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RESEARCH OF RADIATION AND RADAR CHARACTERISTICS OF A GROWING ICE COVER

A. A. Gurulev*, S. V. Tsyrenzhapov, Y. V. Kharin

Institute of Natural Resources, Ecology and Cryology SB RAS
16a, Nedorezova Str., Chita, 672014, Russian Federation
*E-mail: lgc255@mail.ru

Remote methods of monitoring terrestrial and water objects in the microwave range, both active and passive, are widely used at present. One of such objects is the ice cover, which is associated with the development of the Arctic and the Subarctic, as well as in connection with the climate change on the planet. For this reason, knowledge of the radiation and scattering characteristics of the ice cover in the microwave range is an urgent task. In this paper, we describe a technique for the simultaneous measurement of the radiothermal radiation and the backscattering coefficient of the growing ice cover. The technique is that measurements are made alternately of the power of the radiothermal radiation and the power of backscattering from the medium under study, and the radiation is received on the same horn antenna. Receiving of electromagnetic radiation was carried out using a microwave radiometer on two linear polarizations: horizontal and vertical. The switching time between the active and passive measurements was 10 minutes. Measurements of the radar and radiative characteristics of the growing fresh ice cover at a wavelength of 2.3 cm have been performed. It is shown that the active and passive radiolocation of the investigated object carries a complementary information. Radiometric measurements show interference, which is associated with a change in the thickness of the ice cover. Active radar methods record inhomogeneities comparable to the wavelength, which was confirmed in this paper, using the example of ice cover. This method of research (simultaneous measurements of the radiation and scattering properties of the medium in the microwave range) can be used at various objects where quasistatic processes are observed, for example, when measuring vegetation, drying, freezing or moistening of the soil cover, etc.

Keywords: ice cover, microwave range, radiometry, radar studies, ice-water phase transition.

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ИССЛЕДОВАНИЕ ИЗЛУЧАТЕЛЬНЫХ И РАДАРНЫХ ХАРАКТЕРИСТИК РАСТУЩЕГО ЛЕДЯНОГО ПОКРОВА

А. А. Гурулев*, С. В. Цыренжапов, Ю. В. Харин

Институт природных ресурсов, экологии и криологии СО РАН
Российская Федерация, 672014, г. Чита, ул. Недорезова, 16а
*E-mail: lgc255@mail.ru

Дистанционные методы наблюдения за земными и водными объектами в СВЧ-диапазоне, как активные, так и пассивные, широко используются в настоящее время. Одним из таких объектов является ледяной покров, что связывается с освоением Арктики и Субарктики, а также в связи с изменением климата на планете. По этой причине знание радиационных и рассеивающих характеристик ледяных покровов в микроволновом диапазоне является актуальной задачей. Описывается методика по одновременному измерению собственного радиотеплового излучения и коэффициента обратного рассеяния растущего ледяного покрова. Методика заключается в том, что попеременно производятся измерения мощности радиотеплового излучения и мощности обратного рассеяния от исследуемой среды, причем прием излучения осуществляется на одну и ту же рупорную антенну. Прием электромагнитного излучения осуществлялся с помощью СВЧ-радиометра на двух линейных поляризациях: горизонтальной и вертикальной. Время переключения между активным и пассивным режимом измерений составляло 10 минут. Выполнены измерения излучательных и радарных характеристик растущего пресного ледяного покрова на длине волны 2,3 см. Показано, что активная и пассивная радиолокация исследуемого объекта несет в себе взаимодополняющую информацию. При радиометрических измерениях проявляется интерференция, которая связывается с изменением толщины ледяного покрова. Активные методы радиолокации фиксируют неоднородности, сравнимые с длиной волны, что было подтверждено в данной статье на примере ледяного покрова. Данную методику исследований (одновременные измерения радиационных и рассеивающих свойств среды в микроволновом диапазоне) можно использовать на различных объектах, где наблюдаются квазистатические процессы, например, при измерениях растительного покрова, иссушения, промерзания или увлажнения почвенных покровов и др.

Ключевые слова: ледяной покров, микроволновый диапазон, радиометрия, радарные исследования, фазовый переход «лед–вода».

