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Computation And Reconstruction of the Mass Balance and Glacier Runoff in the Akshiyrak Glacier System : Tien Shan

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SYNOPSIS

The Akshiyrak mountain-glacier system in the Tien Shan, consists of 178 glaciers. The comparison of two topographic surveys of 1943 and 1977 has permitted to obtain graphic and numerical data on the area, volume and altitude of the surface changes for each glaciers. Akshiyrak has lost 3.566 km^3 of ice during between surveys period. Annual net mass balance was -25.6 gr/ cm^2 .The mass balance computation of the western part of the Akshiyrak with the area 125 km^2 was carried out. Altitudinal distribution data of the glacierization of this part of the range are used. The Sary-Tor glacier data combined with the data of the direct Sary-Tor mass balance measurements are included in this investigation. The computational results are compared with the survey data. It is established that the changes of the glacier volume is related to its surface altitude change. The fronts of the glaciers hardly changed during the observation period.

INTRODUCTION

Many researchers pay attention to the analyses of fluctuations of glaciers results and their mass balance changes inside the mountain system for the last years (Dedieu, Reynaud, 1990).

The period of direct mass balance observations rare reaches some decades and usually lasts several years. As a rule they extrapolate the mass balance series by studying the connection between climate and glaciers fluctuations. For that purpose, precipitation and air temperature are often used (Vallon et al., 1986). Either the climatic mass balance index (Glazirin,1985; Konovalov,1987) or the relationship between the balance and meteorological parameters (Dyurgerov, Popovnin,1988; Letreguilly,1988) are used. This approach allows to resolve the problem of separate glaciers mass fluctuations. It is important to compare the reconstructed data or calculation by meteorological parameters with measured mass balance (Glazirin,1985). For this reason, mass balance counting by meteorological data can be carried out only for the glaciers with measured mass balance (we call them base glaciers) during rather long period. Usually, there are only several base glaciers in one mountain system. There are not even one base glacier in the most regions of mountain ranges (the Himalayas, the Karakoram, the Kun Lun, the Andes, the eastern Siberian mountains). As for the whole glacier system there are some difficulties due to different reaction of various glaciers to the same climatic changes.

CLIMATIC CONDITIONS OF AKSHIYRAK GLACIERS MASS BALANCE FORMATION

It was never achieved to evaluate actual mass balance change of all system glaciers for the instrumental observation period for an entire glacier system. This was done for the first time for the Akshiyrak system in the Tian- Shan (Kuzmichenok,1989). This mountain glacier system consists of 178 glaciers with the total area 411 km^2 (Fig. 1). The comparison of two topographic surveys of 1943 and 1977 allowed V.A.Kuzmichenok to obtain the data on area, volume, length and surface altitude changes for each of 178 glaciers. The Akshiyrak has lost 3.566 km^3 of ice during 34 years (1943-1977). Annual net mass balance was -25.6 gr/cm^2. Climatic conditions of this region for the period between these surveys are characterized using data of "Tien Shan" meteorological station situated nearly to the glaciers of Akshiyrak west ranges. The observations showed that 77% of the annual precipitation sum falls in May-September. Consequently, glacier feeding occurs mainly by summer precipitation (Voloshina,1988) and mass loss is determined by temperature conditions of the summer period. Fig.2 shows the temporal curve of the annual total precipitation (from September to August). Also represented the running mean for 5 years. There is a clear tendency of increase from 1947 to 1970.

Temporal curve of the summer mean air temperature (Fig. 3) demonstrates its decrease from the mid-30s to the end of 40s. And since the end of the 40s its increase is observed. So, in spite of the stable increase of air temperature, resulted in considerable negative mass balance in this mountain region.

CALCULATION OF THE GLACIER SYSTEM MASS BALANCE

There are seven large glaciers form the western part of the Akshiyrak glacier system with total area 125 km^2. The total decrease of ice volume for this glaciers was established. The regime peculiarities of these glaciers were investigated in detales for estimating and mass balance and run-off monitoring at the base Sary-Tor glacier situated very near the "Tien Shan" meteorological station. The common tendency in changes in masses of all glaciers allows to calculate mass balance of this part of the Akshiyrak system using observation data for the Sary-Tor glacier. It is possible to compare the calculated cumulative annual mass balance with ice volume changes obtained by the comparison of the two topographic surveys.

Mass balance estimations for the large glacier systems is rather complex problem. The main idea was taken into consideration is that the mass balance field is characterized by relatively spatial homogeneity (Reynaud,1980; Letreguilly,Reynaud, 1989). The relationship between annual mass balance and equilibrium line altitude **ELA** fluctuations is approximated by hypsographyc curve of that glacier. It means that hypsographyc glaciarization curve approximates the unknown relationship between mass balance **B_n** and **ELA** of the glacier system (Dyurgerov, Mikhalenko, 1991; Dyurgerov et al.,1992; Mikhalenko,1990).

