PHASE TRANSITION ANALYSIS IN FREEZING MOIST SOILS CARRIED OUT ON THE BASIS OF PHASE TRANSITIONS CHARACTERISTIC TO THE DIFFERENT TYPES OF SOIL WATER

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ABSTRACT

The analysis of the mass exchange between the nonfreezing bound and nonfreezing transient water types, as well as that between the nonfreezing transient water and ice in frozen soils has been done. The comparison between results obtained with radiometric and calorimetric methods made it possible to to explain apparent heat capacity behavior during a freezing event using the observed phenomena of phase transition in bound, transient, and capillary soil water types.

Index Terms— Permittivity, phase transition, heat capasity

1. INTRODUCTION

In microwave remote sensing of the cold region territories, the dielectric models of the freezing and thawing soils is a crucial element for developing the algorithms to retrieve contents of unfrozen water and ice contained in frozen soils, with the temperature decreasing [1]. The following look at the mechanism of phase transition in moist soils is commonly accepted: 1) simultaneously with instant formation of ice in the soil, some water in soil remains unfrozen. 2) with temperature decreasing further, the unfrozen water is gradually turning into ice by infinitely small portions; 3) this process continues up to the temperatures of about minus 100-150°C. In brief, the mechanism of phase transition in frozen soil is thought to be a direct transformation of unfrozen water in ice. This mechanism is accepted in the dielectric model of frozen soil [1] to develop a dielectric model of frozen soil and an inversion algorithm to retrieve amount of unfrozen water in soil from the measurements of its radiobrightness temperature.

However, recently it was shown [2]-[6] that when the temperature of frozen soil drops below the freezing point (beginning of ice formation), only a small proportion (about 15%) of initially formed unfrozen water turns into ice, in accordance with the above mechanism. At the temperature of about -15°C, this transition is nearly terminated, and a constant mass of unfrozen water (residual unfrozen water) is remained in a frozen soil, with the temperature decreasing further. In addition, the residual unfrozen water was shown to undergo a phase transition of its own nature without loss of its mass. With this in mind, the approach to developing inversion algorithms like in [1] needs to be thoroughly revised. For this purpose, a clear understanding of the phase transition process in frozen soils has to be worked out, taking into account new results [2]-[6] in this area. This subject is exactly what this paper aims at.

2. PHASE TRANSITIONS OF SOIL WATER TYPES IN FREEZING SOILS

The dielectric spectroscopy methodology was used in [2]-[6] to distinguish between different types of soil water and study their phase transitions with the temperature decreasing. As a result, the presence of three soil water types that is, 1) bound (tightly bound) water, 2) transient (loosely bound) water, and 3) capillary (free) water were distinctly identified. And the method of measuring their individual masses alongside with their specific complex dielectric constants was worked out, allowing to individually study phase transitions of all the type of soil water. It was also shown that the total of bound and transient water types constitute an unfreezing water in frozen soils. While the capillary water in frozen soils is represented only with ice matter.

In this paper, the analysis of phase transitions was carried out on the example of four sample of organic and mineral soils, measured in frequency and temperature ranges from 500 MHz to 15 GHz and from -30°C to +25°C, respectively. Sample no. 1 – shrub tundra organic soil of Alaska was studied in detail in [3], [4]. Sample no. 2 – tussock tundra organic soil of Alaska was originally analyzed. Sample no. 3 – coniferous litter from Siberian taiga was studied in detail in [2]. Sample no. 4 – bentonitic clay was studied in [5].

