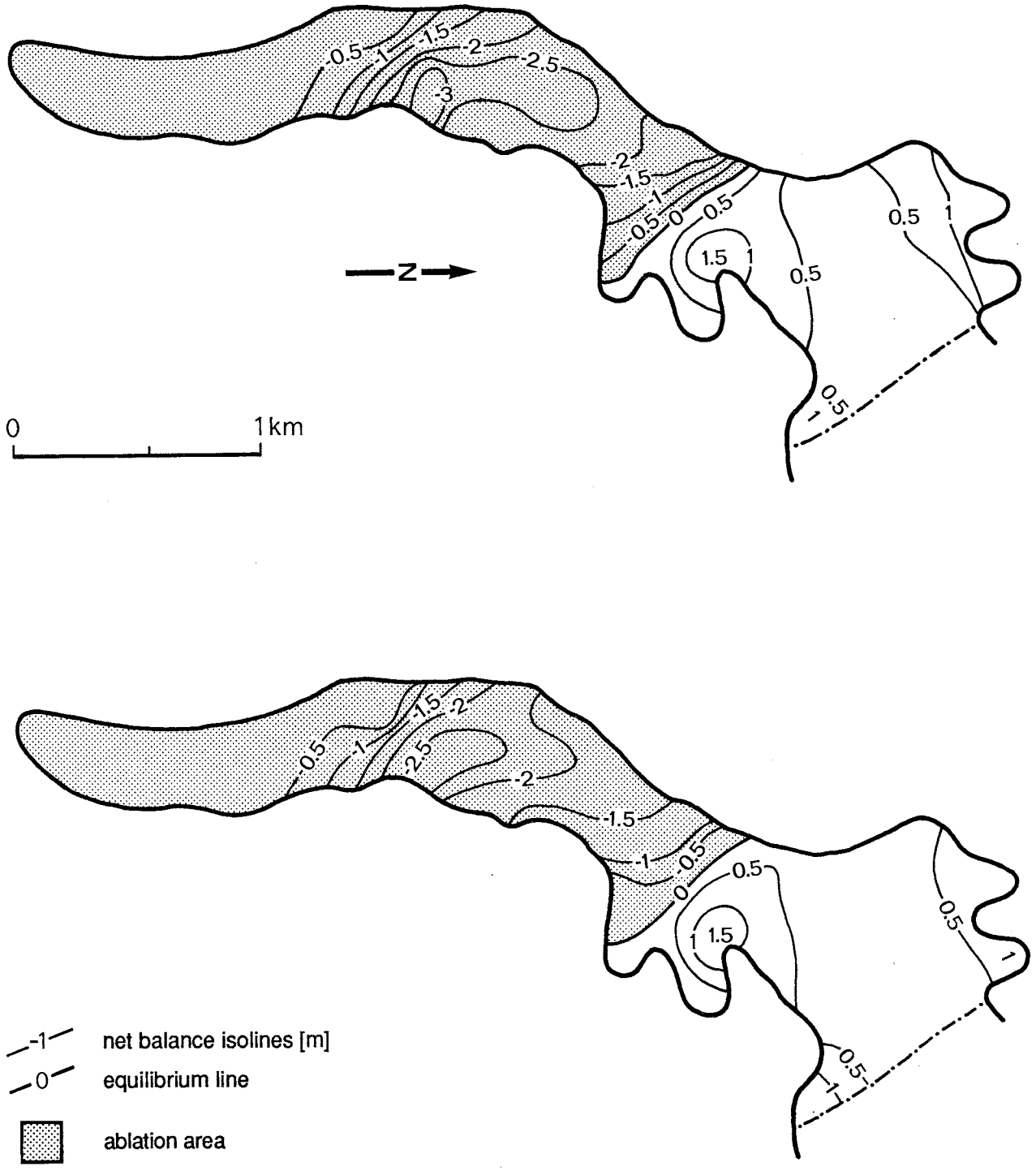
The valley-type glacier is located on the eastern slope of Avachinskiy Volcano in the Vostochny Range of Kamchatka Peninsula and extends from 2,050 to 870 m a.s.l. Its surface area is 1.80 km^2 and the exposure is S. Annual mean air temperature at the equilibrium line of the glacier (around 1,300 m a.s.l.) is -3.5 °C. The glacier is thought to be temperate, perhaps with a cold surface layer in the upper parts of the ablation area. Average annual precipitation as measured at 1,850 m a.s.l. is about 2,100 mm. A 1:5,000 topographic map of the glacier in 1975 has not yet been published. The main peculiarities of the glacier are the sub-lengthwise orientation of the equilibrium line and a zone covered by volcanic ash in the upper reaches of the glacier, where mass balance remains zero.

