Russian Journal of Earth Sciences

Special Issue: "Advances in Environmental Studies, from the VIII International Scientific and Practical Conference 'Fundamental and Applied Aspects of Geology, Geophysics and Geoecology Using Modern Information Technologies' "

Distribution of Avalanche Foci Across the Territory of the All-Season Tourist and Recreational Complex Elbrus

A. Kh. Adzhiev, N. V. Kondratieva, and Z. M. Kerefova*

High Mountain Geophysical Institute, Nalchik, Russia
* **Correspondence to:** Zalina Kerefova, zknyaz-kbsu@mail.ru

The article presents the results of a study on the distribution of avalanche centers on the territory of the Elbrus all-season tourist and recreational complex (ATRC). The constructed maps of the surface slopes of the study area with the boundaries of the identified avalanche catchments are provided. In the work, all areas with a steepness from 25° to 60°, which are included in the boundaries of the avalanche catchments, were considered as probable zones of avalanche origin.

Keywords: Avalanches, resort area, slope map, avalanche catchment, slope, cable car.

Citation: Adzhiev A. Kh., Kondratieva N. V., and Kerefova Z. M. (2025), Distribution of Avalanche Foci Across the Territory of the All-Season Tourist and Recreational Complex Elbrus, *Russian Journal of Earth Sciences*, 25, ES6004, EDN: BNWFQK, https://doi.org/10.2205/2025ES001073

Research Article

Received: 2025-09-10
Accepted: 2025-11-10
Published: 2025-12-10

Introduction

The work on the study of avalanche centers on the territory of the all-season tourist and recreational complex (ATRC) Elbrus was carried out in the Elbrus district of the Kabardino-Balkarian Republic (KBR). The study area is located in the high-mountain zone, where the altitude marks vary from 2100 to 5642 m. The Elbrus region, like the entire axial part of the Central Caucasus, belongs to the territories with high avalanche activity according to [*SP 115.13330.2016*, 2018] and the Atlas of Snow and Ice Resources of the World [*Atlas…*, 1997].

Monitoring of avalanche processes in the KBR and other regions includes an integrated approach taking into account the distribution, dynamics and superposition of avalanches, as well as the peculiarities of the development of the territory [*Anaev et al.*, 2022].

Methods of monitoring avalanche processes include:

Meteorological observations [*Kondratieva et al.*, 2021; *Lur'e and Panov*, 2011]; snow cover observations [*Adzhiev et al.*, 2023; *Vikulina et al.*, 2023]: visual observations, snow depth measurements, snow density determination, snow temperature determination at different depths, snow stability tests; remote sensing [*Safarov and Fazylov*, 2020; *Volodicheva and Oleinikov*, 2008]; automated monitoring systems [*Kalach et al.*, 2016].

The territory of the Elbrus ATRC can be considered insufficiently studied in terms of avalanche activity. To date, no assessments of the effectiveness of measures to protect against avalanches and mudflows have been conducted for the study area.

Description of methods and materials

During the work, the materials of avalanche studies of the territory were collected, analyzed and summarized. Cartographic materials (scales 1:100,000 – 1:25,000), topographic plans, aerial photographs and Earth remote sensing data contained in archival reports were analyzed to identify existing and probable avalanche origins, areas of slope process development, and preliminary determination of avalanche origin areas.

The collection of literary and archive materials, materials from previous years research is aimed at obtaining information on the conditions and factors of hazardous processes and phenomena in the area of the work, establishing patterns of snow avalanche development in the study area and in the adjacent territory, including studying geological, geomorphological, geobotanical and hydrometeorological factors of their formation, transit and accumulation.

Discussion of results

Climate warming has a significant impact on avalanches in the mountains, changing the nature of precipitation, leading to the melting of snow and ice, and changes in the structure of the snow cover.