The hipsographyc curves of the Sary-Tor glacier and the system area distribution are represented in Fig.4. The fluctuation range and the **B_n** scale are determined by annual mass balance measurement and **ELA** of the Sary-Tor glacier .Then glacier mass balance of the western Akshiyrak part is defined using reconstructed **B_n** meanings for the Sary-Tor and algorithm which takes into account glacierization area distribution data by altitude (Dyurgerov, Mikhalenko, 1991) (See Table 1). Its value will be more positive than for Sary-Tor glacier so far as the considerable part of system's glaciarization area is located above the area of the glacier. The glacier volume change **dV**, determined by this method, is found to be during 34 years, is $-1238.884 *10^{-3}$km^3. V.A.Kuzmichenok [1989] comparing topographic surveys received the volume of $-1024,135 * 10^{-3}$ km^3 , i.e. the difference between measured and calculated was 17%.

The glacier system lost this water irrevocably due to negative. mass balance of the glaciers for this period. The total mass loss due to evaporation **Eo** is included into this volume besides water was brought additionally to the run-off because of negative glacier mass balance **dRg** :

$$dRg = dV - Eo$$

The evaporation from glacier surface in the central Tien Shan forms 15% from the annual precipitation sum, i.e. approximately 6 gr/cm^2 per year, as was estimated by (Bakov,Safonova, 1982). We can do not take into consideration in this case the evaporation comparing it with melted water contributed into run-off value. The total decreasing of glaciarization for the last decades characterizes not only for Akshiyrak glacier system but for other regions of central Tien Shan and the whole central Asia. The process of glacier retreating at the internal Tien-Shan has its peculiarities relatively to "maritime" glaciers at the same time.

FLUCTUATION OF AKSHIYRAK GLACIERS

The shifts of glaciers edges are usually taken into account studying glacier fluctuations. This way of observations needs minimum of expenditures. There are collected rather long observation series for the separate glaciers now. But measurements of the position of glacier edges do not reflect quite correct situation of glacier oscillation. Because, usually not only glacier length changes (and as a consequence the height of its tongue) but area, volume and surface altitude change as well.

It was established that for mountain glacier Akshiyrak system there is no connection between glacier volume changes **dV** and their length changes **dL**. The glacier mass fluctuations are connected much more closely with its surface altitude lowering **dh** (Fig. 5). This dependence is not quite well expressed for whole Akshiyrak system but nethertheless for separate basins it is beyond any doubt. At the same time glacier areas **S** changed a little for the same period (see Table 2), and some of them were stable relatively to **dS** . The volumes of absolutely all glaciers considerably decreased for that period. So, glacier mass balance changes at the Akshiyrak system can be revealed mainly not in the area and length fluctuations but in their surface altitude changes. The main cause of such stable position of glacier fronts during the long period is the negative ice temperature at the low parts of the glaciers .It results in frozen together bed and tongue. The similar behavior was observed for "cold" Scandinavian glaciers as well (Grudd, 1990).

So, the glacier edge position changes which usually are identified with its fluctuations do not give complete information concerning the glacier system evolution in case when cold high-mountain continental glaciers are considered. It is necessary the area and altitude changes data for studying systems of such kind especially for short time intervals.

AKSHIYRAK SYSTEM CHANGES.

If all changes were taken place with Akshiyrak glaciers we will imagine in unfolded view to altitude and exposition there will be possibility to conceive the glacier system as a whole. Volume change of the Akshiyrak system for the period 1943-1977 is represented in Fig.6 (**dV** is normalized). Two large "craters" in the middle part of the system near equilibrium line are marked out in connection with the total glacier mass decreasing. These sources of mass loss are the result of surging glacier activity: Northern Karasay at the south and Glacier No.333 at the north. The Northern Karasay has lost 0.7267 km^3 of ice between two topographic surveys 1943-1977, and it contains 20% from the total mass decreasing of Akshiyrak's glaciers. At the same time its length increased by 60 m and the area decreased by 0.36 km^2. The considerable surface altitude elevation at the lower part of glacier (up to 30 m) occurred due to glacier tongue advance.And at the middle part the surface altitude lowered for 30-35 m. The surface altitude lowering took place at the large area - 47.4 km^2 The intensive melting and irretrievable loss of the large ice volume followed by such considerable decrease of the mass. The area of the glacier No.333 is equal to 8.22 km^2. So, the ice loss is much less in an absolute value - only 0.1148 km^3 However, its tongue has retreated since 1943 for 560m, and the surface altitude decrease in the lower part reached 80 m.

