Propagation of a cold wave in the snow during the preparation of ski slopes by salting

Denis Frolov[1*], *German* Rzhanitsyn[1], *Sergey* Sokratov[1], *Vasilisa* Cherkasova[1], *Andrey* Koshurnikov[1] and *Vladimir* Gagarin[1]

[1]Faculty of Geography, Lomonosov Moscow State University, 1, Leninskie Gory, Moscow, 119991, Russia

Abstract. The paper presents a method of hydrological and hydrophysical studies to observe the propagation of a cold wave in the snow during the preparation of ski slopes by salting. Salting is used in the preparation of ski slopes for competitions, especially when the average daily air temperature is approaching positive levels, and during the day there is a melting of snow cover, for a short-term decrease in the temperature of the snow column and its partial freezing. The experiments were carried out in the summer of 2021 and 2022 on the Dzhanquat and Garabashi glaciers of the Caucasus. The experiments used thermal sensors and a temperature logger manufactured by LLC "MSU-Geophysics". The temperature sensors were located on a rod stuck in the snow with an interval of 5 cm. The temperature was measured every minute. With a single salting, a cold wave was observed for about 4-5 hours and with freezing of the lower strata with a decrease in the temperature of the underlying snow layers to -3--5 °C. The analysis of the observational data showed the propagation of the cold wave deep into 50-60 cm. The research method will allow us to investigate the peculiarities of the propagation of the cold wave during salting and optimize the salting process for the most effective preparation of ski slopes for competitions.

1 Introduction

The paper presents a method of hydrological and hydrophysical research to observe the propagation of a cold wave in snow during the preparation of ski slopes by salting. It is known that when preparing ski slopes for competitions, especially when the average daily air temperature approaches positive levels, and during the day the snow cover melts, salting is used to temporarily lower the temperature of the snow mass and partially freeze it. The experiments were carried out in the summer of 2021 and 2022 on the Dzhankuat and Garabashi glaciers of the Caucasus.

[*] Corresponding author: denisfrolovm@mail.ru

 https://doi.org/10.1051/e3sconf/202236301054

2 Data and Methods

To study the thermal state of the snow mass during salting, a thermoscythe , thermal sensors and a temperature logger produced by MGU-Geophysics LLC were used. The temperature sensors were located on a rod stuck into the snow at intervals of 5 cm. The temperature was measured every minute. With a single salting, a cold wave was observed for about 4-5 hours and during freezing of the lower thickness with a decrease in the temperature of the underlying snow layers to -3--5 °C. An analysis of the observational data showed the propagation of a cold wave to a depth of 50–60 cm (Fig. 1). The appearance of the device is shown in Figure 2.

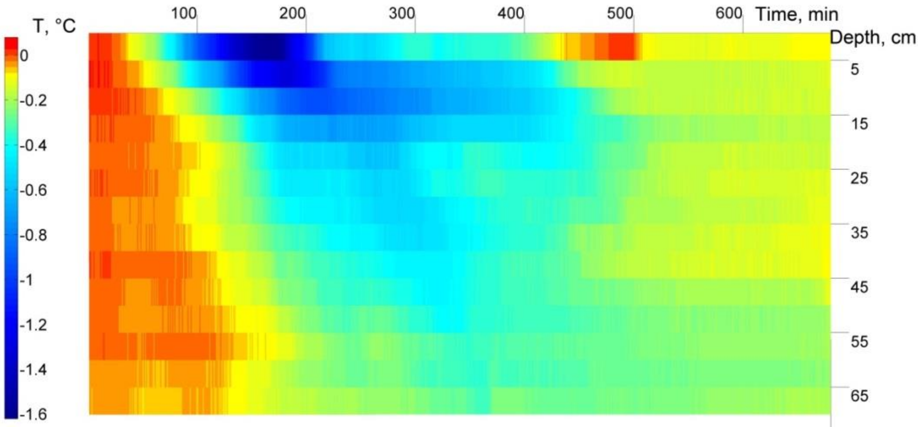

Fig. 1. Propagation of a cold wave during the salting of snow on the Dzhankuat glacier.

