Influence of the Phase Transitions of Water in Permafrost on Natural and Technological Electromagnetic Fields

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Abstract. Frozen ground deformations, resulting from the volumetric changes, associated with the phase changes of water are accompanied by the phenomenon of electromagnetic emission. Based on monitoring data from an experimental site near Yakutsk, this study has shown that the vertical component of magnetic field strength increases at low frequencies in the spectrum of accepted signals in the spring and autumn periods. Seasonal increases in the natural electromagnetic field are attributed to electromagnetic emission which is observed in the frequency range 5-300 kHz when permafrost soils thaw or freeze. Monitoring data on the seasonal increase of natural and technological fields, strength at low frequencies, are presented. In sandy soils, the relative increase of the natural field was 543% during thawing in May and 208% during freezing in October. The relative increase of the field strength of a radio station was 1014% in May and 178% in October. Electromagnetic emission in sandy soils was found to result in a twice higher relative increase in natural magnetic field strength upon thawing than upon freezing. The relative increase in magnetic field strength of radio stations is six times greater during spring thawing compared to autumn freezing. This is explained by better conditions for radio wave distribution on the line during the spring.

1. Introduction

The spring-summer phase transitions of water in the active layer of permafrost are related to thawing of soils which have frozen during the winter. The autumn-winter phase transitions of water occur with subsequent freezing of soils which have thawed during the summer. Upon thawing, the soil changes from a four-component system consisting of mineral particles, ice, unfrozen water, and air into a three-component system with no ice. Freezing brings back ice into the soil structure, making it a four-component system again. The change of water into ice results in volumetric expansion. On thawing, an opposite phase change occurs accompanied by loss of solidity and volumetric contraction of water. These transformations result in soil deformations and associated electromagnetic emission.

Observations of electromagnetic pulses associated with stress, strain, and destruction of rocks have long been reported. It is also known that the stress-strain state, deformations and cracks in rocks, as in other solid bodies, can generate electromagnetic emission [1]. Static or slowly varying loading of dielectric materials causes pulses of the electromagnetic field both at the moment micro- or macrocracking and at the stages prior to failure [2]. Also, external and internal surfaces of dielectrics generating an alternating electrical field during the oscillatory movement of electrostatic charge are
assumed to be sources of electromagnetic emission signals [2]. However, electromagnetic emission in frozen soils induced by their thawing or freezing has not been described before.

Thawing and freezing of soils are always accompanied by various deformations. This paper discusses electromagnetic emission in the active layer induced by deformations upon seasonal thawing and freezing. Electromagnetic emission in this case is induced by numerous local deformations in the active layer. As a result of superposition, they will generate some electromagnetic field around it. Electromagnetic emission upon water phase changes in soils was detected by an anomalous increase in the background values of the electromagnetic field during radio signal monitoring at low frequencies [3].

2. Methods
In 2017-2018, seasonal changes in geoelectrical parameters of frozen soils were monitored using radiomagnetotellurics (RMT) sounding equipment [4-10]. The monitoring site was located at the Tuymada Station of the Melnikov Permafrost Institute SB RAS near Yakutsk [11-19]. The M-K5-SM25 digital recorder with a set of receiving magnetic antenna and the orthogonal symmetric nongrounding receive lines for the horizontal component of the electrical field were used [20]. The magnetic antennas received the vertical and horizontal field components. The received signals were digitized, recorded and presented as amplitude spectra in the working frequency range for preliminary viewing. Measurements were made in the frequency range from 1 to 1000 kHz weekly from March to November at an open site and in pine forest. Meteorological data from the Internet site "rp5.ru" were used to determine the influence of climatic factors.

3. Results and discussion
Processing and analysis of the monitoring data revealed the effect of seasonal increases of radio noise. An increase in radio noise at low frequencies was observed in spring and autumn. A similar effect was detected by our earlier studies, using another method and equipment. Now, the capability of the equipment has allowed us to quantitatively assess the range of frequencies at which an increase of the noise component in the general spectrum of electromagnetic signals was observed, as well as to estimate the amplitude of such increase.

In the spectrum of the electromagnetic field signal received by weekly monitoring, we found that in comparison to data obtained on May 10, 2018 when the radio noise signal was stable (figure 1), there was an increase of its level on May 17 and 25, 2018 in the frequency range 5-300 kHz (figure 2). The vertical component of the magnetic field strength was 56 µV higher than stable signal level. The relative increase was 543%.