As it was shown the surges of some large glaciers could cause the main mass loss in glacier system in comparison with gradual total decreasing of area and volume. The decrease in glacierization volume caused the total reducing of glacier area. However, **dV** field is found to be similar to **S** field (Fig. 7). It confirms the defining importance of surface altitude lowering in the total glacier mass decrease. So, the analyses of **dh** distribution at the height and exposition in the system is rather informative. Some **dh** increase at the upper part of glaciers is marked and shown at Fig. 8. It is mainly observed for small glaciers which area do not exceed 0.5 km^2. As for the exposition it is impossible to pick out the rumb which has the priority surface altitude increase. Surface altitude lowering for the glaciers with south exposition occurs from the higher altitude. At the lower part of the glacier system the distortion put into the mentioned surging glaciers

CONCLUSION

Comparing **dV** and **dh** for all glaciers we can see that the main mass loss has taken place in large area in a height range 4.0-4.6 km due to surges of two glaciers. At the same time surface altitude in this range did not decrease much. The relative volume decrease of the lower parts of glaciers is negligible. At the tongues the surface altitude changes considerably which confirms the assumption about slight reaction of glacier edges. The area changes at the upper part of the system are not large (localized) as well as **dV**. The maximum values of **dS** and **dV** are in the middle of the glacier system and **dh** is in the lower part. The surface altitude change gradient is not fixed at the upper part up to four km high. At the upper mountain zone (from 4.6 to 5.1 km) it was not marked the surface altitude changes and glacier volumes. Income and expenditure of the mass is balanced due to proportional interior and external mass exchange. We can mark the conventional boundary of zero balance for the period 1943-1977 at the altitude 4.6 km. And the largest changes of volume are take place.

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Table 1

Year	P, mm	Ts, grad C	Bn gl, gr/cm^2	ELA gl, m	Bn sys, gr/cm^2
1945	302	3.4	-7	4262	-0.85
1946	320	2.5	19.7	4134	17.95
1947	210	3.3	-6.4	4259	0.95
1948	271	3.6	-5.8	4256	2.05
1949	341	3.2	-0.3	4230	4.95
1950	341	3.7	-17.9	4314	-10.55
1951	307	2.4	21.5	4126	19.35
1952	315	3.6	-12.1	4286	-3.55
1953	330	3.8	-17.9	4314	-8.05
1954	344	2.6	18	4143	16.75
1955	224	3.4	-15	4300	-4.85
1956	395	3.6	-17.7	4313	-7.95
1957	310	3.1	1	4224	8.15
1958	322	3	4.7	4206	8.95
1959	395	4.3	-2.8	4242	4.15
1960	268	3.7	-11.4	4283	-3.25
1961	291	4.2	-24.2	4344	-15.05
1962	293	3.5	-10	4276	-2.25
1963	294	3.3	-3.2	4244	3.55
1964	382	2.6	16.5	4150	17.15
1965	335	3.3	-3.7	4246	2.95
1966	318	4.1	-23.8	4342	-14.65
1967	398	3	7.9	4191	14.95
1968	278	3.8	-19.8	4323	-11.45
1969	367	3.3	-3.7	4246	2.95
1970	362	3.2	-0.7	4232	4.75
1971	336	3.7	-15.8	4304	-5.05
1972	310	3.5	-16.5	4150	-7.65
1973	295	4.4	-31	4376	-23.25
1974	353	2.8	10.2	4180	15.15
1975	343	3.3	-3.7	4246	2.95
1976	244	3.2	-1.6	4236	3.95
1977	239	4.1	-28	4362	-20.25

Table 2

Fluctuations of glaciers in western part of the Akshiyrak system (1943-1977)

(by V.Kuzmichenok,1989)

Glacier	**dL**	**dS**	**dh**	**dV**
	km	km^2	m	km^3
Petroff	-0.19	-0.37	-3.5	-0.2350
Lysiy	-0.26	-0.23	-18.1	-0.0897
Davidoff	-0.38	-0.38	-17.7	-0.2131
Sary-Tor	0.0	-0.09	-19.0	-0.0694
Bordu-1	+0.16	0.0	-16.4	-0.1036
Bordu-2	-0.23	-0.24	-11.5	-0.0915
AkBell	-0.40	-0.18	-10.	-0.0270

KEY FOR FIGURES

Fig. 1. Location of the Akshiyrak glacier system in central Asia. The described glaciers are indicated.

Fig. 2. The 1931-1988 annual precipitation at the Tian Shan meteorological station. Vertical axis is normalized.

