DIELECTRIC MODEL IN THE FREQUENCY RANGE 0.05 TO 15 GHZ AT TEMPERATURES -30°C TO 25°C FOR THE SAMPLES OF ORGANIC SOILS AND LITTER COLLECTED IN ALASKA, YAMAL, AND SIBERIAN TAIGA

V. L. Mironov, I. V. Savin and A. Yu. Karavaysky

Kirensky Institute of Physics SB RAS

ABSTRACT

We prove the possibility of creating a temperature dependent multi-relaxation spectroscopic dielectric model (TD MRSDM) for a set of organic soil containing 50% (Yamal tundra), 80% (Alaskan tundra) and 90% (boreal pine litter) of organic solids. The created model is based on the previously developed TD MRSDM for the Yamal tundra soil complemented with specific temperature dependences for the hydrological parameters pertaining for each specific soil. At that, the same values for spectroscopic and thermodynamic parameters of the TD MRSDM can be applied, as those were previously obtained in the case of the Yamal tundra soil. The statistical evaluation of the errors for the predicted values of complex dielectric permittivity in the cases of both the thawed and frozen soils with respect to the measured values were carried out. The standard deviations calculated for the Alaskan soil and the Siberian boreal litter appeared to be on the same order as the ones pertaining to the Yamal tundra soil.

Index Terms— Organic soil, moisture, temperature, dielectric model, thawed and frozen soil, remote sensing

1. INTRODUCTION

Currently, technology of microwave satellite remote sensing allows to conduct research and monitoring of moisture and temperature in the case of thawed and frozen mineral soils. However, to perform such monitoring in the case of rich organic matter soils (organic content ≥ 30%), there must be known dielectric models of such soils providing dependencies of soil complex dielectric constant (CDC) on moisture, wave frequency, and temperature. However, the problem of creating dielectric models for organic soils typical of Arctic tundra and boreal forest zones still remains unsolved.

This paper shows that the TD MRSDM, developed in [1], [2] for the tundra soil collected in the Yamal peninsula (50% of organic matter) can be used to calculate the CDC of the Alaska shrub tundra soil (80% of organic matter) [3] and Siberian boreal pine litter (90% of organic matter) [4] in frozen and thawed states. At that, there must be used individual temperature dependences of the hydrological parameters for each specific soil. Thus developed dielectric model for organic rich soils can be used in the moisture range from zero to the maximum field capacity, in the frequency range from 50 MHz to 15 GHz, and in the temperature range from -30°C to + 25°C. It should be noted that the dielectric models of [3] and [4] considered only single frequency dielectric relaxation.

2. DESCRIPTION OF THE USED SOIL SAMPLES

The analyzed Yamal soil (YS) samples come from fieldwork conducted [2] at the site situated at N70º25′52″, E68º25′19″, which represents a typical grassy moss tundra. The sample consists of mineral solids and decomposed organic matter, having the following percentages: organic matter ~50%, quartz ~30%, potassium feldspar ~5-10%, plagioclase ~5-10%, and chlorite, mica, smectite in trace amount (< 1 percent). The Alaska soil (AS) samples come from fieldwork conducted by De Roo [3] at the site situated at N68º38′, W149º35′, which represents typical shrub tundra. with the following percentages of its contents: organic matter ~80%, tiff ~4.5 %, quartz ~7.5-8.2%, mica ~0.75-1.5%, plagioclase ~0.75%, smectite ~0.75%. The boreal litter soil (BLS) samples come from fieldwork conducted at the site situated at N 56º22′07″, E 92º57′17″ in East Siberia. The sample consists of organic matter ~90%, and mineral solids such as quartz, plagioclase, potassium feldspar and mica (~10%).

3. COMPARISON OF DIELECTRIC MEASUREMENTS DATA

Methods of dielectric measurements, the equipment used, as well as the TD MRSDM of organic soil of the YS are , described in detail in [1], [2]. According to [1], [2], the TD MRSDM is based on the refractive mixing dielectric model that represents the moisture dependence of the reduced refractive index (RI), $(n_s-1)/\rho_d$ and reduced normalized attenuation coefficient (NAC), κ_s/ρ_d (see equations (2) (3) in [2]) as a piecewise linear function. For example, the RI dependences on moisture for the YS, AS, and BLS at the frequency f = 1.4 GHz and the temperatures of T = 20°C and T = -20°C are shown in Fig. 1.