Introduction. Current methods of remote monitoring of the Earth from space require brand new knowledge about radiation and scattering properties of the underlying terrain in the microwave range. Using the systems with the synthetic aperture in active radio-sounding methods enables to identify properties of the natural objects spatial resolution by an order of magnitude of two meters [1]. The resolution is thousands times worse by the passive radiolocation [2]; yet, it is widely used for problem solving for a variety of reasons [3; 4]. It is related to the fact that by simultaneous use of the active and passive radiolocation much more information about the targets can be obtained. In the paper [5] it is shown by the example of the ice cover of a fresh eutrophic lake that radar and radiometric measurements enable to reveal different kinds of inclusions such as gas bubbles, frosted higher aquatic vegetation etc. Moreover, the investigation is carried out with the use of the orbital satellite, aircraft and vehicular equipment for closer spatial resolution and correct data comparison. In the paper it is also shown [6] that by simultaneous active and passive methods of the sea ice investigation, high-level accuracy of the arctic ice cover relative area can be reached. Knowledge of the radar and radiative surface characteristics is an urgent task for more effective interpretation of the data obtained by using remote methods of investigation in the microwave range. This can be achieved by the common application parameters (antenna directivity diagram, angle of sounding diagram, pattern parameters diagram). There are series of objects whose parameters change over time. They include the growing ice cover. The growth of ice cover is a quasistatic process i. e. its characteristics change relatively slowly over time [7]. Investigating the radar and radiative properties of a given object, measurements can be taken by alternating between the active and passive methods of investigation.

For more informative value it makes sense to take measurements alternatively on two linear polarizations: horizontal and vertical. However, geometrical configuration of measuring system remains constant and it enables to measure the radar and radiative characteristics of the investigated object almost at the same time.

Thus, it will likely be possible that simultaneous measurements of the radar and radiative characteristics of different media in the microwave range whose parameters change relatively slowly over time, for example, freezing soil cover, growing ice or vegetation is an urgent task. In this paper a method of simultaneous measurement of the medium radar and radiative characteristics without changing antenna parameters, geometrical configuration of application and patterns through the example of the growing ice cover is provided.

The measurement technique. We used a setup to measure characteristics of the growing ice cover alternately. Its schematic is on the fig. 1. A radiometer *2* and a Gunn diode oscillator *3* were set on the flat surface. The microwave radiometer enabled to take radiometric measurements on four linear polarizations at an angle of 45° relative to one another. To minimize the influence of the generator on the radiometer because of lower beams of the sending and receiving antennas a screen *5* was put between the devices. The experiments proved that the operating generator does not influence the receiving microwave module in active measurement mode. A photo of the experimental unit is presented in fig. 2. The measuring instruments were set at an observation angle (α) to the test medium. The devices operated at a frequency of 13 GHz in the experiment.

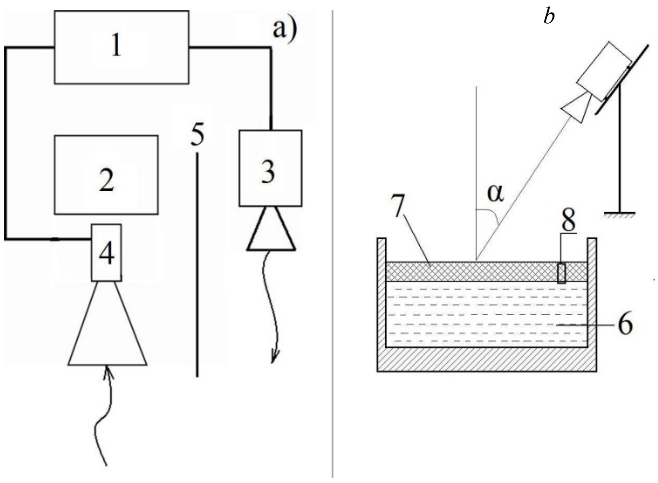

Fig. 1. Schematic of the experimental setup:
a – top view: *1* – control unit; *2* – microwave radiometer; *3* – microwave generator; *4* – electronic attenuator; *5* – the screen; *b* – side view: *6* – container with water; *7* – growing ice cover; *8* – sensors for ice thickness and temperature

Рис. 1. Схема экспериментальной установки:
а – вид сверху: *1* – блок управления; *2* – СВЧ-радиометр; *3* – СВЧ-генератор; *4* – электронный аттенюатор; *5* – экран; *б* – вид сбоку: *6* – резервуар с водой; *7* – растущий ледяной покров; *8* – датчики толщины льда и температуры

The measurement technique can be described in the following way. As the process of ice cover growth takes much time, the active and passive radar measurements of the growing ice cover can be taken alternately at 10 min intervals. During the experiment the generator was switched on and off every 10 min. When it was switched on, an attenuator was triggered in the ingress path of the radiometer with attenuation 25 dB and it made the signal recording impossible . By switching off the generator and the attenuator the radiometric measurement mode was on. The radiation was realized on the vertical polarization and the reception was carried on the four linear polarizations: horizontal, vertical and at angles of 45° relative to the vertical plane at one minute intervals. The output signal recording was performed by the Agilent information gathering system. At the same time the generator and the growing ice thermodynamic temperature radiating power were recorded.