Fig. 3. The 1931-1988 summer mean temperature at the Tian Shan meteorological station. Vertical axis is normalized.

Fig. 4. The hypsographic curves of the Akshiyrak glacier system and the Sary-Tor glacier. The points of $\mathbf{B_t(ELA_t)}$ are shown.

Fig. 5. The volume change, **dV**, - surface altitude change, **dh**, relation for the Akshiyrak glacier system.

Fig. 6. The volume change, **dV**, distribution in the Akshiyrak glacier system. The axes are normalized.

Fig. 7. The area, **S**, distribution in the Akshiyrak glacier system. The axes are normalized.

Fig. 8. The surface altitude change, **dh**,distribution in the Akshiyrak glacier system. The axes are normalized.

KEY FOR TABLES

Table 1. The results of mass balance reconstruction of the Akshiyrak glacier system.

Table 2. Fluctuations of glaciers in western part of the Akshiyrak system (1943-1977).

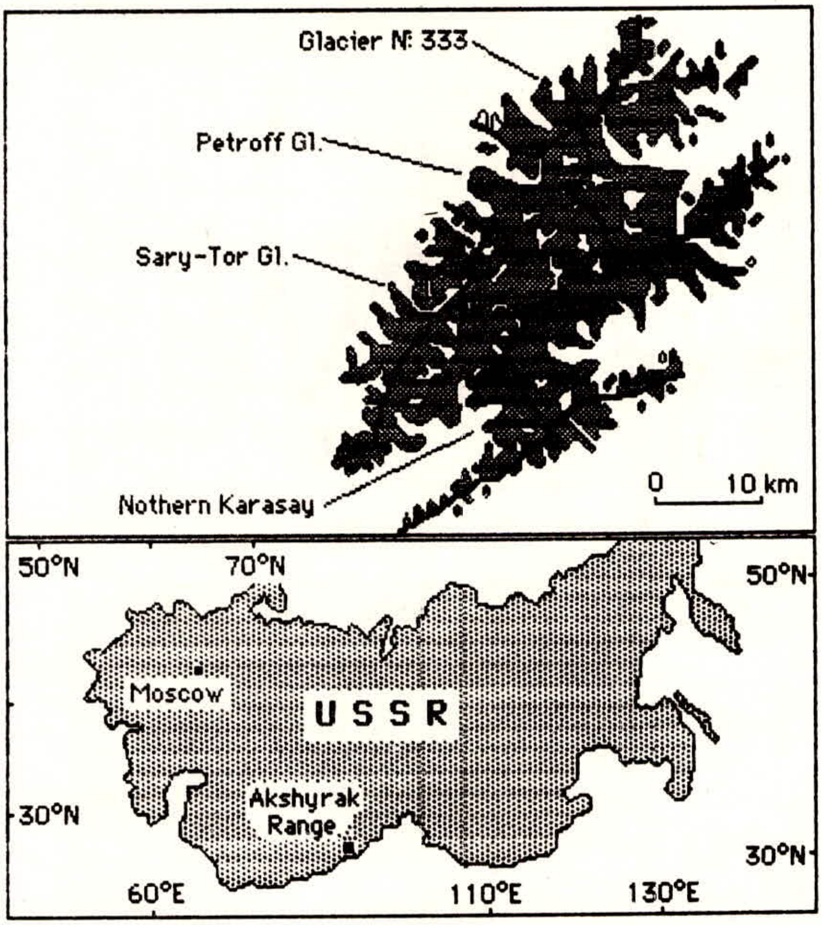
Glacier N: 333
Petroff Gl.
Sary-Tor Gl.
Nothern Karasay
0
10 km
50°N
70°N
50°N
Moscow
U S S R
30°N
Akshyrak
Range
30°N
60°E
110°E
130°E

Fig. 1

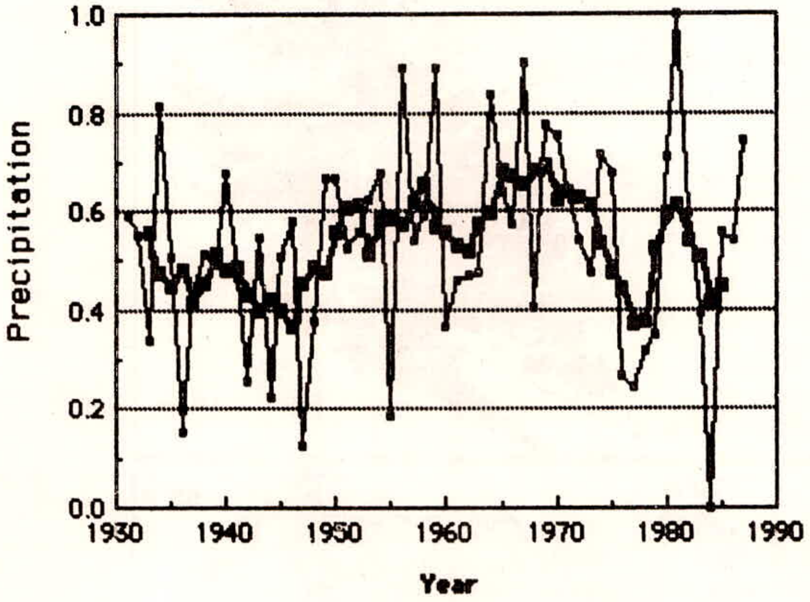
Precipitation
1.0
0.8
0.6
0.4
0.2
0.0
1930
1940
1950
1960
1970
1980
1990
Year

