

# ON THE HEAT BALANCE OF THE SURFACE OF THE FEDCHENKO GLACIER

1960

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**Abstract**

**Full Text**

**GEOPHYSICS**

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## **ON THE HEAT BALANCE OF THE SURFACE OF THE FEDCHENKO GLACIER**

*(Presented by Academician A. A. Grigor'ev, 30 IV 1960)*

Under the IGY program, an expedition of the Academy of Sciences of the Uzbek SSR carried out, on the Fedchenko Glacier in its various parts, gradient measurements of wind speed, temperature, and humidity near the glacier surface, as well as measurements of the intensity of solar radiation. The results of measurements in the upper part of the glacier on the firn surface, at an elevation of 5000 m above sea level, in the summer of 1958 were published earlier (1). In the summer of 1959, the author, with a group of observers as part of the same expedition, carried out analogous measurements in the middle part of the zone of intensive melting, at an elevation of 3800 m above sea level, on a surface free of snow. These measurements make it possible to form a concrete idea of the mechanism of accumulation and melting of material in the glacier.

The Fedchenko Glacier has a length of 78 km and an average channel width of 2.5 km. Its sources are at an elevation of 6000 m, and the lower part (tongue) is at an elevation of 2900 m above sea level. The glacier channel, almost straight, undergoes a certain bend in its middle part. For an approximate estimate of the reserves of material in the glacier, let us assume that the cross-sectional area of its channel is everywhere equal to the cross-sectional area of the channel in the region of the high-mountain observatory (middle course of the glacier). According to the estimate of I. S. Berzon, V. A. Pak, and V. N. Yakovlev (2), it is equal to 1 150 000 m<sup>2</sup>. Under these conditions the total volume of ice in the glacier channel has a value of  $9 \cdot 10^{10}$  m<sup>3</sup>, which corresponds to the water reserves of a reservoir 90 m deep with a surface area of  $10 \times 100$  km<sup>2</sup>.

The glacier surface descends smoothly from the sources to the tongue and, together with the mountain ranges bounding it, forms a gigantic trough; as a result, the wind speed above the surface is always directed along the axis of the glacier from the headwaters toward the tongue, except for a small region adjacent to the glacier tongue, where in the daytime the wind direction changes to the opposite.

In what follows we shall call the measurement point at an elevation of 5000 m above sea level (the middle part of the firn region) point *a*, and the measurement point at an elevation of 3800 m above sea level (the middle part of the ablation zone) point *b*. All the measurement results and estimates of heat fluxes given

Fig. 1

Figure 1: Fig. 1

below refer to the period of intensive melting (July, August, and the beginning of September). At points *a* and *b* the wind speed is on average the same and equal to 4 m/sec at a height of 1 m above the surface.

The air temperature near the glacier surface has a pronounced diurnal variation. At point *a*, at a height of 1 m above the ground surface, it takes values of about  $+1^\circ$  by day and about  $-7^\circ$  at night; at point *b*, at the same height, about  $+6^\circ$  by day and about  $+2^\circ$  at night.

The vertical profiles of wind speed, temperature, and specific humidity are well described by a logarithmic law of variation with height. The air temperature both at *a* and at *b* invariably increases with height, i.e., a temperature inversion occurs, as a result of which the turbulent heat flux is directed downward. The vertical profile of specific hum—

humidity at points *a* and *b* differs substantially. At point *a*, the specific humidity during the greater part of the day (including the daytime hours) decreases sharply with height, which indicates intense evaporation from the surface. At point *b*, on the contrary, humidity always increases with height, and therefore the turbulent flux of water vapor here is directed in the opposite direction—from above downward (condensation of water vapor occurs on the surface). This phenomenon is connected with the fact that the air in region *b* has a humidity close to saturation conditions (at a height of 1 m above the surface the specific humidity is 7—6 g/kg and changes almost not at all during the day).

To estimate the magnitudes of the turbulent fluxes of heat and water vapor, the method proposed in <sup>(3,4)</sup> was used.