Based on the results of the route survey, analysis of topographic maps in accordance with the recommendations of [*SP 428.1325800.2018*, 2019], a map of the surface slopes of the study area was constructed with the boundaries of the identified avalanche catchments, avalanches from which can threaten the facilities of the Elbrus ATRC resort (Figures 1 and 2). All areas with a steepness from 25° to 60°, which are included in the boundaries of the avalanche catchments, were considered as probable avalanche initiation zones**.**

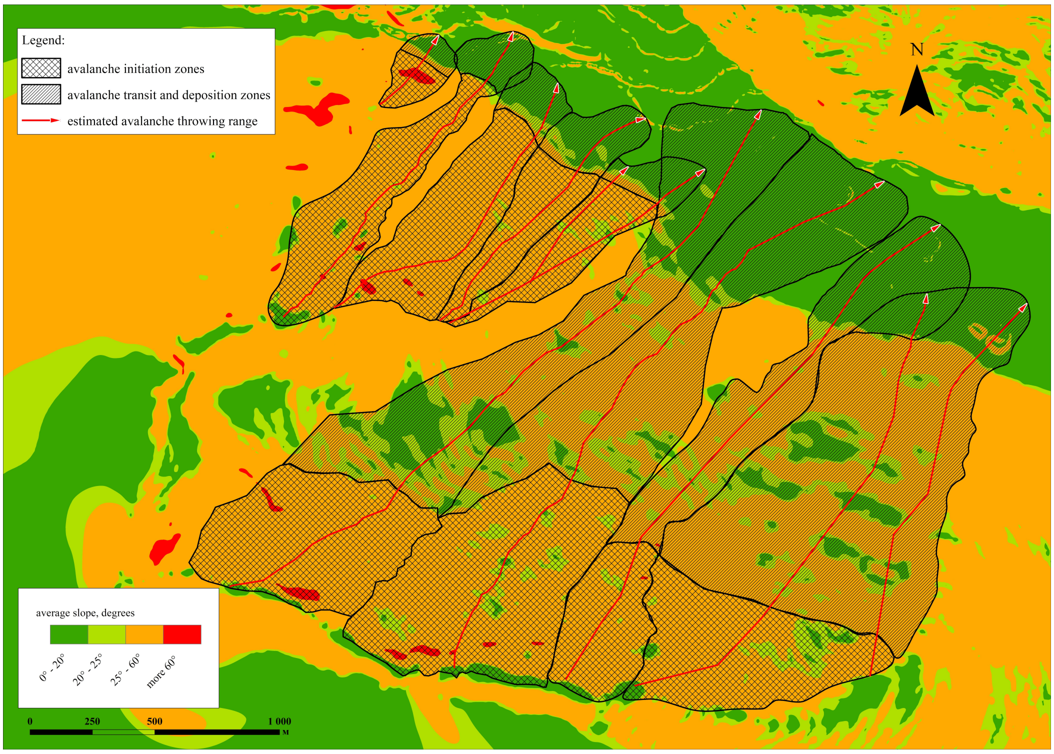

Figure 1. Map-scheme of the surface slopes of the study area of the Elbrus ATRC (northern slope of Mount Cheget).

To determine the range of avalanche ejection in avalanche centers, snow avalanche calculations were performed. The values of the avalanche ejection range were used to construct the boundaries of avalanche impact. The characteristics of the snow cover at different altitudes were calculated by linear extrapolation of the values of the snow cover depth and water storage according to the data in tables 1, 2, 3 [*Adzhiev et al.*, 2021].

Table 1. Maximum snow depth 2% probability, cm

Terskol 2100	2350–2550	2550–2750	2750–2950	2950–3150
163	185	215	256	278

Table 2. Maximum snow depth 1% probability, cm

Terskol 2100	2350–2550	2550–2750	2750–2950	2950–3150
180	200	230	260	290

Table 3. Snow cover density, kg/m^3 and water content in snow cover (mm) at the heights of the survey object

Height, m	Density, kg/m^3	Water reserve, mm
2100–2350	350	280
2350–2550	350	315
2550–2750	350	420
2750–2950	350	525
2950–3150	360	648

The data provided were used to determine the coefficients of total resistance to avalanche movement $\tan\Psi$ for channeled avalanches and wasps when calculating the range of avalanche ejection.

Avalanche foci on the territory of the Elbrus ATRC are shown on the orthophotomap in Figure 3.

The avalanche throw range was determined using the graph-analytical method in accordance with [paragraph B.3.3, Appendix B of *SP 428.1325800.2018*, 2019].