Fig. 2

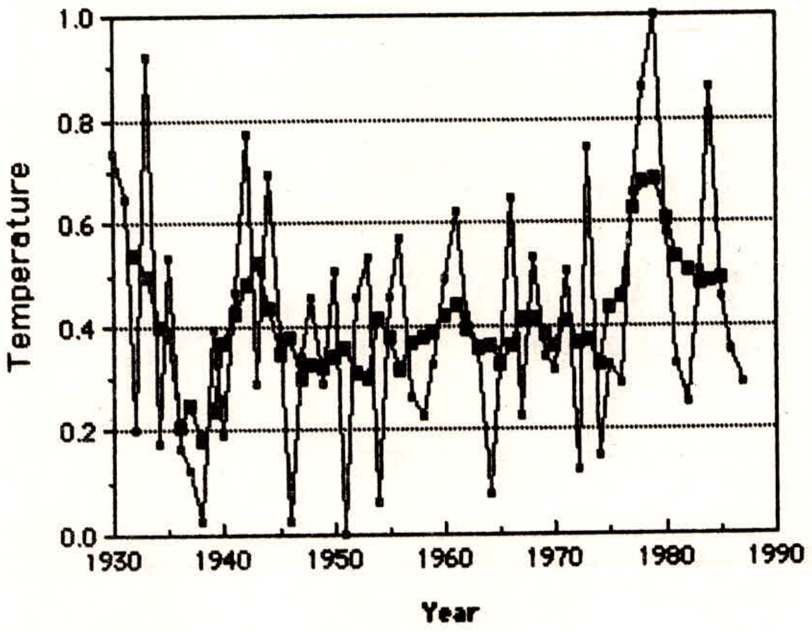
1.0
0.8
0.6
0.4
0.2
0.0
Temperature
1930
1940
1950
1960
1970
1980
1990
Year

Fig. 3

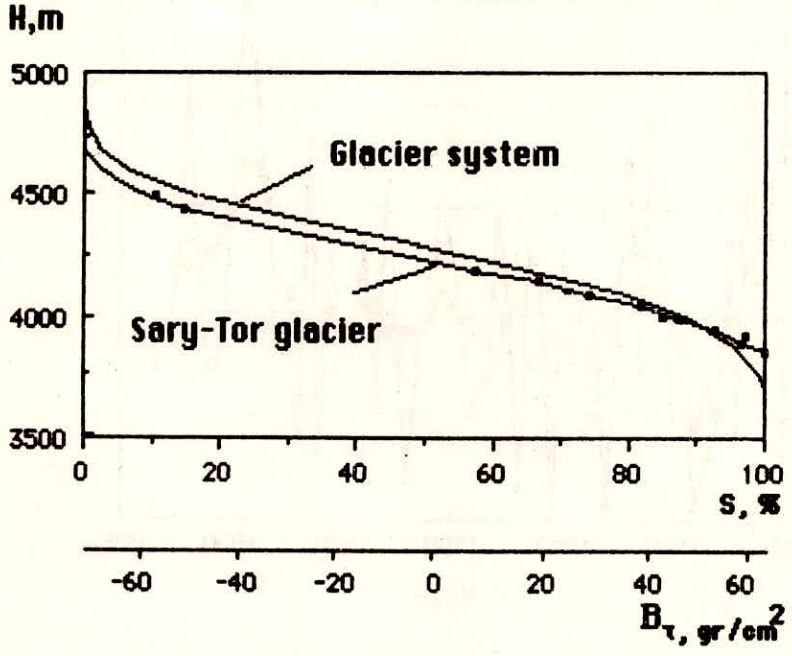
H,m
5000
4500
4000
3500
Glacier system
Sary-Tor glacier
0
20
40
60
80
100
S, %
-60
-40
-20
0
20
40
60
B_τ, gr/cm^2