The radiometer was calibrated against the intrinsic thermal radiation of the cold sky reflected from the metal sheet and the ideal radiator with the known thermodynamic temperature [8]. Both the metal sheet and the ideal radiator had the same geometric dimensions.

Water was poured into the wooden case with the foam thermal insulation covering the inside surface to ensure the even ice cover. Measurements were taken in winter so that cooling action was naturally caused by sub-zero air temperature. Taking into account that the Transbaikal air is quite frozen out and cloudless, its impact on the brightness temperature is deemed negligible. Measurements were taken by cloudless days.

By using the measurement technique as described above, we took measurements of radiation and scattering characteristics of the growing fresh ice cover.

The water with the initial mineralization 250 mg/l was poured into the basin 60×60×30 cm^2. The maximal ice thickness reached the level 10 cm per day at an ambient temperature of ~ –30 °C. However, the average mineralization of ice measured by the conductometric method using the HANNA conductometer was around 10 mg/kg. But at the initial time faster growth of ice was noticed and it absorbed more salt. That is why the mineralization in the upper layers of ice is 3 or 4 times more than the one in the layers which form much slower. In the paper [9] it is shown that an integral coefficient of salt absorption by fresh ice cover in the natural bodies of water depends on different factors and, as a rule, is no more than 10 %.

Obtained results of measurements and analysis. As a result of measurements at a frequency of 13 GHz the relationship between brightness temperature and ice cover thickness on the horizontal and vertical polarization and backscattering power on the horizontal and vertical polarization by radiation on the vertical polarization over time was obtained.

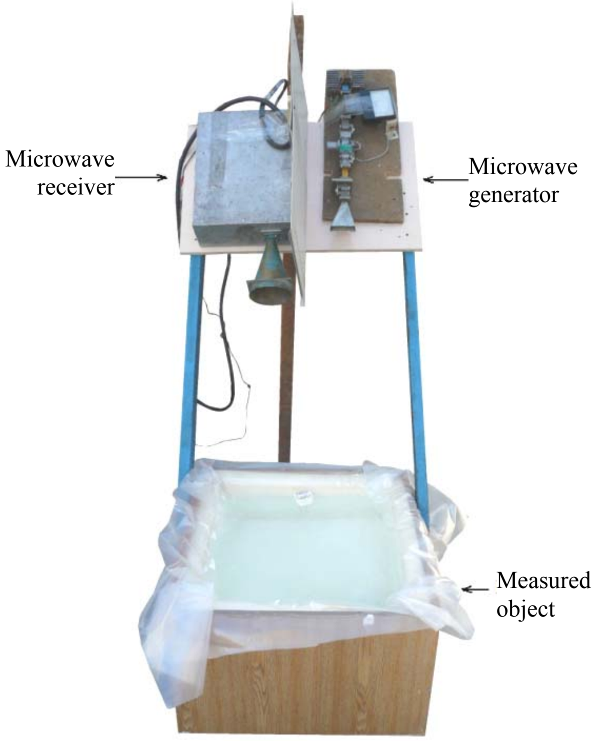

Fig. 2. Photo of an installation for measuring the radiative and scattering properties of a growing ice cover at a frequency of 13 GHz, using a single antenna

Рис. 2. Фотография установки для измерения излучательных и рассеивающих свойств растущего ледяного покрова на частоте 13 ГГц с использованием одной антенны

The relationship of brightness temperature on the horizontal and vertical polarization is shown on fig. 3. It is obvious that there were brightness temperature variations by ice growing. It should be noted that there are some errors in the fringe pattern because of ice inhomogeneity. One of the reasons of its appearance is internal mechanical stresses during the crystal growth under conditions of limited space [10]. It can lead to ice amorphization [11; 12] or crack initiation and water penetrating these cracks. Such types of crystal habit disturbance would be hard to differentiate by one type of measurement. However, the differentiation is possible by scattering radiation measurements of an external source. For example, cracks of ice are visible on the radar image [13].

Power change of the backscattering radiation from the growing ice cover on the horizontal polarization is shown in fig. 4. As is seen from this diagram there are certain variations of radiation power, which do not depend on the thickness of ice cover but they are linked with inhomogeneity within the ice cover which is commensurable with the wavelength and the reflecting increase of the ice cover thickness.