On the longitudinal profile of the avalanche path, constructed according to the topographic plan, at point O, corresponding to the position of the avalanche separation line, coordinate axes L and H were drawn, corresponding to the horizontal projection of the slope and the height. From point O, at an angle Ψ, the tangent of which was determined according to [Table B.6 of *SP 428.1325800.2018*, 2019] as the coefficient of total resistance to avalanche movement, an inclined line was drawn until it intersected with the avalanche collection profile line at point A, corresponding to the leading edge of the avalanche deposits [Figure B.1, *SP 428.1325800.2018*, 2019].

The depth of snow cover with 1% and 2% probability at different heights H (the height of the point of avalanche breakaway from the avalanche source) is calculated using formulas (1) and (2).

$$h1\%(H) = 0.1048\,H - 40, \tag{1}$$

$$h2\%(H) = 0.1095\,H - 66.95, \tag{2}$$

where h is the height of the snow cover (cm), H is the height above sea level (m).

The results of the conducted research show that a significant part of the territory of the Elbrus ATRC is exposed to avalanches. At the same time, the Concept of "Adjustment of the territory planning project, development of the territory surveying project, adjustment of the development plan and the corresponding material and technical equipment, development of an interactive information 3D model of the special economic zone of the tourist and recreational type within the boundaries of the Elbrus municipal district of the Kabardino-Balkarian Republic (Elbrus ATRC) and the adjacent territory" provides for the development of the entire territory of the ATRC in the coming years.

Comparisons of the avalanche drainage area boundaries in the design area of the facilities and the adjacent territory with elevation contours (Figures 1, 2) with the ATRC planning scheme show that a number of objects fall into the zone of possible avalanche impact: planned ski stations, cable cars, cable car supports and some objects in the Azau Glade. To ensure safety and minimize the risks of impact on existing and planned ob-