Fig. 4

Fig. 4

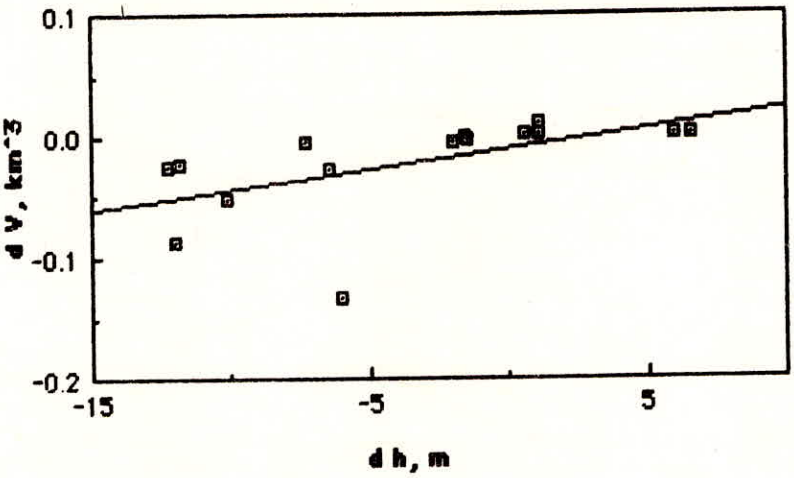

Fig. 5

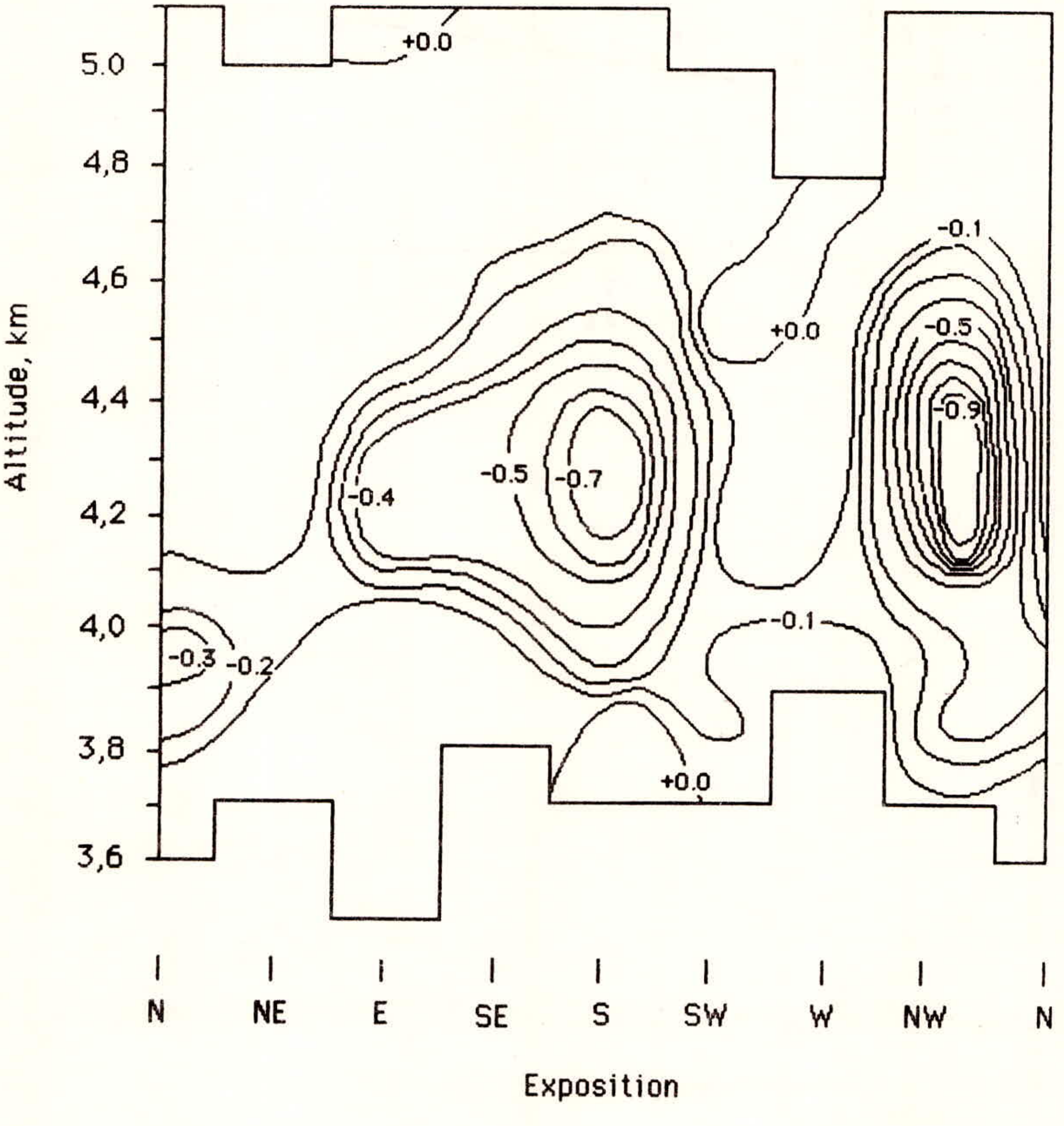
5.0
4,8
4,6
4,4
4,2
4,0
3,8
3,6
Altitude, km
+0.0
-0.1
+0.0
-0.5
-0.9
-0.4
-0.5
-0.7
-0.1
-0.3
-0.2
+0.0
N
NE
E
SE
S
SW
W
NW
N
Exposition