Mass balances during both reported years were negative. Accumulation and ablation in 1991/92 deviated less than 10% from the norm and mass loss equalled 0.41 m water equivalent. In 1992/93, winter precipitation and summer melting were about 20% below average and resulted in a modest mass loss of 0.35 m water equivalent. In spite of the predominantly negative mass balances during the last years, a trend towards slow advance of the glacier snout recently became identifiable.

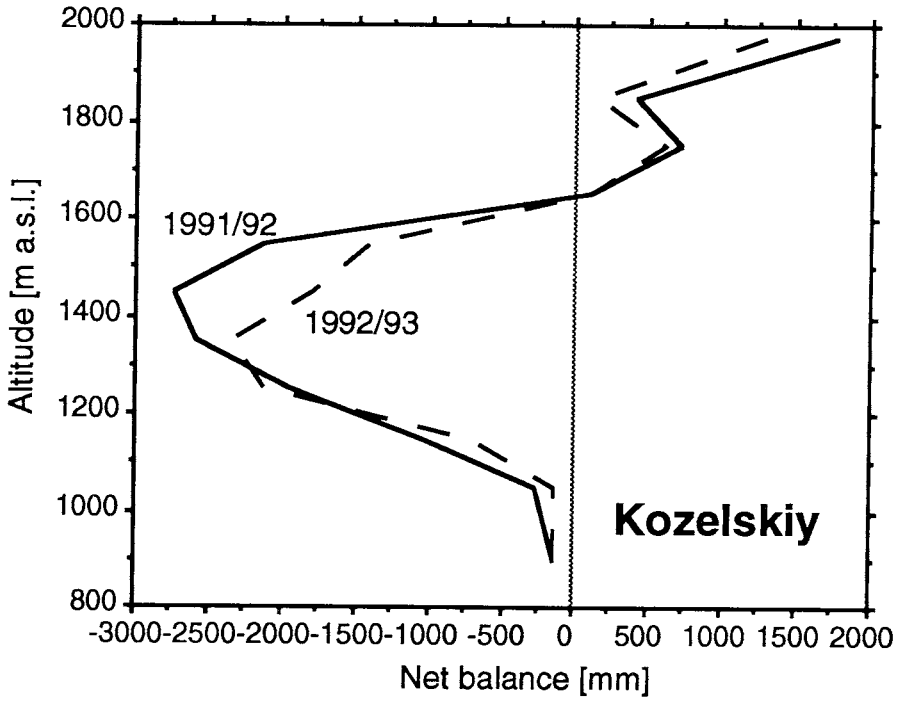
3.9.1 Topography and observational network



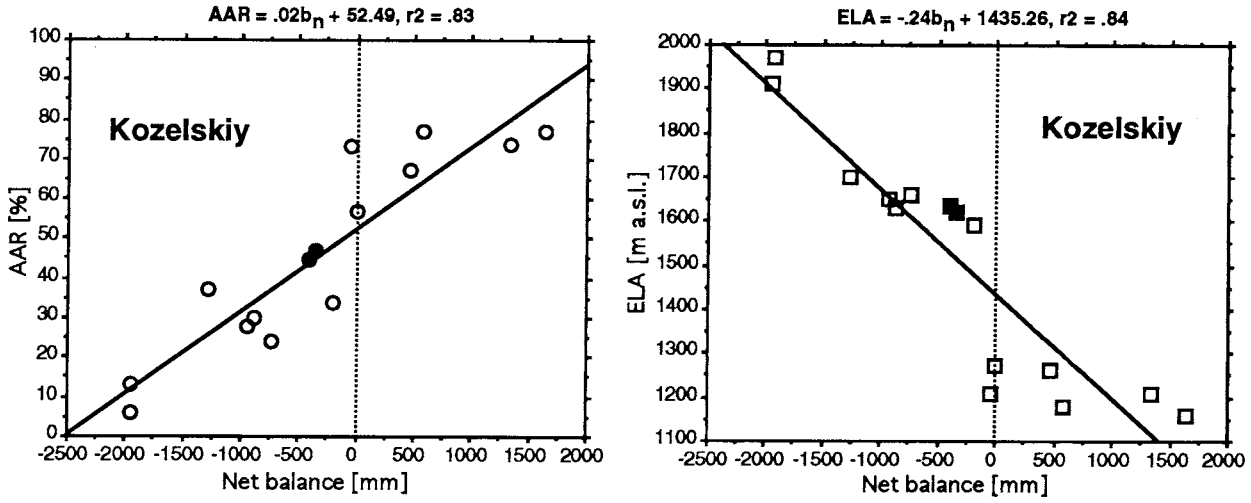
3.9.2 Net balance maps 1991/92 and 1992/93