The supply of heat to the surface at point *a* occurs through radiative and turbulent heat fluxes, whose daily mean values are 85 and 76 cal/cm<sup>2</sup> · day. The heat assimilated by the surface is spent: on evaporation, 96.5 cal/cm<sup>2</sup> · day (for the latent heat of evaporation of firn the value 670 cal/g was adopted <sup>(1)</sup>); on melting,

### Fig. 1

63.5 cal/cm<sup>2</sup> · day; and the remaining part goes into the thickness of the firn by thermal conduction (this quantity is negligibly small in comparison with the other components both at *a* and at *b*). Thus, the part of the heat expended on evaporation amounts to 60% of the sum of the heat arriving at the surface, and that expended on melting to 40%.

At point *b*, the supply of heat to the surface also occurs through the radiative heat flux, whose magnitude is 650 cal/cm<sup>2</sup> · day, and the turbulent heat flux, 620 cal/cm<sup>2</sup> · day. The amount of heat released at the surface through condensation

of water vapor proves to be negligibly small in comparison with its supply by radiation and turbulence, but in order of magnitude it is comparable with the amount of heat expended on evaporation at point  $a$ . Thus, practically all the heat arriving at the surface in region  $b$  is spent on melting.

From the estimates presented it is evident that at point  $b$  the radiative and turbulent heat fluxes are almost an order of magnitude greater than the fluxes at point  $a$ . This circumstance is associated with the large difference in elevation and, consequently, in air density and, chiefly, with the sharp difference in the albedo of the underlying surface (at point  $a$  it is 80%, and at point  $b$  26%). It should be noted that the intensity of the downward radiation at points  $a$  and  $b$  is almost the same (the maximum values in the mean daily course are  $\sim 1.5$  cal/cm<sup>2</sup> · min and are reached at the same time—about 11–12 hours by mean solar time).

Measurements at points  $a$  and  $b$  give a characteristic picture of the heat balance for two different regions into which the glacier is divided according to the type of surface: for the firn region  $AB$  (see Fig. 1) and for the zone of intense ice melting  $BC$ .

The firn region (from the sources  $A$  to a certain boundary  $B$ ) is characterized by the fact that, on average over the year, material is supplied to it by falling precipitation. Snow, falling mainly in the winter and spring months, does not melt completely during the warm months, but each year leaves a layer of firn, which, as new layers accumulate, descends, is compressed, and gradually turns into ice. The zone

intensive melting of ice (from boundary  $B$  to the terminus  $C$ ) is characterized by the fact that in it there is an outflow of material from the surface due to melting. Snow that falls during the winter months melts here completely in the warm season of the year, and in summer the glacier surface in zone  $BC$  is free of snow and consists of exposed, intensively melting ice. During the summer and the beginning of autumn a considerable layer of exposed ice melts away, and this is what determines the mean annual outflow of material from the glacier surface due to melting. The melted thickness of ice is compensated by the flux of ice flowing into zone  $BC$  from the higher-lying areas. Let us denote by  $q$  (g/cm<sup>2</sup> · yr) the quantity characterizing the mean annual influx or outflow of material from a unit area of the surface. The relation between  $q$  and the flux of ice flowing in the glacier is expressed by the continuity equation

$$\frac{dQ(x)}{dx} = q(x),$$

where  $x$  is the direction along the glacier axis and  $Q$  is the flux of ice in the body of the glacier through the transverse cross section of the bed. In the present case

$$q(x) = \int_0^l q dy,$$

where  $l$  is the width of the glacier at point  $x$ .

Region  $AB$  is characterized by  $q > 0$ , while region  $BC$  is characterized by  $q < 0$ ; at boundary  $B$  (the snow line)  $q = 0$ . In absolute value,  $q$  increases from boundary  $B$  toward the sources  $A$  and toward the terminus  $C$ .

