Variations in the radiothermal radiation of the ice cover of Lake Arakhley as a geo-indicator of deformation and cracking

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Abstract. In January–March, 2020–2021, radiophysical studies were conducted of radiothermal radiation intensity for the testing site for Lake Arakhley, Transbaikalia, Russia. The set of equipment consisting of four microwave radiometers for the wavelengths from 0.3 to 2 cm was placed on the shore of the lake mounted on a stationary platform. The temperature and deformation of ice were simultaneously measured at the depth of 0.4 meters in two orthogonal directions: west-east and north-south. The temperature was measured with heat gauges in a vertical profile at the depths of 5, 10, 15, 20 and 40 cm. In the process of contact measurements in the period of cracking, signal impulses were recorded in the channel of the deformation sensor placed in the direction of the lake center (west-east). The measurement results were used in monitoring of the condition of the water body. It turned out that in the periods of registering the deformation impulses, changes in the radio brightness temperature and decrease in the ice temperature were observed. The microwave characteristics correlate with the temperature and deformation of the ice cover and may serve as an indicator of the meteorological conditions of the region.

1. Introduction
The object of the given study was to measure intensity of radio thermal radiation of the upper layer of the ice cover of the freshwater lake, as an indicator of its temperature regime and deformation. Such studies are required for developing the remote sensing methods of investigating freezing water bodies [1]. The daily variations in the radio thermal radiation of the ice cover were measured on Lake Arakhley in the territory of the Ivano-Arakhley natural park (Transbaikalia). The equipment was placed on an onshore platform of the cryogenesis geophysics laboratory of the Natural Resources, Ecology and Cryology SB RAS. The measurements of variation in the radiothermal radiation at a small slant angle of sensing were made simultaneously with the contact measurements of ice deformation in a hole 40 cm deep. In addition, the ice temperature profile was measured at the depths of 5, 10, 15, 20 and 40 cm.

2. Experimental
In the study, a special technique was used of simultaneous remote measurements of radiothermal intensity and of contact data from the ice cover deformation and temperature sensors. The measurements of the radiothermal radiation intensity were made from a stationary platform from the
height of 20 meters above the lake level (figure 1) [3, 4]. The radiometric complex included microwave radiometers (R) for the wavelengths (λ): 0.3 cm, 0.8 cm, 1.4 cm and 2 cm.

The signals in the channels of the set of microwave radiometers were registered by a system of data acquisition by Agilent Technologies into a computer. The measurements were made with a remote access to the array of data for analysis, synchronizing with the contact data and further processing [3; 4]. The radiometer complex was calibrated according to the readings from the reference load under conditions of the cloudless sky, with the nadir-oriented antennas.

In the works conducted in 2020, the sensor of ice deformation (sensitivity is ~ 1mV per 10 µm) was inserted into a hole at the depth of 40 cm in the west-east direction. The ice deformation and temperature gauges were switched to the autonomous data acquisition system (figure 2). The data acquisition system was developed using a 16-bit analogue-digital converter AD7739 and a microcontroller STM32 (data output at the rate of 1 s in 2020 and 0.1 s in 2021 on an SD-card) [3].

The ice deformation gauge was based on registration of the position of a ferromagnetic core in the inductance divider of the high-frequency reference signal, while the equipment case was fixated on the hole bottom [2]. The ferromagnetic core was firmly fixated on the end of a rod made of invar, alloy with a low temperature deformation coefficient ~ 1 m long. The second end of the rod was fixed on a shaft frozen into ice.

The developed system of acquisition of digital data worked on a battery which was replaced every 6-8 days. In the works conducted in 2021, the system of contact sensors was placed in close proximity
from the antenna spot of the antenna direction plot at the distance of ~ 300 m from the shore in a hole covered with boards and is complemented by an ice deformation gauge in the north-south direction.

3. Results
In February-March, 2020, the ice deformation gauge registered ice deformation impulses (figure 3).

![Figure 3](image)

**Figure 3.** Ice temperature (1) at the depth of 40 cm and deformation (2) in the east-west direction from 13.02.20 to 21.02.20.