3.9.3 Net balance versus altitude (1991/92 and 1992/93)



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



3.10 URUMQIHE S. NO. 1 (CHINA)

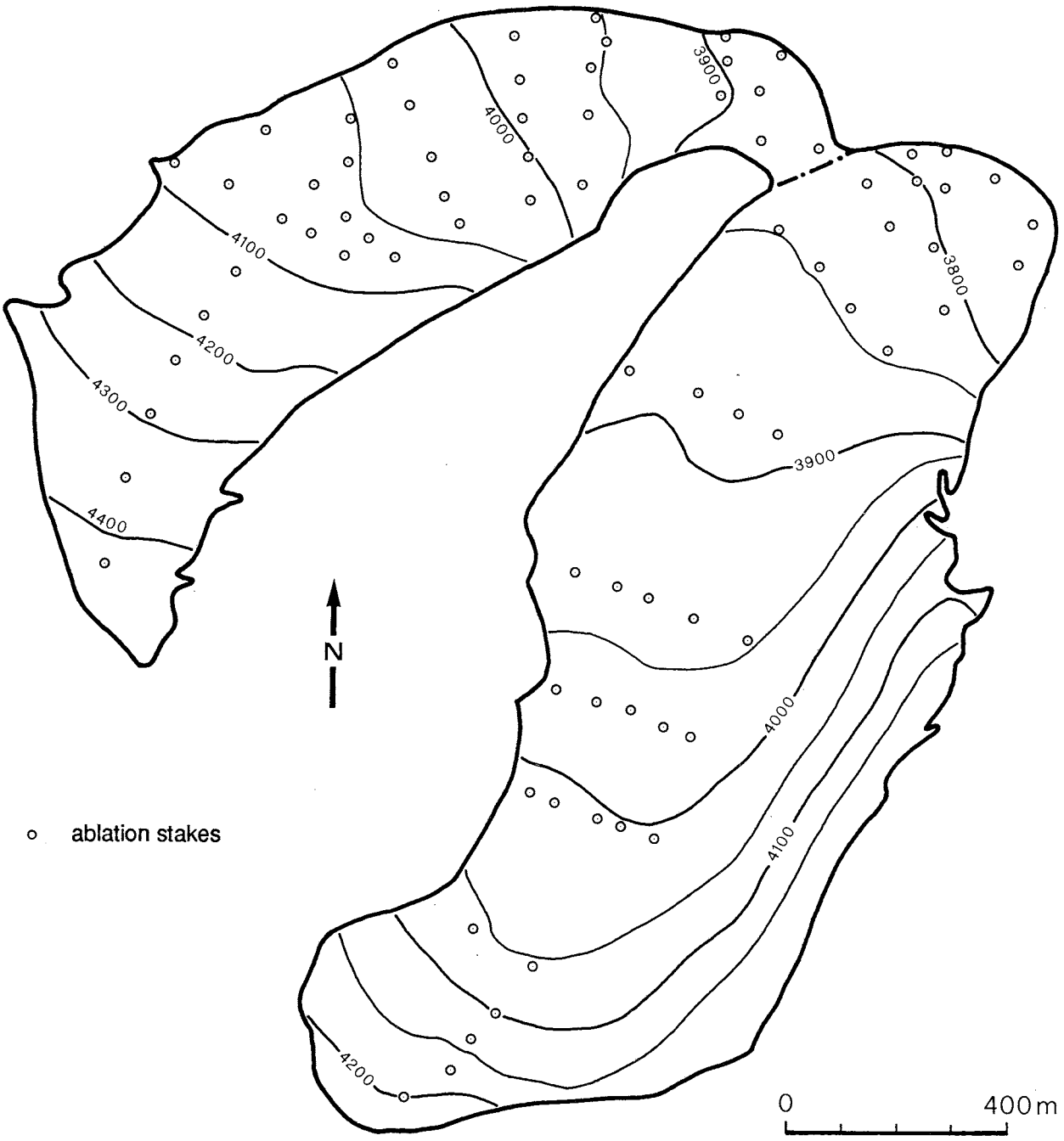
COORDINATES: 43° 05' N / 86° 49' E

Author and date of Photo not reported.