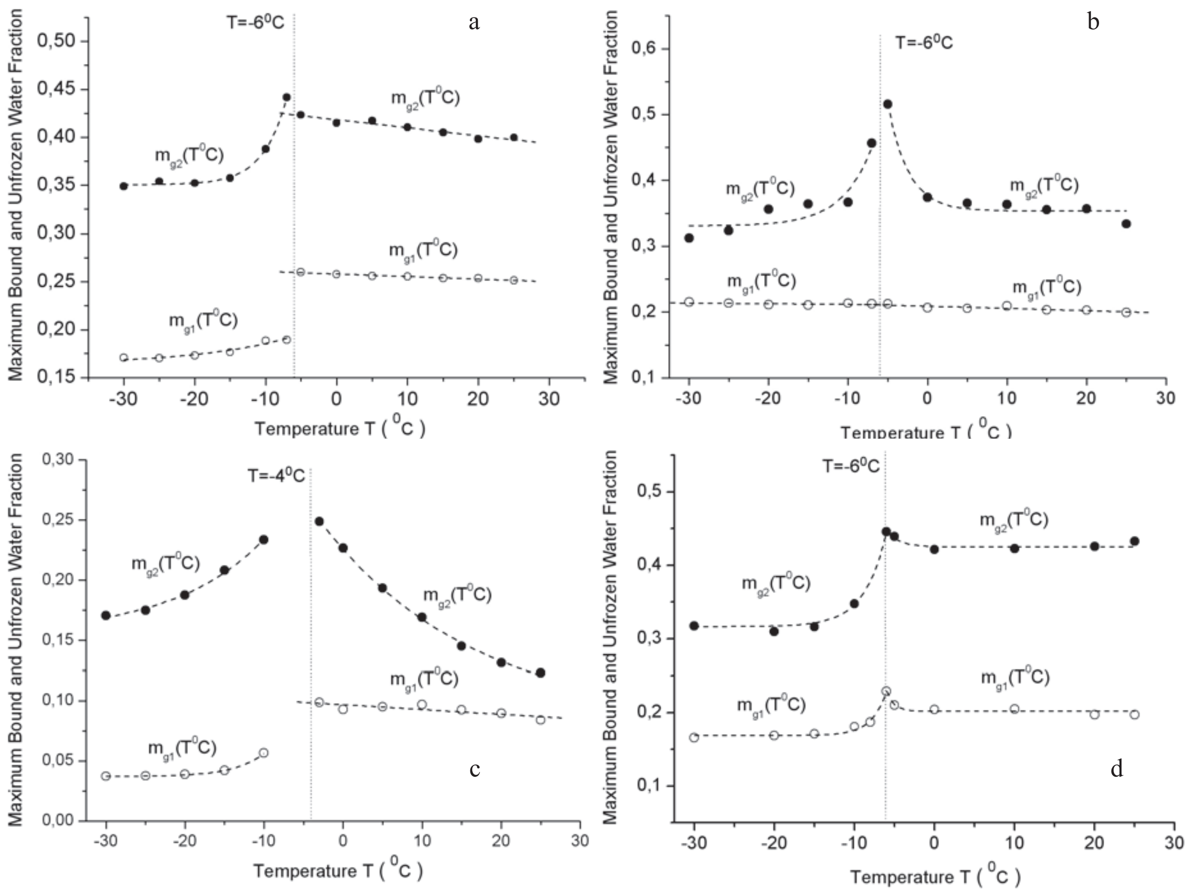

Fig.1 Temperature dependencies maximum gravimetric fraction of bound water and the maximum gravimetric fraction of unfrozen water consist of unfrozen bound water and unfrozen transient water in soils (sample №1 – a, sample №2 – b, sample №3 – c, sample №4 – d).

In Fig. 1, for a number of soils, the temperature dependencies are shown for maximum gravimetric fraction of bound water, m_{g1}, and the maximum gravimetric fraction of total amount of bound and transient water, m_{g2}. The latter constitutes the amount of unfrozen water. As seen from Fig. 1, the amount of unfrozen water decreases as the temperature of frozen soil drops below the point of soil freezing, which is about minus 5°C. As a result of this process, the amount of ice increase at the cost of the transient water. But this process is seen to have terminated at the temperatures 10 to 15°C. The amount of bound water is also decreasing with the temperature decreasing due to its turning into the transient water in the same range of temperatures. As a result of this analyses, it can be stated that, with the temperature of frozen soil decreasing, there is not only phase transition of unfrozen (namely transient) water into ice, but also mutual phase transitions of the bound soil water and transient soil water types into each other are clearly registered.

In Fig. 2, the temperature dependencies of the refractive index for bound, transient and capillary water types contained in different samples of soil are shown. For a capillary water type in all the soils, a break decrease of refractive index is clearly seen. This behavior is typical for a first-order phase transition, at which crystallization process of water occurs instantly, in a very narrow range of temperatures. In contrast to that, the refractive index of transient and bound water types are observed to undergo a gradual decrease, which is characteristic to a blur phase transition similar to the second-order phase transition. This behavior of the refractive index proves the unfrozen water, consisting of the bound and transient water types, to undergo phase transition of its own, which is complementing the phase transitions of this water types between each other.

In [7], the measurement of thermodynamic properties of silt loam soil has been conducted. In Fig. 3, the temperature dependency of this soil apparent heat capacity, C_a, is shown. The measured (symbols) and modeled (solid line) C_a

