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Methods of research of radiothermal radiation of cryospheric objects in the microwave range

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Abstract. Many cryospheric formations on Earth have an inaccessible location. For example, when studying ice sheets located on the water surface, at the initial moment of ice formation, it becomes difficult to take samples. Remote monitoring methods in the microwave range can be used to study such objects. For example, install a microwave radiometer on an unmanned aerial vehicle and use its own thermal radiation from a cryogenic object to record various kinds of features. For radiometric measurements using microwave radiometers, it is necessary to calibrate the measuring device. In this paper, the radiometer calibration method is considered. For these purposes, two objects with known radiative characteristics were measured. The first is fresh open water with a known surface area and thermodynamic temperature against the background of a frozen cloudless atmosphere. The second is a section of the sky reflected from a metal sheet, with the same area. As an example, radiometric measurements of the ice cover of the Ingoda River, located in the Transbaikal Territory (Russia) at a frequency of 34 GHz, were performed. This measurement technique will be useful to specialists in the field of environmental monitoring of cryospheric formations by microwave remote methods in winter.

1 Introduction

Cryospheric formations are widespread on Earth. They are presented in the form of ice sheets, glaciers, snow, etc. Continuous monitoring of the condition of such objects is an urgent task in various fields of human activity. The role of monitoring cryospheric objects in forecasting the Earth's climate should be particularly noted. An example is the work [1], which shows the influence of the albedo of sea ice on the climate of the Arctic zone. The importance of modeling the Earth's climate is recognized by the world community, which is confirmed by the award of the Nobel Prize in Physics in 2021 to Shukuro Manabe, Klaus Hasselman and Giorgio Parisi.

To monitor objects containing water in a solid aggregate state (ice), remote research methods in the microwave range are used, in particular, using radiometric and radar equipment installed on artificial Earth satellites. As a result, it is possible to register various parameters of the state of cryospheric objects, for example, sea ice [2, 3], physical parameters of glaciers, in particular, ice of Antarctica [4], the state of snow cover [5], as well as

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characteristics of fresh ice cover located on the water surface [6]. This is possible due to differences in the dielectric properties of ice and water in the microwave range.

Using microwave radiometry of ice structures, it is possible to identify a number of their features. For example, the presence of small amounts of salt inclusions in fresh ice cover can be determined by the power of radiothermal radiation in the centimeter range. For these purposes, radiometric equipment was installed on the car. However, in the case of irregularities and inhomogeneities that occur on the ice cover, it is difficult to move by motor transport. For example, Figure 1 shows a photograph of the ice surface of the Ingoda River (Russia), where surface irregularities are clearly visible, which cause difficulties for movement by vehicle. In addition, in the case of a car moving through icy obstacles, due to changes in the viewing angles of the antennas, the value of the radio brightness temperature of the medium under study will also change. For these purposes, it is convenient to use radiometric equipment installed on an unmanned aerial vehicle, for example, a quadcopter. At the same time, the speed of data acquisition will be increased, as well as a sufficiently high spatial resolution. It will be less than one meter (depending on the altitude of the unmanned aerial vehicle and the characteristics of the antennas). From spacecraft, the resolution of the satellite image with radiometry in the microwave range ranges from units to several tens of kilometers.

Fig. 1. Photo of heterogeneity in the ice cover of the Ingoda River (Russia) (February 2024).

Therefore, it is obvious that microwave radiometry of cryospheric formations from low altitudes allows solving a number of practical problems. However, to determine the value of the radio brightness temperature, it is necessary to calibrate the radiometers.

2 The method of the experiment

For calibration of radiometric equipment, we propose the following method. Measurements of cryospheric formations are proposed to be performed on a cloudless winter day. In the studied regions, as a rule, low humidity is observed in winter, which makes it possible to take the value of the radio brightness temperature of the atmosphere in the studied microwave range for a relatively constant value. Based on the data obtained from the weather balloon (humidity, temperature) in height, it is desirable to clarify its value using calculations or a well-known literary source.

Radiometers record the antenna temperature, determined by the formula (1)

$$T_a = T_m + T_b + T_{am} \tag{1}$$

where T_m is the temperature of the main lobe of the antennas, T_b is the temperature of the background radiation along the side lobes of the antenna, T_{am} is the temperature associated with the radiation of the antenna material and the transmitting path.