According to the meteorological data, maximum near-surface air temperature increased during this period from 12°C on May 16 to 27°C on May 25. This resulted in intensive thawing of the active layer, which caused soil deformations and associated electromagnetic emission. The electromagnetic emission which, in this case, occurred in the large area, caused an increase in the intensity of radio noise at low frequencies. A significant increase in the radio noise signal was also observed in the autumn of 2017. Compared to the level of October 6 (figure 3), the vertical component of the magnetic field increased on October 18 by 57 µV at the frequency range 5-200 kHz (figure 4). The relative increase was 208 %. In this case, the increase of the signal level was caused by freezing of the active layer. Meteorological data for this period indicate that minimum near-surface air temperature lowered from -3°C on October 6 to -13°C on October 18, resulting in intensive freezing of the active layer and soil deformations. Deformations were accompanied by electromagnetic emission, which increased the level of the background electromagnetic field at low frequencies.

In both cases, the increase in the level of strength of electromagnetic field was caused by electromagnetic emission resulting from soil deformations upon thawing and freezing of the active layer.
Figure 1. Frequency spectrum signals of a vertical magnetic component of the field in range 0.01-100 kHz, May 10, 2018.

Figure 2. Frequency spectrum signals of a vertical magnetic component of the field in range 0.01-100 kHz, May 17, 2018.
Figure 3. Frequency spectrum of signals of a vertical magnetic component of the field in range 0.01-100 kHz, October 6, 2017.

Figure 4. Frequency spectrum of signals of a vertical magnetic component of the field in range 0.01-100 kHz, October 18, 2017.
Electromagnetic emission in soils is generated by volumetric changes associated with thawing and freezing. Volumetric changes in soils are, in turn, connected with internal strains and stresses. On thawing, ice-cementing bonds between soil particles and their aggregates are broken off. On freezing, as is known, there is moisture accumulation at the freezing front, ice formation and cementation of particles and their aggregates. In both cases, the volumetric changes lead to deformations and cracking. The stress-strain state, deformation and cracks in soils, as well as in other solid bodies, can cause electromagnetic emission, as shown in [2]. This occurs both in thawing and freezing soils.

Electromagnetic emissions associated with soil deformations upon thawing and freezing occur over large areas and sum up following the principle of superposition to generate an electromagnetic field at low frequencies.

The electromagnetic field generated by electromagnetic emission in freezing or thawing soils increases not only the natural levels of radio noise, as shown above, but also changes the levels of signals of radio stations working at low frequencies. Thus, if at concurrence of phases of fluctuations the level of a signal of a radio station rises, at opposite meanings of phases the level of a signal can be lowered. In both cases, the change of a level by a noise component of radio station signal of will be a handicap for qualitative reception. On the data of monitoring the level of a signal of a radio station, for example, on frequency 150 kHz from May 10 till May 25, 2018 has increased on 178 μV. The relative increase was 1014%. In the period from October 6 till October 18 the signal level increased by 245 μV, with a relative increase of 178 %. The significant difference between the increases of the natural and syntetical fields is explained by the fact that the spring increase in the radio station field related to thawing of the active layer is caused not only by electromagnetic emission, but also by improvement of conditions for radio wave distribution.

4. Conclusion
In summary, the following conclusions can be drawn.

1. Soil deformations resulting from volumetric changes of water due to phase changes cause electromagnetic emission of thawing and freezing soils in permafrost areas.

2. Electromagnetic emission of thawing and freezing soils explains the seasonal increases in the amplitude of the radio noise component of the electromagnetic spectrum in the frequency range 5-300 kHz detected by RMT sounding in perennially frozen sands.

3. Relative increases in the amplitude of the natural electromagnetic field of the 5-300 kHz range due to electromagnetic emission of sandy soils were 543 % upon thawing in May 2018, and 208 % in the range 5-200 kHz upon freezing in October 2017. The relative increase in the signal amplitude caused by electromagnetic emission of sandy soils was twice higher upon spring thawing than upon autumn freezing.

4. The relative increase in the intensity of a magnetic field of radio stations is six times greater upon thawing of sandy soils in spring compared to that upon freezing in autumn. This is due to improvement of conditions of distribution of radiowaves on a line with thawing of the active layer.

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