Fig. 6

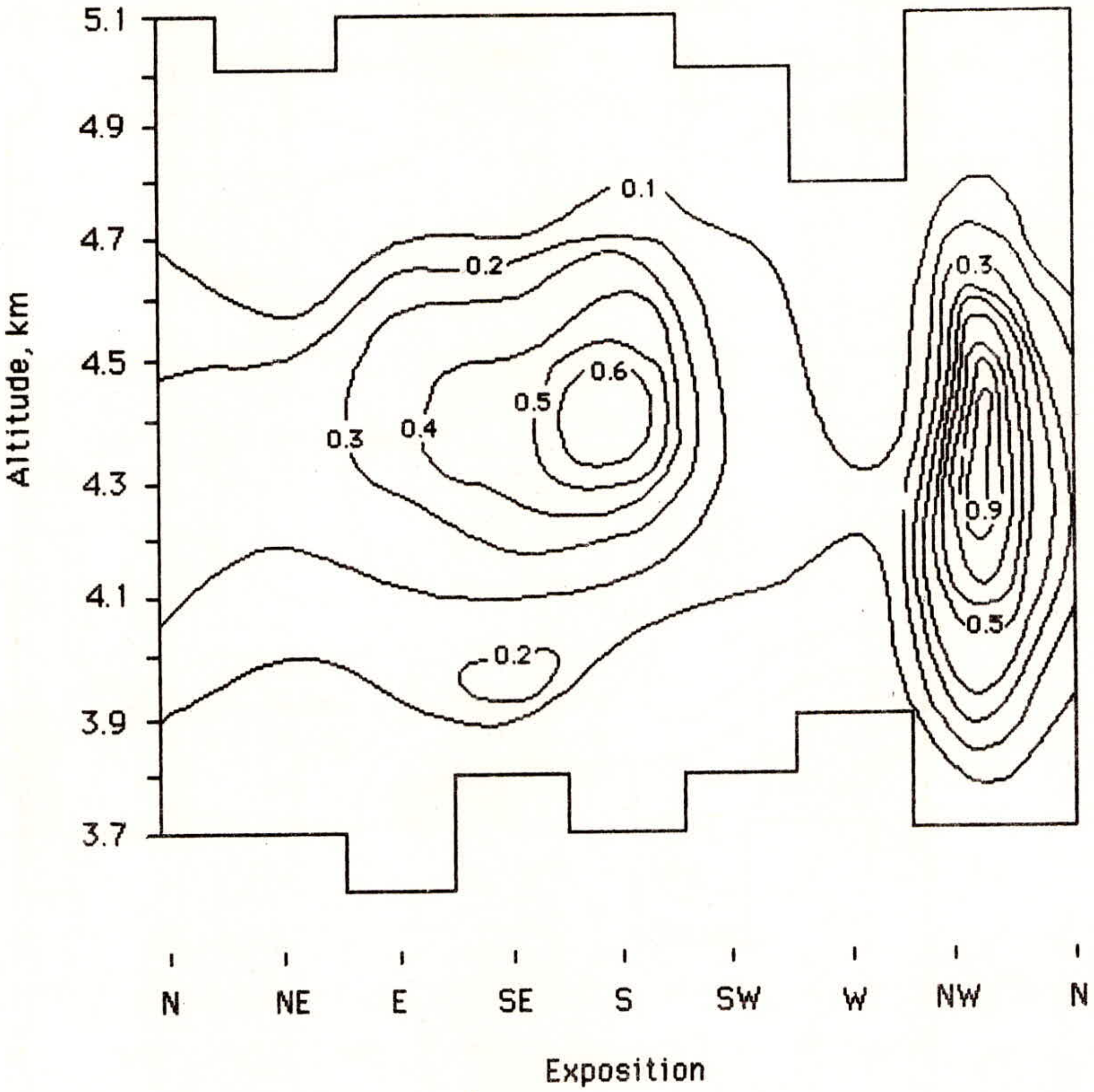
5.1
4.9
4.7
4.5
4.3
4.1
3.9
3.7
Altitude, km
0.1
0.2
0.3
0.4
0.5
0.6
0.2
0.3
0.9
0.5
N
NE
E
SE
S
SW
W
NW
N
Exposition