To take into account the signal level of the side lobes and the temperature of the antenna material, the following steps were performed. In the area of the main lobe, a metal sheet with linear dimensions of 80×80 cm^2 reflecting the thermal radiation of the sky was placed horizontally on the ice sheet. The value of the output voltage coming from the radiometric receiver was recorded. Then a recess was made in the ice cover of exactly the same area and filled with fresh water. The thickness of the water layer in the recess was 30 cm. According to the known dependence of the imaginary and real parts of the relative permittivity of water on temperature [7, 8], (angle of observation and polarization), the value of the radio brightness temperature at a wavelength of 0.88 cm (in this experiment) was determined. The value of the radiometer output signal was recorded, which determines the value of the radio brightness temperature of the water. Thus, we determined two values of the output signal from the measuring device and at the same time had two calculated values of the radio brightness temperature (sky and smooth undisturbed fresh water surface). Given that the background radiation remains a constant value and the radiometric receiver has the same gain value, it is possible to determine the temperature at any point of the cryospheric formation under study. The final formula is defined by the following expression (2)

$$T_{\text{medium}} = [(T_{\text{water}} - T_{\text{atmosphere}})/(U_{\text{water}} - U_{\text{atmosphere}})](U_{\text{medium}} - U_{\text{water}}) + T_{\text{water}} \quad (2)$$

where T_{medium} – is the radio brightness temperature of the medium under study, T_{water} and $T_{atmosphere}$ – are the calculated value of the radio brightness temperature of water and cloudless atmosphere, U_{water}, $U_{\text{atmosphere}}$ and U_{medium} – are the readings of the output voltage of the microwave radiometer.

With this calibration method, the relative error in determining the radio brightness temperature is 0.04%.

A photo of the installation during calibration on the water surface of fresh water is shown in Figure 2.

Fig. 2. Calibration of a microwave radiometer at a wavelength of 0.88 cm in fresh water.

3 Results and discussion

We installed calibrated radiometers at a wavelength of 0.88 cm and 2.3 cm on a mobile vehicle (car). Radiometric measurements of the fresh ice cover of the Ingoda River were performed. When crossing this river, radio brightness temperature graphs were obtained, which are shown in Figure 3. The thickness of the ice sheet at the time of measurement was about 130 cm.

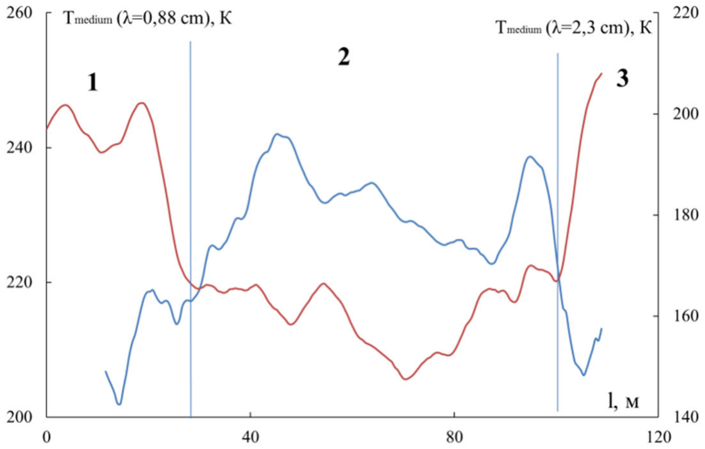

Fig. 3. Trace recording of radio brightness temperature at a wavelength of 0.88 cm (blue) and at a wavelength of 2.3 cm (red) of the fresh ice cover of the Ingoda River (February 16, 2024).

For comparison, the value of the trace recording of the radio brightness temperature determined at a wavelength of 2.3 cm is given. A characteristic feature of radiation at a wavelength of 0.88 cm is that the thickness of the forming radiation layer of the ice sheet does not exceed one meter. For the centimeter range, it is on the order of several meters. For this reason, it is possible to determine the place where the water is located under the ice cover by the value of T_{medium}. In the graph shown (Fig. 3), sections 1 and 3 correspond to a section of the ice sheet lying on the ground. Section 2 – the ice sheet is located on the water surface. As can be seen from the graphs above, the T_{medium} value varies over a wide range and at a wavelength of 0.88 cm the increment is 20 K, which may be due to the presence of inhomogeneities in the ice cover. In section 2, the value of the radio brightness temperature at a wavelength of 0.88 cm takes on an increased value compared to sections 1 and 3, in contrast to the wavelength of 2.3 cm. This question is interesting and indicates the great informative value of using different wavelengths in the radiometric study of cryospheric objects.

4 Conclusion

Thus, the paper shows a method for calibrating radiometers based on the intrinsic thermal radiation of a fresh water surface with a known thermodynamic temperature and atmospheric radiation reflected from a metal sheet having the same geometric dimensions as an open water surface. Full-scale measurements of the power of radiothermal radiation at a wavelength of 0.88 cm and 2.3 cm of the fresh ice cover of the Ingoda River (Russia) were performed. The installation of a radiometric complex on an unmanned aerial vehicle is promising, which will ensure the efficiency of the information received and the determination of the parameters of cryospheric objects in hard-to-reach places.

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