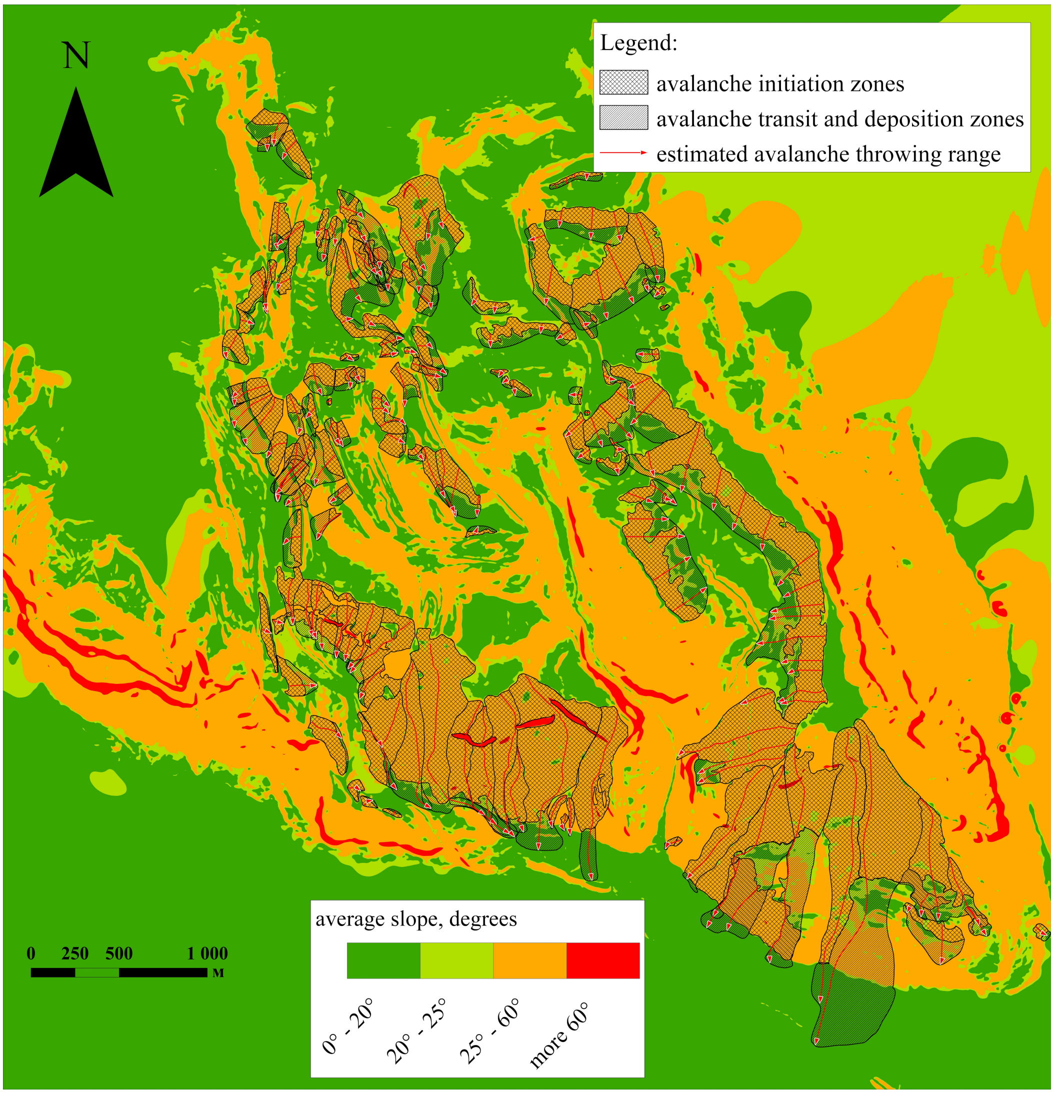

Figure 2. Map-scheme of the surface slopes of the study area of the Elbrus ATRC (southern slope of Mount Elbrus).

jects within the framework of the Planning Concept [*Resolution…*, 2023] from avalanches, avalanche protection structures located on the northern slope of Mount Cheget (Figures 5, 6) and on the southern slope of Mount Elbrus (Figures 7, 8) are currently used. Figure 5 shows avalanche-braking structures and Figure 6 shows an avalanche-arresting dam on the northern slope of Mount Cheget.

Avalanche protection structures on the northern slope of Mount Cheget are intended to protect existing and planned objects within the Concept from the impact of avalanches from foci. Figures 7, 8 show snow-retaining structures on the southern slope of Mount Elbrus.

Avalanche protection structures on the southern slope of Mount Elbrus are designed to protect existing and planned objects within the Concept from the impact of avalanches.

During the period of operation of snow-retaining structures, some sections have been destroyed (Figure 8) and require inventory and restoration.

The frequency of avalanches in this area is from 0.1 to 1 avalanche per year [*Zalikhanov*, 2014].

A necessary condition for organizing effective anti-avalanche measures should be considered the continuation of the study of the actual avalanche regime of the territory and obtaining observed parameters of the snow cover and avalanches.