Fig 2. Appearance of the device.

 https://doi.org/10.1051/e3sconf/202236301054

3 Results

The research method will allow to investigate the features of cold wave propagation during salting and to optimize the salting process for the most effective preparation of ski slopes for competitions. The observations showed a good agreement with last year's results, when, in accordance with the temperature measurements of the snow mass during the preparatory work of ski slopes by salting on the slope of the Garabashi glacier on 06/25/2021 - 07/01/2021, the thermal field in the snow was simulated. The density of snow in the area of the compacted track at the measurement point was 350-400 kg/m3. The initial temperature data were the results of recording two loggers located (buried in the snow) at different depths (one closer to the surface, and the other at a depth of 40 cm). On the basis of the difference approximation of the differential equation in partial derivatives for thermal conductivity (of the first order in time and the second in space), a calculation was made of the propagation of a cold wave during salting from the surface deep into the snow. The results of calculating the temperature distribution over depth and over time in the snow at the studied point of the route during salinization can be seen in Figure 3.

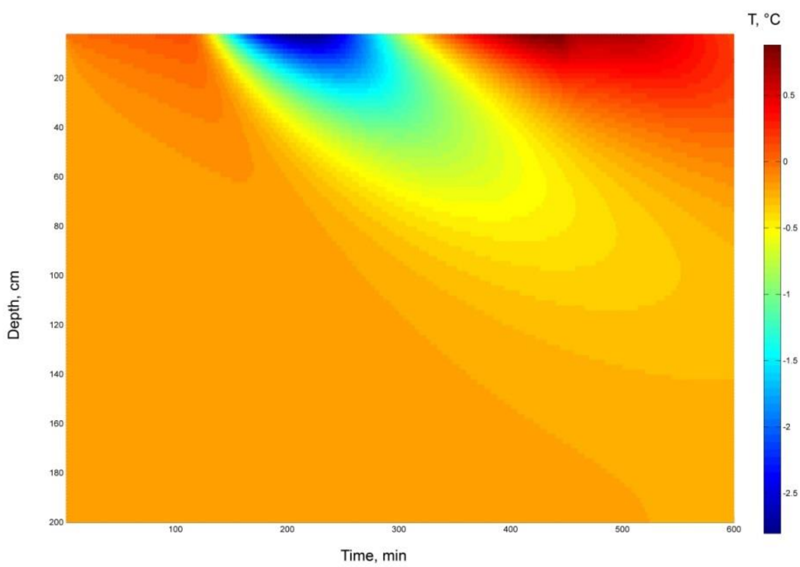

Fig. 3. Temperature distribution by depth and time in snow at the studied point of the route during salinization (calculation results).

The initial data of the calculation were the results of measuring the temperature of the logger closer to the surface, and the results of calculating the temperature at a depth of 40 cm are consistent with the measurement data of the second logger. The calculations were carried out using the difference scheme obtained on the basis of the Fourier heat equation.

Thus, the temperature field in the snow was described by the Fourier heat equation:

$$C_i \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(K_i \frac{\partial T}{\partial x} \right) \quad (1)$$

where *Ki* , *Ci* - coefficients of conductive thermal conductivity and heat capacity, T - temperature, °C, *t* - time. The dependences of the coefficients of conductive thermal conductivity and heat capacity of snow on its density are expressed by the relations

K s \u003d 0.018 + 0.87 ρ / 10 [3] ; *Cs* = *ρ* _ *Cl* _ at 120<ρ< 350 kg/m [3] ,

where *C l is* the coefficient of heat capacity of ice, ρ is the density of snow. The boundary conditions for the heat equation were set as follows: T = Tsurf = T_logger 1 was set on the snow surface . ρ = 350 kg/m3 · Cl =2100 J /(°C kg), Cs = 420000 J /(°C m3), Ks =0.194 J /(°C c m). The depth of the snow thickness of 2 m was divided into i =1, n (=200) parts of 1 cm each. The difference equation was written

$$C_i \frac{T_i^{j+1} - T_i^j}{\Delta t} = K_i \frac{T_{i+1}^j - 2T_i^j + T_{i-1}^j}{\Delta x^2} \quad (2)$$

which gives a new temperature value on a new time layer

$$T_i^{j+1} = T_i^j + \Delta t / C_i * K_i \frac{T_{i+1}^j - 2T_i^j + T_{i-1}^j}{\Delta x^2} \quad (3)$$

