Hydrological role of avalanches in the Caucasus

M. Ch. Zalikhanov

Abstract. Redistribution of snow by avalanches in the Caucasus is of great significance in the nourishment of glaciers and the runoff, since, in general, the thickness and density of avalanche banks are considerably greater than the normal snow cover and reaches a volume of 3-4 million cubic metres.

From field observations for 1964-69 we obtained the dependences between the volumes of avalanche banks and areas of avalanche snow catchment for five regions in the Caucasus. These data show clearly that in the West Caucasus avalanches transport 38% more snow than do avalanches in the Central Caucasus, and 25% more than those in the East Caucasus (with equal number of snow catchment areas). Avalanches transport the most snow from north and north-east slopes and the least from south and south-east slopes. This difference increases with absolute elevation of the area up to an altitude of 3500 m above sea level. The greatest amount of snow is transported from the altitudes of 3500-4000 m above sea level in all regions of the Caucasus.

The other indicator-coefficient of potential snow avalanche storage, calculated as a relation of avalanche slope areas to the total area of the region, has an equal value for all alpine zones in the West, Central, and East Caucasus. The difference of values of this coefficient for slopes of different orientation decreases with elevation. These calculations show that in the alpine and nival zones of the Caucasus, 30-64% of the snow accumulation can be transported by avalanche to the valley bottoms.

Avalanches are a characteristic feature of all mountain regions, and their role in glacier nourishment is well known. A great amount of avalanche snow accumulates on glacier surfaces every year; its contribution to glacier nourishment, based on the data of several researchers, varies from 10% to 65%, depending on the type of glacier (Kotlyakov, 1968; Losev, 1966; Tsomaya, 1963).

Avalanches in the Caucasus and other mountain regions transport millions of cubic metres of snow to both glacier surfaces and valley bottoms, filling up depressions in the relief and often blocking mountain rivers. Avalanche snow patches, because of their high density, melt slowly and therefore reduce runoff in the spring, and increase it in the summer (Losev, 1960; Puchkova, 1964; Sosedov, 1967). During 1962-63, a
winter of heavy snowfall in the upper parts of the Nakra and Dolra basins (southern slopes of Central Caucasus) and in the Central Tien-Shan, avalanche snow patches reached diameters of 200-400 m, a thickness of 35-37 m, and a density of 0.70-0.75 g/cm$^3$. If such heavy-snow winters occur frequently, cirque glaciers could begin to form at the location of these snow patches.

Iveronova (1962, 1963) and Seversky (1969) have carried out a quantitative evaluation of the hydrological role of avalanches in two small valleys in Central Asia. Not only the influence of the amount of snow upon the occurrence of avalanches and the formation of glaciers is known, but climate in winter as well (Shults, 1963).

Our first investigations in the Central Caucasus in 1962 showed that the hydrological role of avalanches is great. In the Kabardinian-Balkar Republic, for example, approximately 2500 avalanches fall from 1120 catchment areas during one winter. These avalanches bring 12.5 million m$^3$ of snow to the valley bottoms in alpine and subalpine zones. The volume of each avalanche varies from 1000 to 200,000 m$^3$. During heavy-snow winters the avalanche snow patches may be even larger. For example, in the summer of 1963 the volume of avalanche snow was 3-4 million m$^3$ on the southern slope of the Central Caucasus.

Using our field investigations of 5000 avalanche sites, and the research of others (Abdushelishvili, 1970; Sulakvelidze, 1953; Tushinsky, 1949), we studied the hydrological role of avalanches in the Caucasus. The relation was obtained between the mean volume of avalanche snow and the catchment area of avalanches. This relation is based on investigations of avalanche cones in the Baksan valley (Central Caucasus) in 1962-63, a winter of heavy snowfall. This relation is:

$$V = 23\sqrt{S}$$

Here $V$ is the mean volume in 1000 m$^3$ of avalanches and $S$ is the catchment area of avalanches in hectares.

The relation for normal winters from 1964 to 1969 became

$$V = 6.9\sqrt{S}$$

Similar relations were obtained for the other regions of the Caucasus (Fig. 1):

- $V = 11\sqrt{S}$ — northern slopes of the West Caucasus,
- $V = 4.5\sqrt{S}$ — the East Caucasus,
- $V = 11\sqrt{S} + 1.8S$ — southern slopes of the Caucasus,
- $V = 6.7\sqrt{S} + 1.1S$ — southern slopes of the Central Caucasus.

These equations are valid for the West Caucasus from 1100 to 1200 m and higher, for the Central Caucasus from 1300 to 1400 m and higher, and for the East Caucasus from 1800 to 1900 m and higher. The minimum area used in the relation is 0.2 — 0.3 km$^2$. By comparing these relations we can see that the same area provides 38% more snow in the West Caucasus than in the Central Caucasus. If we compare the East and West Caucasus, we see a 120% difference in favour of the West. On the southern slope of the West Caucasus there is 40% more avalanche snow than on the southern slopes of the Central Caucasus. The amount of snow which is transported to 1 km of valley bottom varies greatly, depending on the altitude and orientation.