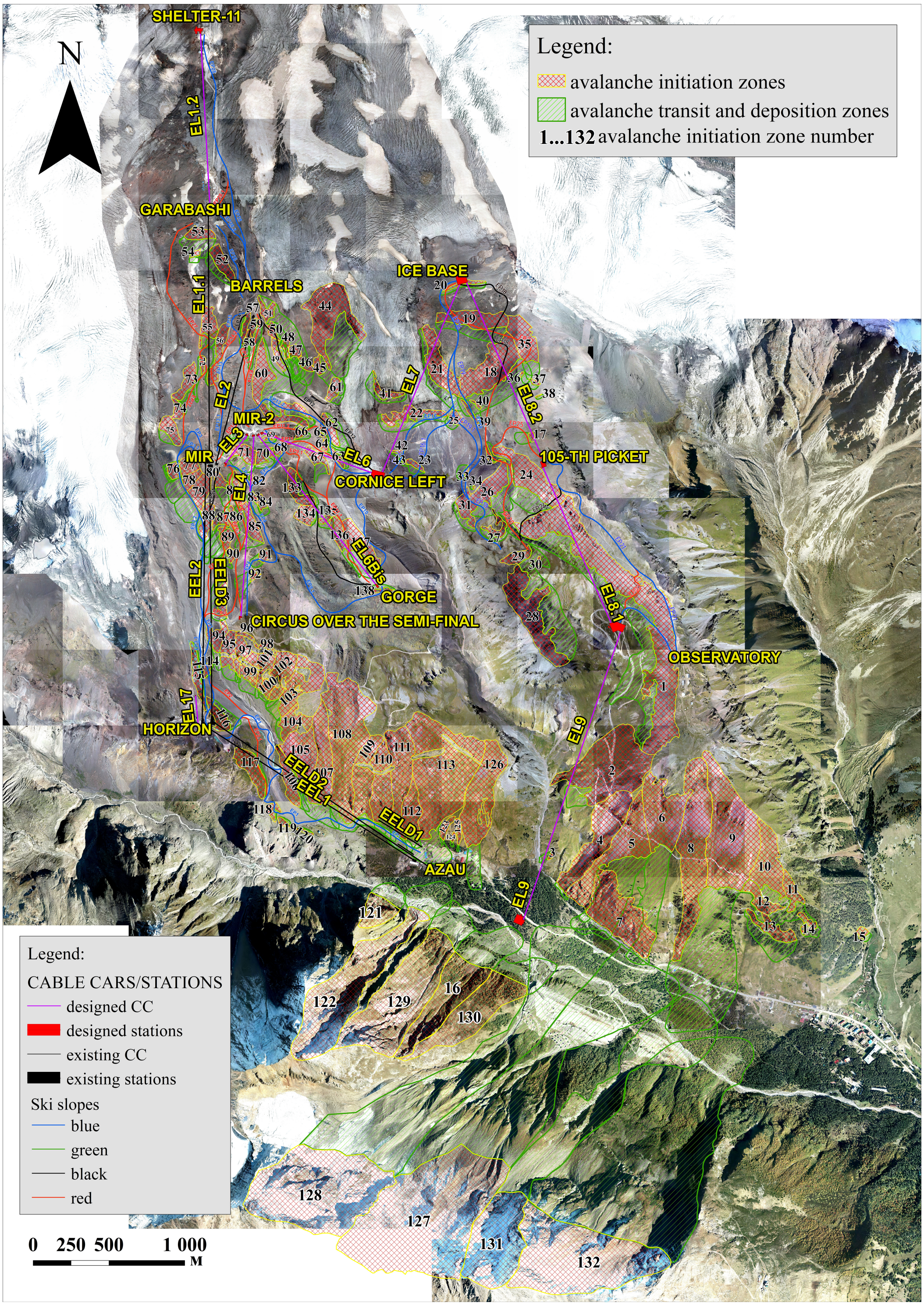

Figure 3. Avalanche foci on the territory of the Elbrus ATRC on the orthophotomap (southern slope of Mount Elbrus).

When designing and constructing, it is recommended to minimize the conditions favorable for the formation of avalanches, take into account the avalanche hazard of access roads.

It is necessary to take into account the change in the conditions of the snow cover regime on the territory of the facility, associated with the violation of the natural cover of the slopes due to construction work and other man-made activities on the territory of the ATRC.

Figure 4. Avalanche-braking structures on the northern slope of Mount Cheget. Photo, June 2022.

Figure 5. Avalanche dam on the northern slope of Mount Cheget. Photo, June 2022.

Figure 6. Snow retention structures on the southern slope of Mount Elbrus. Photo August 2022.

Figure 7. Snow retention structures on the southern slope of Mount Elbrus. Photo August 2022.

Figure 8. Destroyed sections of snow retention structures on the southern slope of Mount Elbrus. Photo August 2022.

Conclusions

As a result of global climate change, the avalanche situation in the area of the planned resort is changing, therefore, in order to monitor the avalanche danger and safely operate the Elbrus ATRC, it is necessary to continue avalanche observations on the territory of the complex and meteorological services during the construction and operation of the facilities.

The protection of the research area can be implemented within the framework of a set of measures for engineering protection. These measures include the entire list of protection methods known to world practice:

1. Avalanche forecast.
2. Construction of protective engineering structures.
3. Active interventions for the purpose of preventive and controlled descent of avalanches.
4. Restorative and protective melioration measures.

Acknowledgments. The work was supported by a grant from the Russian Science Foundation (Agreement No. 23-17-20001).