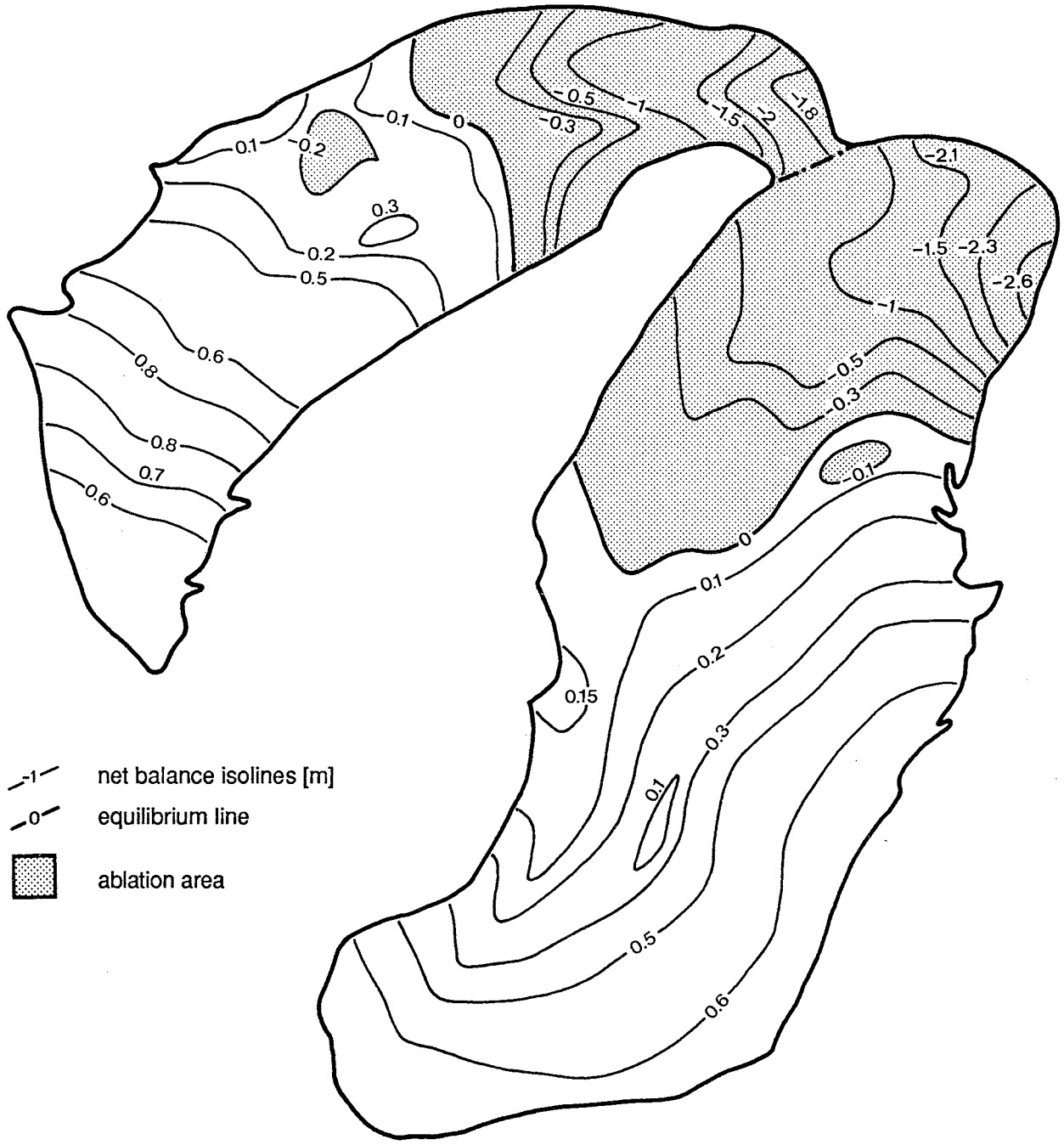
The Glacier No. 1 in the headwaters of Urumqi River in the Chinese Tian Shan is a small valley-type glacier with a total surface area of 1.84 km^2 and consisting of two branches, both exposed to the NE. The highest and lowest points of the glacier are at 4,486 and 3,740 m a.s.l. Annual mean air temperature 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 elevation change. 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 eastern and western branches of the glacier tend to become completely separated.