In February 2021 in the same period from 13.02.21 to 21.02.21, smaller gaps in the night and day temperatures were observed and a smaller number of the ice deformation impulses were registered (figure 4).

![Figure 4](image)

**Figure 4.** The temperature and ice deformation in the west-east direction from 13.02.21 to 21.02.21.

Analysis of the data obtained showed that, according to the ice deformation gauge in the direction of west-east (from the shoreline to the center of the lake), it is possible to judge about the process of
formation of dry cracks in the ice cover. Judging by the fast recovery of the signal emissions, it was possible to assume appearance of the water film on the boundaries of the rips and its fast freezing. The rips influence the intensity of radiothermal radiation of the ice cover in the microwave band [1, 5]. The registrations at the depth of 40 cm in the ice hole showed daily variations of temperature reaching 2°C and ice deformation reaching 50-70 µm (per one meter). The deformation impulses were accompanied by the increment of the radio brightness temperature. More considerable increment values of the radio brightness temperature were obtained in channels R0.8 and R1.4.

Registration of the vertical temperature profile allowed us to evaluate its impact on the emergence of critical mechanical tensions at cracking (figure 5).

![Figure 5. The data from the deformation gauge and of the vertical temperature profile.](image)

The emergence of the ice deformation impulses may be related to the change of temperature in time in the vertical profile of the ice cover in time from decrease to increase. The rise of the values of its difference at different depths was observed.

Shown in figure 6 are the synchronized measurement data in the radiometer channel R1.4 and channels of the contact sensors. The intensity of radiothermal radiation is presented in relative units.

In the east-west deformation direction, at 05:20 p.m. on 24.02.2021, a brief impulse with the amplitude of ~ 25 µm was registered (figure 6b). At 07:40, the beginning of cracking was registered, with the crack size reaching ~ 27 µm, followed (by 08:00 p.m.) by recovery of the ice structure. According to the data obtained from the second south-north deformation gauge, the deformation impulses were not registered (figure 6c). The daily variations in the ice deformation channel in the north-south direction were ~ 16-24 µm per one meter and occurred in antiphase with the channel of the east-west gauge, with the rather big shift of the extreme values in time (figure 6b-c).
The correlation coefficient of the remote radiometric data of channel R1.4 (figure 6a) with the contact data of the deformation channel in the west-east direction (figure 6a-b), with the window of 2000 dots in the range from 06:00 p.m. to 11:00 p.m. was more than 0.7.

Figure 6. Variations in the radiothermal radiation signal for R1.4 (a), in the west-east deformation (b), in the south-north deformation (c) and temperature at four depths of the ice cover (d).

The plot of channel R1.4 functioning at the time of cracking showed increment of the intensity of radiothermal radiation as the ice temperature decreased in the vertical profile (figure 6, a-d). This effect is possible when the radiation intensity rises due to appearance of cracks in the ice cover of the water body. The temporal course of temperature in the ice profile at the depths of 5, 10, 15, 20 and 40 cm allowed us to observe the impact of the vertical temperature gradient on the critical mechanical tensions. In addition, the results of seasonal and daily variations in the temperature and radiothermal radiation in the period of cracking were compared.

Based on the results of synchronous remote and contact measurements, data were obtained regarding the condition of the water body and the intensity of radiothermal radiation in the period of temperature and dynamic loads at the beginning of cracking.

4. Conclusions
In the period of maximum thermal and dynamic loads on the ice cover surface, variations in the intensity of radiothermal radiation may serve as an indicator of its temperature regime and deformation.

Registration of temperature inside the ice deformation gauges and in the vertical profile at the depths of 5, 10, 15, 20 and 40 cm allows researchers to evaluate the conditions of emergence of critical tensions of cracking and increment of radio brightness temperatures of the thermal radiation in the microwave band.

The readings of the ice deformation gauge in the east-west direction in 2020 and 2021 demonstrated seasonal variations in the appearance of cracking impulses influencing the increment of radiothermal radiation in the microwave band.

Variations in the intensity of the radiothermal radiation of the ice cover of a water body may serve as an indicator of the condition of the temperature regime, ice deformation, cracking and climatic conditions of the region.

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