From the continuity equation it is evident that  $Q$  increases from the sources  $A$  in the direction of flow and reaches a maximum at boundary  $B$ , decreasing toward the terminus. This circumstance must be manifested, in particular, in the fact that the surface velocity of ice flow—if one assumes that the area of the transverse cross section of the bed changes little along the length of the glacier and neglects the influence of lateral tributaries—must be greatest in the middle part of the glacier (in the region of boundary  $B$ ). Measurements carried out by a group of glaciologists under the direction of V. K. Nozdryukhin show that the surface velocities of ice flow on the glacier axis do indeed attain their greatest values in its middle part (downstream from the snow line, in the region of the Nalivkin Glacier and the High-Mountain Observatory, the velocities of ice flow are 80–100 cm per day). Toward both the sources and the terminus the velocities decrease, and at point  $a$  the velocity of ice motion was found to be 50 cm per day.

The quantity  $q$ , characterizing the accumulation and melting of material on the glacier surface, is ultimately related to the thermal regime of the surface, since it is determined by the amount of heat assimilated by the surface and expended on melting. For this reason, it appears important to study the thermal regime of the glacier surface in its different parts, especially in the summer months during the period of intensive melting.

From the estimate given above of the amount of heat arriving at the surface at point  $a$  and expended on melting (60%) and on evaporation (40%) from the surface, the role of evaporation becomes clear as a factor that retards melting in the firn region and thereby determines the accumulation of material. Indeed, despite the fact that a large part of the heat is expended on evaporation, the amount of evaporated material is small, since the latent heat of evaporation of water is almost 10 times greater than the latent heat of melting of ice. Therefore, if evaporation from the surface were absent, the layer of melted material would be  $2\frac{1}{2}$  times greater (the layer of firn recalculated as water is meant).

In zone  $BC$ , at point  $b$ , above the surface of exposed ice, the evaporation factor retarding melting is absent, as a result of which intensive melting of ice takes place. According to our estimate, at point  $b$  the thickness of the layer of ice melting on average per day (July, August) is 16.6 cm, and over 60 days of intensive melting it is 10 m.

The role of the glacial wind also becomes clear as a factor regulating the processes of evaporation and condensation of water vapor on the ice surface and, consequently, determining the conditions for the accumulation of material in the firn zone of the glacier and for intensive melting in its middle and lower parts. Since, as was noted above, the movement of air over the glacier surface always occurs in one direction—along the glacier axis from its upper reaches toward the tongue—and since dry air flows over the surface of the firn area at an altitude of 5000–6000 m above sea level, conditions are created here for intensive evaporation from the firn surface. As the air mass moves downward, toward the glacier tongue, it gradually becomes saturated with water vapor, evaporation from the surface decreases and, finally, ceases when the air becomes saturated with moisture. This occurs in the zone of intensive ice melting. Even the opposite situation may be observed, as was noted above: the turbulent flux of water vapor changes direction to the opposite one, and vapor condenses on the ice surface.

The described mechanism of accumulation and melting of material is especially clearly traceable on the Fedchenko Glacier because of its gigantic dimensions (length 78 km). However, to one degree or another this mechanism is apparently common to all valley-type glaciers.

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Received  
27 IV 1960

## REFERENCES CITED

- <sup>1</sup> A. B. Kazanskii, V. N. Kolesnikova, *Izv. AN SSSR, ser. geofiz.*, No. 4 (1960).
- <sup>2</sup> I. S. Berzon, V. A. Pak, V. N. Yakovlev, *Glaciological Expedition to Fedchenko Glacier*, Collected Articles, Publishing House of the Academy of Sciences of the Uzbek SSR, Tashkent, 1960.
- <sup>3</sup> A. B. Kazanskii, A. S. Monin, *Izv. AN SSSR, ser. geofiz.*, No. 1 (1956).
- <sup>4</sup> A. B. Kazanskii, A. S. Monin, *Izv. AN SSSR, ser. geofiz.*, No. 6 (1958).

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