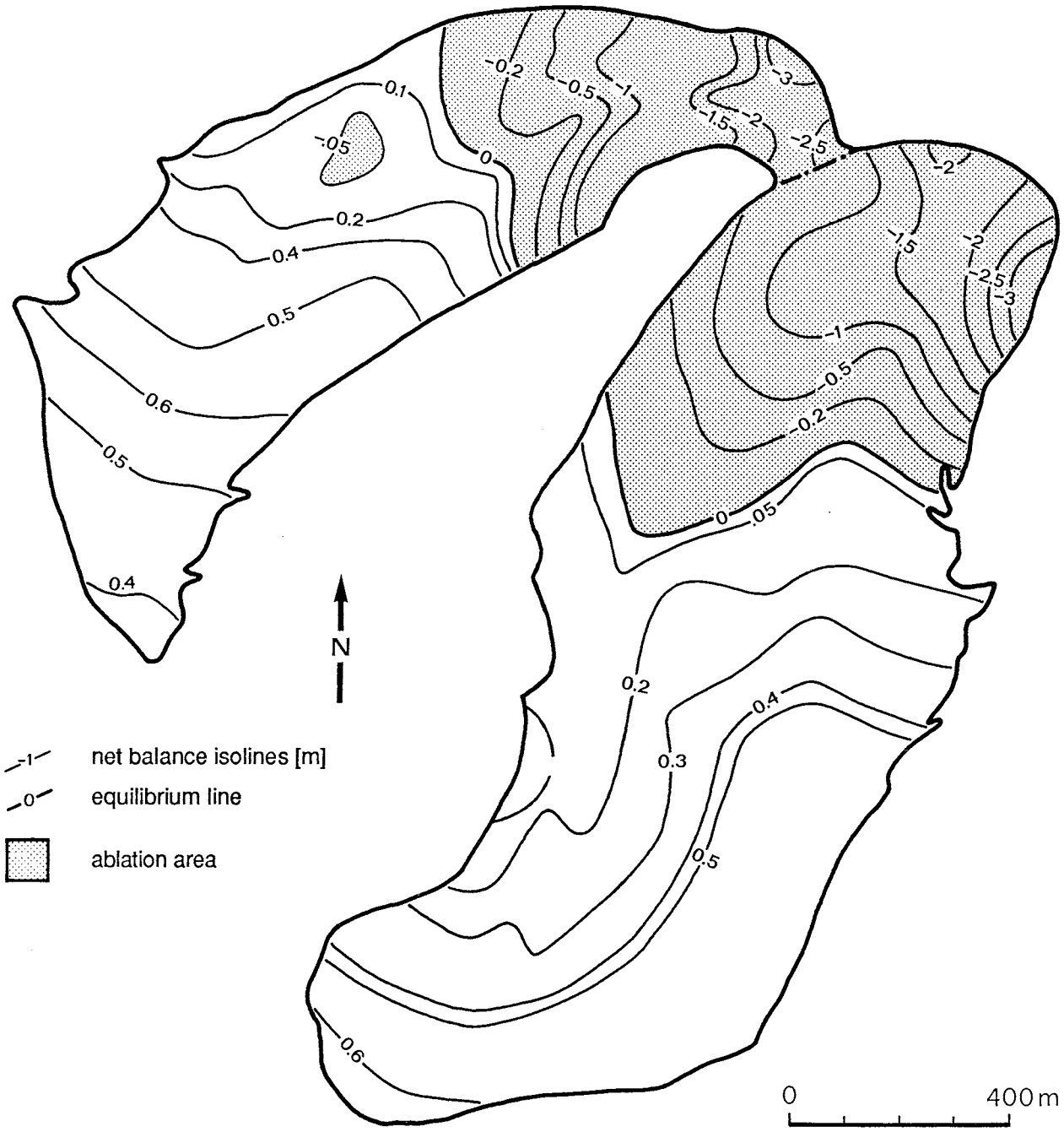
Mass gain (0.23 m water equivalent) in 1991/92 was due to abundant precipitation and cool summer temperatures, whereas unfavourable winter conditions led to a mass loss of 0.29 m water equivalent in 1992/93 despite cool summer temperatures.