In Fig. 1 there is a relation between the avalanches' snow volume and the orientation of slopes, depending on altitude, for a heavy-snow winter in the Central Caucasus. It is seen that the least amount of snow is brought from southern and south-eastern slopes, and the greatest from the northern and north-eastern slopes. This difference increases with altitude at least up to an elevation of 3500 m.

Thus, the slope orientation in the Caucasus is important for avalanche formation. That is the reason that we tried to select valleys of similar orientation to compare regions of the Caucasus.
FIGURE 1. Relation between the avalanche volume and the altitude for a snowy winter for slopes of various orientations in the Central Caucasus.

FIGURE 2. The volume of avalanche snow for one kilometre of valley bottom. 1, East Caucasus; 2, northern slopes of the Central Caucasus; 3, southern slopes of the Central Caucasus; 4, northern slopes of the West Caucasus; 5, southern slopes of the West Caucasus.

In Fig. 2, the relation between the volume of avalanche snow for one kilometre of valley bottom and the altitude for different regions of the Caucasus is shown. The points shown at an elevation of 4000 m are on glacier surfaces. It follows from this figure that at all altitudes the greatest amount of avalanche snow is found in the West Caucasus. The only exception occurs at 2000 m elevation: there the greatest amount of avalanche snow is found on the southern slopes of the Central Caucasus. In the East Caucasus there is much less avalanche snow at all altitudes. For all the regions the greatest amount of avalanche snow is found at altitudes of 3500-4000 m. At these elevations avalanches occur throughout the year, and after every snowfall the avalanche catchment areas are refilled with drifting snow.
Now let us estimate the part of the total snow storage of these areas that is contributed by large avalanches. If we assume that the snow pack is distributed equally on slopes, the ratio \( V_a = \left( \frac{S_1}{S_2} \right) \) can be used to estimate the contribution of potential avalanche snow to the total snow storage. Here \( S_1 \) is the area of avalanche slopes and \( S_2 \) is the total area. In reality, during the snowfall, the snow pack is already drifting to the valley bottoms. However, the main part of it is not redistributed for a long distance, remaining on the catchment areas. That is why when we assume that the snow is distributed equally on the slopes, we underestimate the amount of avalanche snow.

Let us take \( S_2 = 1 \text{ km}^2 \) and call \( V_a \) the coefficient of avalanche snow potential storage (by analogy with the coefficient of avalanche danger (Abdushelishvili, 1970; Seversky, 1969)).

The values of \( V_a \) were estimated using topographic maps and the avalanche inventory in the river basins of Aksaut (West Caucasus), Chegem (Central Caucasus), and Avarskiy Koysu (East Caucasus). The obtained values of \( V_a \) are shown in Table 1.

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>1500-2000</th>
<th>2000-2500</th>
<th>2500-3000</th>
<th>3000-3500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.6-3</td>
<td>9-15</td>
<td>16-21</td>
<td>23-32</td>
</tr>
<tr>
<td>N</td>
<td>3-9</td>
<td>11-13</td>
<td>19-22</td>
<td>24-28</td>
</tr>
<tr>
<td>S</td>
<td>0.1-1</td>
<td>7-12</td>
<td>14-19</td>
<td>24-32</td>
</tr>
<tr>
<td>N</td>
<td>4-10</td>
<td>12-16</td>
<td>19-22</td>
<td>26-41</td>
</tr>
<tr>
<td>S</td>
<td>3-9</td>
<td>7-15</td>
<td>13-22</td>
<td>25-40</td>
</tr>
<tr>
<td>N</td>
<td>16-21</td>
<td>15-24</td>
<td>20-30</td>
<td>29-50</td>
</tr>
<tr>
<td>S</td>
<td>23-32</td>
<td>24-28</td>
<td>24-32</td>
<td>30-62</td>
</tr>
<tr>
<td>N</td>
<td>42-61</td>
<td>40-64</td>
<td>40-64</td>
<td>37-59</td>
</tr>
</tbody>
</table>

There is no difference in \( V_a \) for the West, Central, and East Caucasus. The lowest values are characteristic of the altitudes of 1500-2000 m. They are 0.1-3% for the southern slopes and 1-10% for the northern slopes. With increasing elevation the difference in \( V_a \) between the southern and the northern slopes decreases, becoming zero at an altitude of 3000-3500 m, that is, in the zone of active runoff formation.

Thus, in alpine and nival zones of the Caucasus, 30-64% of total snow storage can be transported by avalanches from the slopes. On the average the area of snow patches is 10-18 times less than the catchment area and the density of patches is higher. As a result, the melting period of the patches is longer.

REFERENCES
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