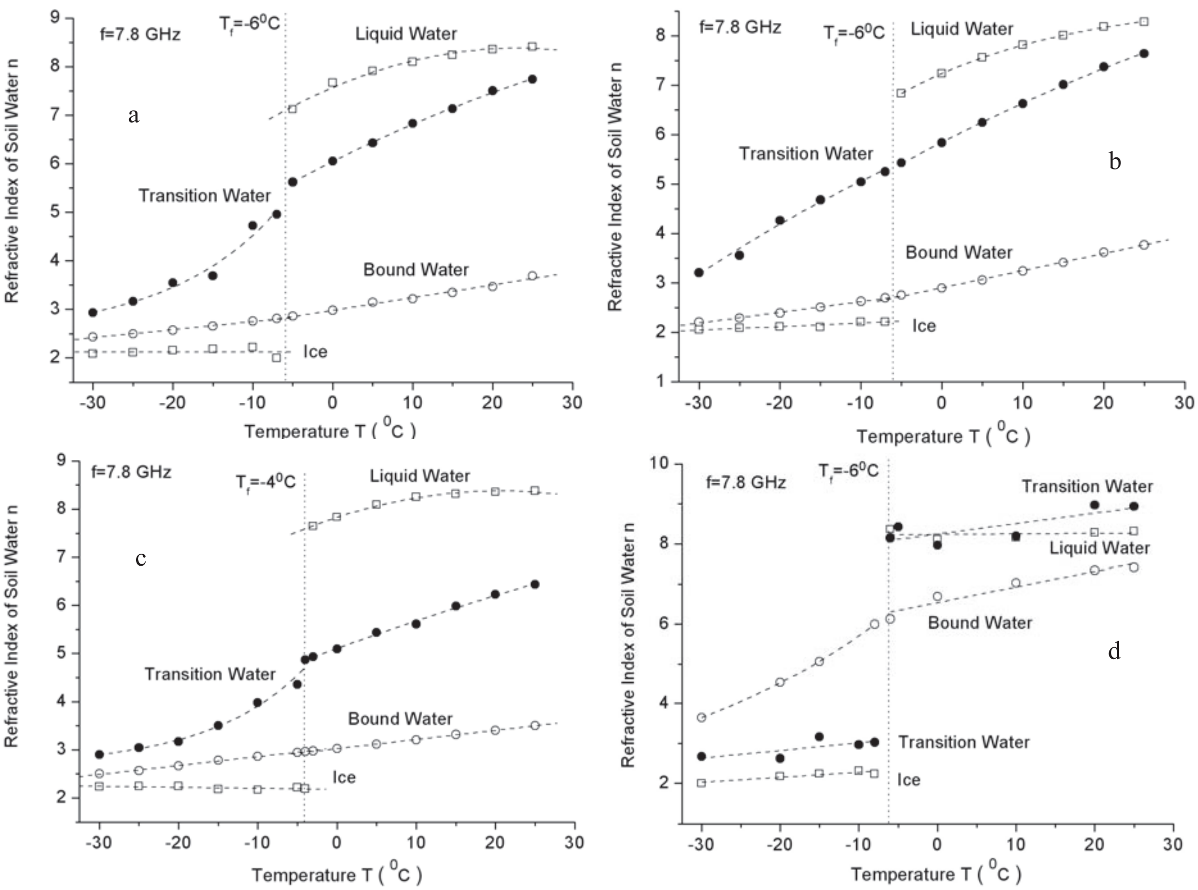

Fig.2 Temperature dependencies of refractive index of moisture soils (sample №1 – a, sample №2 – b, sample №3 – c, sample №4 – d).

demonstrate a large spike at 0°C. This spike occurs due to the fact that the temperature of the moist soil is strongly buffered by the latent heat of fusion as the soil is freezing. The authors of [7] do not explain a gradual slope of C_a in the temperature range from 0 to -7°C.

Such a behavior can be interpreted by using the results represented in this paper. From Figs.1 and 2 follows that the spike in C_a must be really attributed to a first-order phase transition type of capillary liquid water into ice. But in the temperature region from 0 to -10°C, the gradual decrease in C_a must be attributed to phase transition of transient water into ice and smeared phase transitions of the bound water and transient water types into each other, as well as to their own smeared phase transitions as the temperature decreases. It should be noted that the freezing points in our experiments and in [7] differ from each other. This fact should be attributed to super cooling effect of soil water that takes place in the case of confined sample holder used in our measurements. While the authors of [7] carried out in field measurements where an open soil starts freezing at the temperature of 0°C.

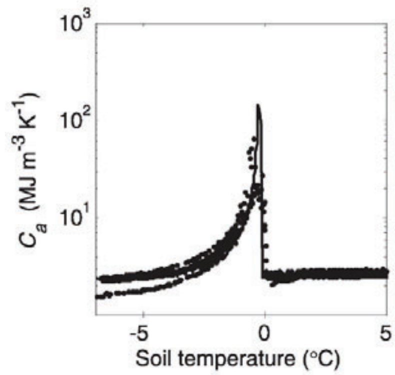

Fig.3 Soil apparent heat capacity (C_a) during a freezing event.

3. CONCLUSION

The phase transition processes in organic and mineral soils have been studied by using the methods of dielectric spectroscopy. The mass exchange between the nonfreezing bound and nonfreezing transient water types have been observed in frozen soils, as well as that between the nonfreezing transient water and ice.

The conducted research made possible to explain apparent heat capacity behavior during a freezing event using the observed phenomena of phase transition in bound, transient, and capillary soil water types. These mechanisms of phase transitions in frozen soils have already been taken into account in the dielectric models for freezing soils proposed in [2]-[6].

4. REFERENCES

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