References

Adzhiev A. Kh., Kondratieva N. V., Yurchenko N. V., et al. Studies of the calculated values of the weight of the snow cover and the values of the altitude coefficient on the slopes of mount Elbrus // Natural and Technological Risks. Building Safety. — 2021. — 2(51). — P. 39–42. — https://doi.org/10.55341/ptrbs.2021.51.2.007. — (In Russian).

Adzhiev A. Kh., Kondratieva N. V., Yurchenko N. V., et al. Long-Term Dynamics of Snow Cover in the Elbrus Region // Science. Innovations. Technologies. — 2023. — No. 3. — P. 47–64. — https://doi.org/10.37493/2308-4758.2023.3.3. — (In Russian).

Anaev M. A., Gunya A. N. and Malneva I. V. Superposition Effects of Hazardous Slope Processes and Management Strategies to Protect Against Them (Kabardino-Balkarian Republic) // Dagestan State Pedagogical University. Journal. Natural and Exact Sciences. — 2022. — Vol. 16, no. 3. — P. 37–44. — https://doi.org/10.31161/1995-0675-2022-16-3-37-44. — EDN: FNUKTL ; (in Russian).

Atlas of snow and ice resources of the world / ed. by V. M. Kotlyakov. — M. : Institute of Geography, Russian Academy of sciences, 1997. — (In Russian).

Kalach A. V., Sharapov S. V. and Krutolapov A. S. Information monitoring of complex processes. — Saint Petersburg : St. Petersburg University of the State Fire Service of the Ministry of Emergency Situations of Russia, 2016. — EDN: YJPJUH ; (in Russian).

Kondratieva N. V., Adzhiev A. Kh., Fedchenko L. M., et al. Avalanche background forecast technique for mountain areas of the Republic of Ingushetia and Chechen Republic // GeoRisk World. — 2021. — Vol. XV, no. 3. — P. 50–63. — https://doi.org/10.25296/1997-8669-2021-15-3-50-63. — (In Russian).

Lur'e P. M. and Panov V. D. Problems of exploration level of hydrometeorological regime of the Northern Caucasus territory // Russian Meteorology and Hydrology. — 2011. — Vol. 36, no. 4. — P. 273–278. — https://doi.org/10.3103/s1068373911040091.

Resolution of the Government of the Kabardino-Balkarian Republic dated December 29, 2023 No. 296-PP. On approval of the planning project and land surveying project for the territory of the special economic zone of the tourist and recreational type within the boundaries of the Elbrus municipal district of the Kabardino-Balkarian Republic (all-season tourist and recreational complex "Elbrus") and the adjacent territory. — Government of the Kabardino-Balkarian Republic, 2023. — 105 p. — (In Russian).

Safarov M. S. and Fazylov A. R. Application of modern remote sensing technologies for monitoring the debris flow-prone areas in the mountainous regions // GeoRisk World. — 2020. — Vol. XIV, no. 2. — P. 32–41. — https://doi.org/10.25296/1997-8669-2020-14-2-32-41. — (In Russian).

SP 115.13330.2016. Geophysics of hazardous natural impacts. — Moscow : Standartinform, 2018. — 32 p. — (In Russian).

SP 428.1325800.2018. Engineering geological survey for construction in snow avalanches-endangered regions. General requirements. — Moscow : Standartinform, 2019. — 40 p. — (In Russian).

Vikulina M. A., Romanenko F. A., Zimin M. V., et al. Structure and dynamics of snow and ice formations in the Khibiny Mountains in the 21st century // Lomonosov Geography Journal. — 2023. — Vol. 78, no. 2. — P. 89–102. — https://doi.org/10.55959/msu0579-9414.5.78.2.8. — (In Russian).

Volodicheva N. A. and Oleinikov A. D. Snow avalanches of the Elbrus glaciation area // Lomonosov Geography Journal. — 2008. — No. 6. — P. 39–44. — EDN: KHMZDH ; (in Russian).

Zalikhanov M. Ch. Snow-avalanche regime and prospects for development of the Greater Caucasus Mountains. — Moscow : Official, Business Russia, 2014. — 612 p. — EDN: WETOAF ; (in Russian).