Fig. 7

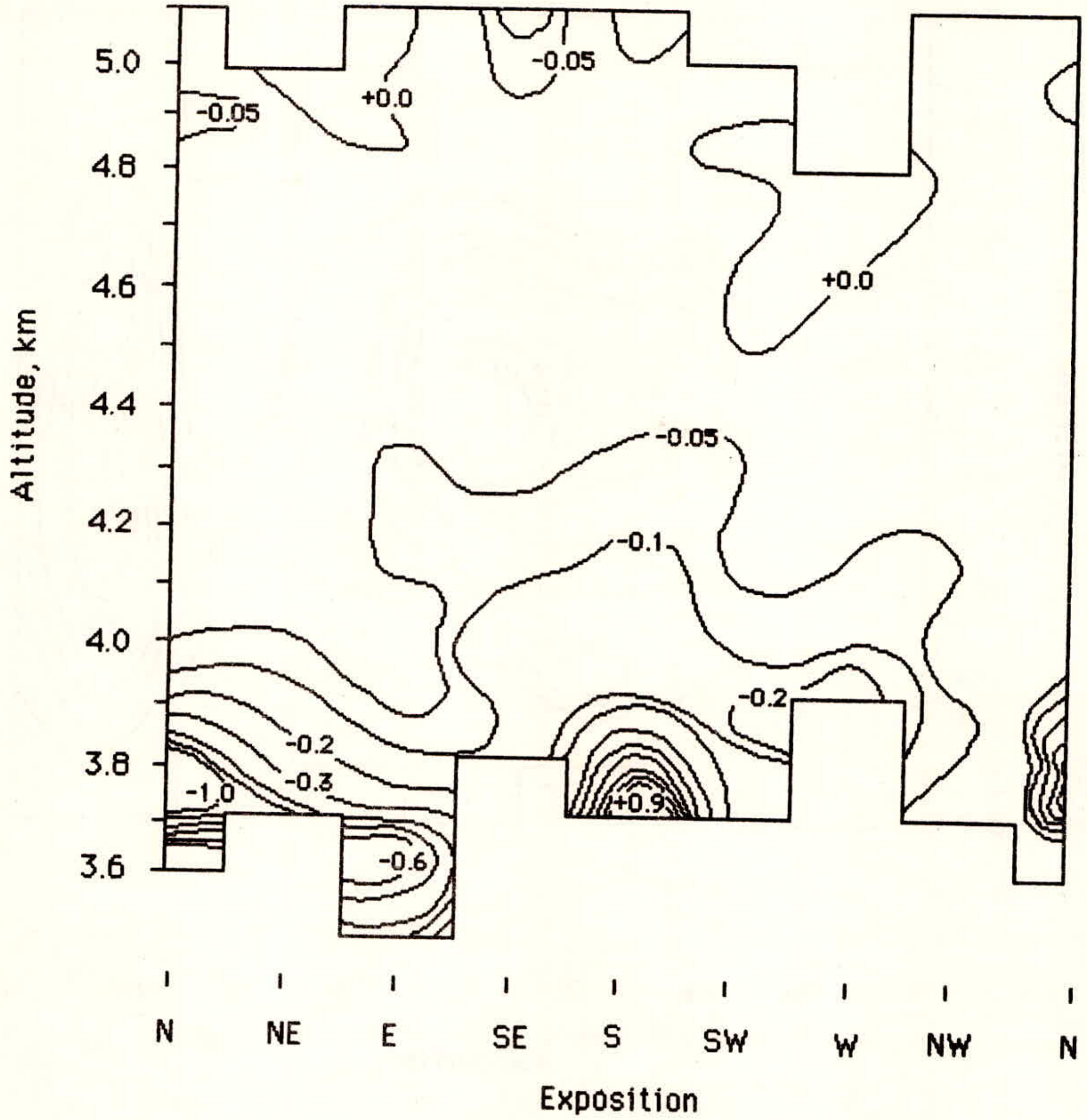
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
Altitude, km
-0.05
+0.0
-0.05
+0.0
-0.05
-0.1
-0.2
-0.2
-0.3
-1.0
+0.9
-0.6
N
NE
E
SE
S
SW
W
NW
N
Exposition

Fig. 8