3.10.1 Topography and observational network

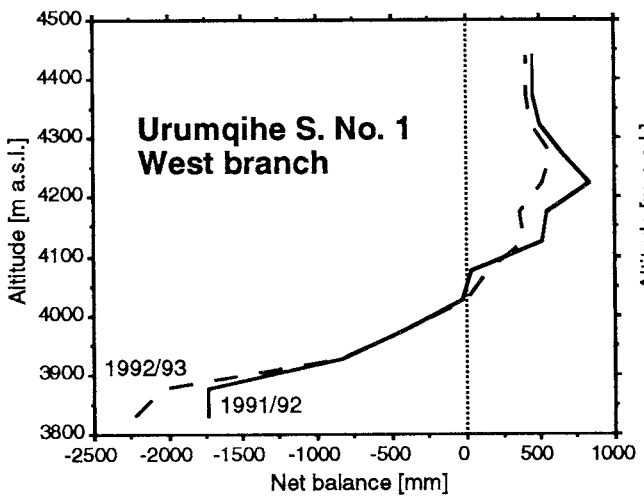


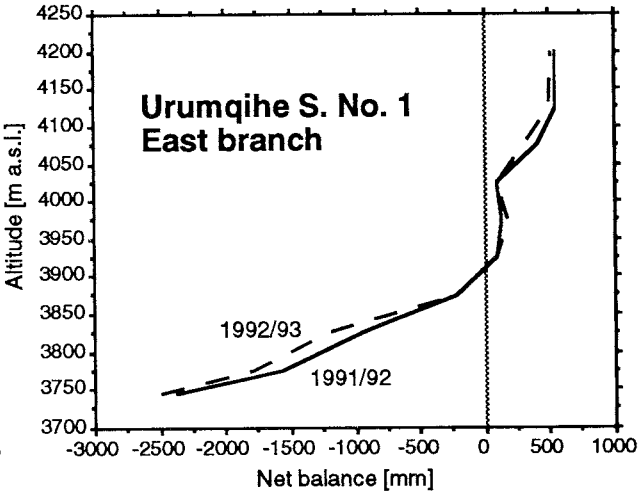
3.10.2 Net balance maps 1991/92 and 1992/93



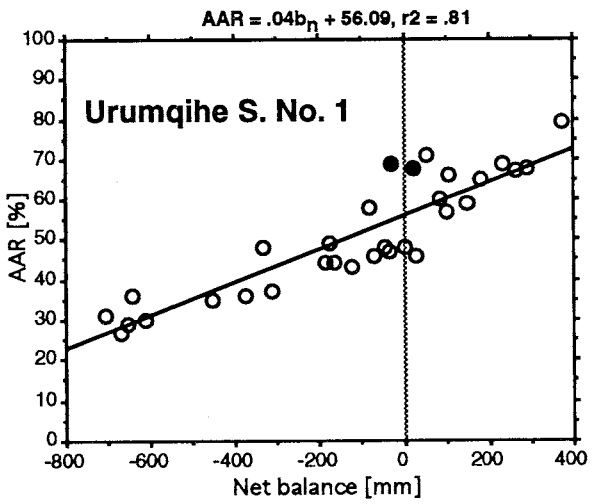

-0.2
-0.5
-1
-3
0.1
-0.5
-1.5
-2
-2.5
0
-2
0.2
-1.5
0.4
-2
-2.5
0.5
-3
-1
0.6
-0.5
-0.2
0.5
0.05
0.4
N
0.2
0.4
0.3
0.5
0.6
-1 net balance isolines [m]
0 equilibrium line
ablation area
0
400 m

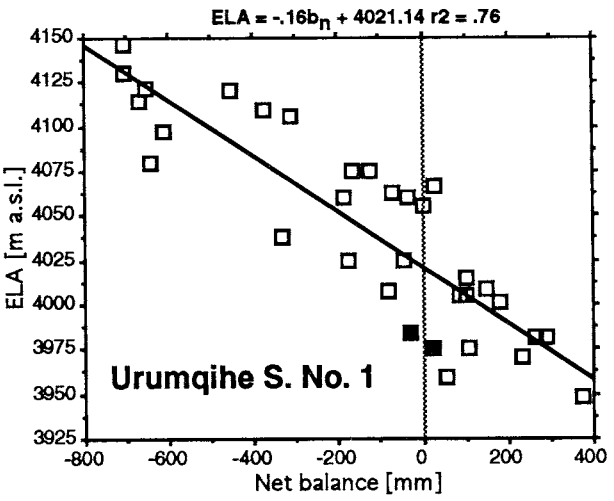
3.10.3 Net balance versus altitude (1991/92 and 1992/93)