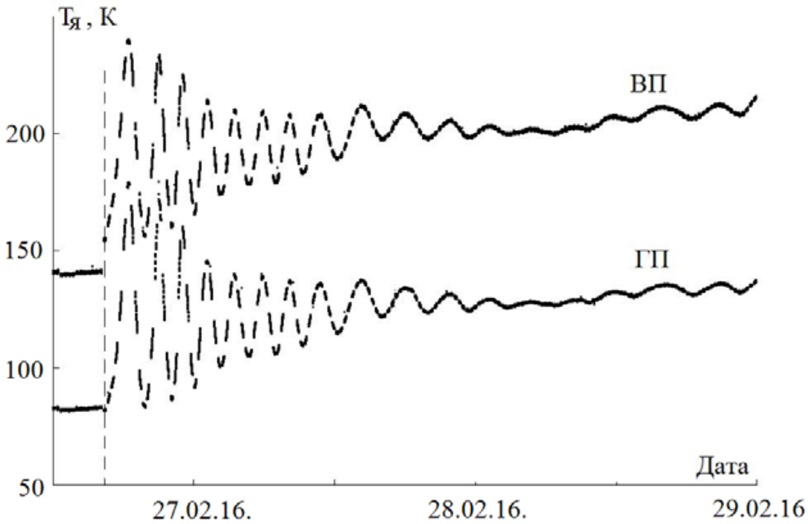

Fig. 3. Change in the radiobrightness temperature of the growing ice cover at a frequency of 13 GHz. The viewing angle is 45°. The band of received frequencies is ~ 1 GHz. The vertical line marks the beginning of the formation of an ice crust

Рис. 3. Изменение радиояркостной температуры растущего ледяного покрова на частоте 13 ГГц. Угол наблюдения 45°. Полоса принимаемых частот ~ 1 ГГц. Вертикальной линией отмечено начало образования ледяной корки

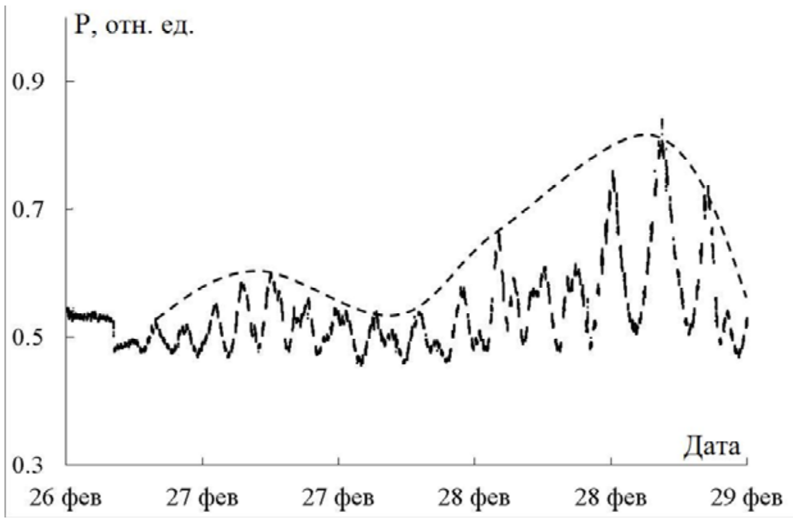

Fig. 4. The power of the scattered signal (P) in relative units from the growing ice cover at a frequency of 13 GHz. Horizontal polarization. The dashed line is the envelope of the interference backscatter maxima

Рис. 4. Мощность рассеянного сигнала (P) в относительных единицах от растущего ледяного покрова на частоте 13 ГГц. Горизонтальная поляризация. Штриховая линия – огибающая интерференционных максимумов обратного рассеяния

Active and passive radar measurements in other cases with different water-soluble additions showed similar proceeding of brightness temperature and backscattering power with the growth of the ice cover.

The supplied results of measurements of the growing ice cover show a substantial difference between the radar and radiometric data. In the paper [5] the reason of some possible variances is nuanced.

Radiometric measurements show interference which is associated with a change in the thickness of the ice cover. This effect is widely known in radiometry for the ice cover at its initial forming stage [14; 15]. By the further growth of the interference event they decrease because of the influence of the frequency range intercepted by a radiometer. Interference variances of backscattering radiation are also determined for radar measurements. Such an effect can be linked with the scattering radiation and its interference from the internal inhomogeneity and roughened surface. As is seen from Fig. 4 this process increased during the growth of ice cover and inhomogeneity production. The envelope of the scattered signal amplitude shows diurnal variations of the backscattering coefficient which can be explained by the difference between air temperature and ice growth rate.

Conclusion. Thus, an alternative technique of virtually simultaneous radar and radiometric measurements of the object parameters with slowly varying characteristics is suggested. The same receiving antenna with fixed geometry is used to obtain data for more meaningful comparison of radiation and scattering surface characteristics. This technique is tried out through the example of the growing ice cover by microwave measurements. Based on the measurement findings, the different features of behaviour of the brightness temperature and the backscattering power for ice are shown and it outlines features of the changing medium structure and its dependence on external conditions.

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