A time step of 30 seconds was divided into intervals of 0.1 seconds and calculated at a new step using

$$K \left. \frac{T_0 - T_1}{\Delta x} \right| = 0, T_{n+1} = Tsurf \quad (4)$$

The difference scheme for performing a step in j was written:

$$T_i^{j+1} = T_i^j + \Delta t / C_i * K_i / \Delta x^2 (T_{i+1}^j - 2T_i^j + T_{i-1}^j) \text{ for i =1,n} \quad (5)$$

and

$$T_0 = T_1, T_{n+1} = T_{surf} \quad \mathbf{(6)}$$

The results of numerical simulation of a cold wave from snow salinization in a foam box under laboratory conditions are shown in Figure 4.

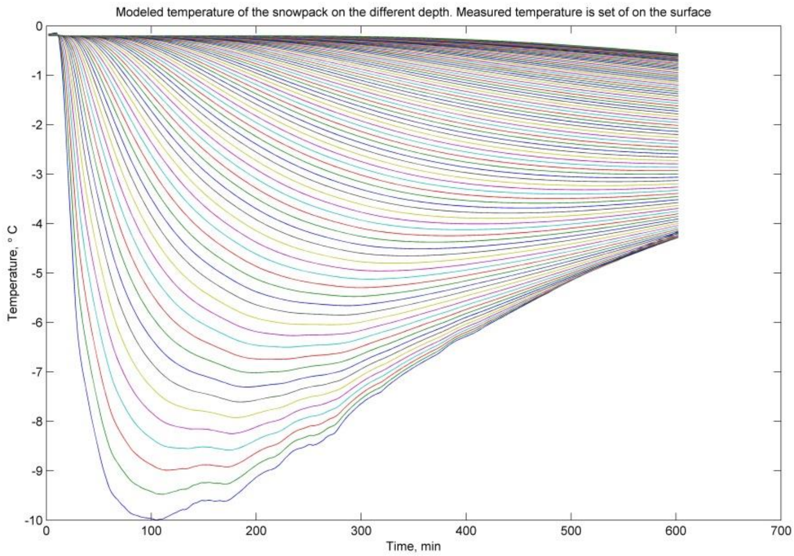

Fig. 4. Results of numerical simulation of a cold wave from snow salinization in a foam plastic box under laboratory conditions (different lines correspond to temperature changes at different depths).

4 Conclusion

When preparing ski slopes for competitions at insufficiently low snow temperatures during thaws, the snow is salted to achieve its freezing. In this work, numerical modeling and comparison of the results of numerical modeling with observational data for the problem of cold wave propagation in snow during salting were carried out. Field observations were made on the Garabashi and Dzhankuat glaciers (Caucasus) in the summer of 2021 and 2022. The observation of the propagation of a cold wave in the snow was carried out by means of a rod with temperature sensors stuck into the snow, which were located on it at intervals of five centimeters in depth. Modeling of cold wave propagation in snow was carried out on the basis of a numerical method based on a difference approximation of the heat conduction equation in partial derivatives of the second order on a rectangular grid. Comparison of numerical simulation results with observational data showed good agreement.

Acknowledgement (if any):

The work was supported by the state budget theme "Danger and risk of natural processes and phenomena" (121051300175-4) and "Evolution of the cryosphere under climate change and anthropogenic impact" (121051100164-0).

References

1. V.A. Kudryavtsev. Fundamentals of Permafrost Forecasting in Engineering and Geological Studies, Ed. Publishing House of Moscow State University, 431 p. (1974).
2. A.A. Samarsky, A.V. Gulin Numerical methods. M.: Nauka, 432 p. (1989)
3. A.N. Tikhonov, A.A. Samarskii Equations of Mathematical Physics, (1999).
4. D.M. Frolov, G.A. Rzhanitsyn, S.A. Sokratov et al. Geotechnical monitoring of snow cover on Elbrus glaciers (Caucasus) // Geophysics. – No. 3. - P. 70–75.(2022)