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





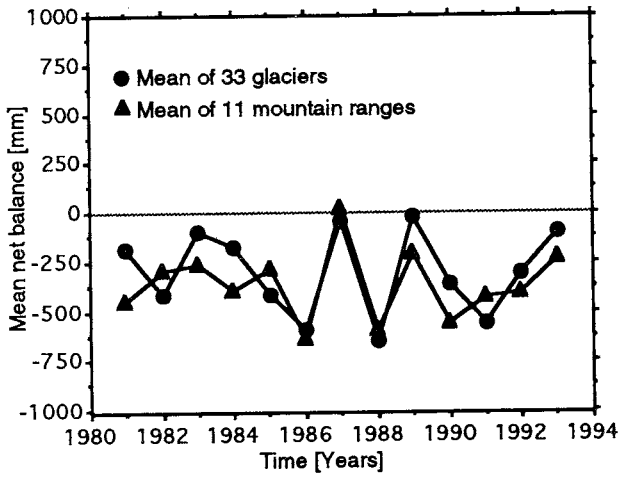
4. FINAL REMARKS AND ACKNOWLEDGEMENTS

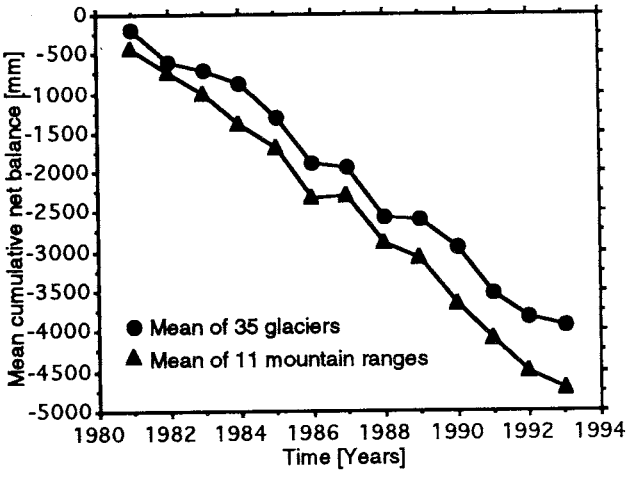
Continuous mass balance records for the period 1980-1993 are now available for 35 glaciers. The corresponding results of this sample from glaciers in North America, Eurasia and Africa can be summarized as follows:

	1980-1990	1991/92	1992/93
mean specific (annual) net balance:	- 296 mm	- 305 mm	- 99 mm
standard deviation:	± 485 mm	±1156 mm	±1045 mm
minimum value:	- 1085 mm	- 2798 mm	- 2342 mm
maximum value:	+ 683 mm	+2340 mm	+2180 mm
range:	1768 mm	4440 mm	4522 mm
positive balances:	23 %	20 %	37 %

Taking the two reported years together, the mean mass balance was negative by roughly two-tenths of a meter of water equivalent per year, a value which is about two-thirds of the decadal average 1980-1990. The proportion of positive mass balances was one-fourth of the sample. Glaciermelt in the northern hemisphere, thus, continued during the two years reported but at a slightly reduced rate. It should be kept in mind, however, that the annual signal of the mean mass balance is smaller by far than the noise of regional variability, and that the signal-to-noise ratio must be improved by cumulating mass balance values over extended time periods. The mean specific net balance (-321 mm) for the three years 1990/91-1992/93 is close to the decadal mean of 1980-1990.

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





The mean of all 35 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 11 mounatin ranges involved. 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 collect and analyze data on maximum ice depth and ablation at the snouts of glaciers with long mass balance records in order to estimate dynamic response times and to derive long-term mass balances from cumulative length changes. 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 Werner Nobs for drawing the maps and to Susan Braun for editing the English. Funding was mainly through IHP/UNESCO, GEMS / UNEP and FAGS / ICSU. It is planned to issue the fourth Glacier Mass Balance Bulletin in winter 1996/97. Suggestions for further improvement of the content and presentation of this new publication series are welcome.

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