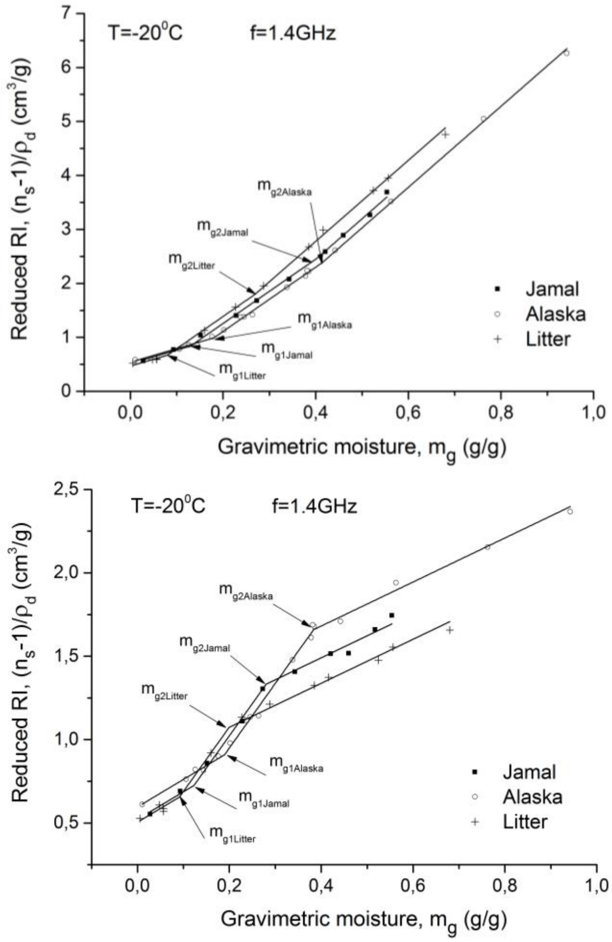

Fig. 1 Behavior of the reduced RI, $(n_s-1)/\rho_d$ vs. gravimetric moisture at the temperatures of 20°C and -20°C and the wave frequency of 1.4 GHz for different organic soils. The RI dependences on soil moisture are piecewise linear functions in certain moisture ranges, indicating contributions of particular forms of soil water. The solid lines show the fits of formula (2) of [2] to the measured data, which are shown by symbols.

As can be seen from Fig. 1, the measured data reveal linear dependencies in the ranges of bound water $0 < m_g < m_{g1}$, transition bound water $m_{g1} < m_g < m_{g2}$ and unbound water $m_g > m_{g2}$. Here, m_{g1} and m_{g2} are maximum amount of bound water and total maximum amount of bound and transition bound soil water, respectively Fig. 1 also shows that the measured values and the corresponding fits for the AS and the BLS agree well with each other. Regression analysis allows to derive the temperature dependences of the hydrological parameters m_{g1} and m_{g2}. In the cases of YS and AS, BLS these dependences are given by (8) of [2] and presented by equations (1), (2), respectively.

$$
\begin{aligned}
&m_{g1}= 0.21-0.002T,\ 0^{\circ}C \le T \le 25^{\circ}C;\\
&m_{g1}=0.149+0.072\exp(T/13.4)\ -30^{\circ}C \le T \le -1^{\circ}C;\\
&m_{g2}= 0.431+0.003T,\ 0^{\circ}C \le T \le 25^{\circ}C;\\
&m_{g2}= 0.322+0.14\exp(T/12.3),\ -30^{\circ}C \le T \le -1^{\circ}C.
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
&m_{g1}= 0.097-3.96\cdot10^{-4}T,\ -5^{\circ}C \le T \le 25^{\circ}C;\\
&m_{g1}=0.087+0.297\cdot\exp(T/3.7),\ -30^{\circ}C \le T \le -7^{\circ}C;\\
&m_{g2}= 0.203+0.144\cdot\exp(-T/19.3), -5^{\circ}C \le T \le 25^{\circ}C;\\
&m_{g2}= 0.155+0.189\cdot\exp(T/11.5),\ -30^{\circ}C \le T \le -7^{\circ}C.
\end{aligned}
\tag{2}
$$

As seen from Figs. 1 and 2, the segments of the piecewise dependences corresponding to the bound water ($0 < m_g < m_{g1}$), transition bound water ($m_{g1} < m_g < m_{g2}$), and unbound water ($m_g > m_{g2}$) seem to be parallel to each other. According to equation (1) of [2], it means that the RIs pertaining to the respective soil water components in different soils are expected to be close to each other as well. Based on this approach, we will calculate the complex dielectric spectra for the AS and BLS using the methodology given in [2] and equations (1)-(7), (9)-(12) of [2], with equation (8) of [2] being substituted by equations (1) and (2) for the AS and BLS, respectively.

Thus calculated spectra and the measured ones for the DC and LF of moist soil are shown in Figs. 2 and 3 in the cases of the AS and BLS, respectively

The samples shown in Fig. 2 contain only bound water (m_g = 0.086g/g < m_{g1}(20ºC) = 0.164g/g, dry soil density ρ_d = 0.619g/cm^3, plot 1), bound water and transient bound water (m_{g1}(-20ºC) = 0.164g/g < m_g = 0.299g/g < m_{g2}(-20ºC) = 0.345g/g, ρ_d = 0.576g/cm^3, plot 2; m_{g1}(20ºC) = 0.164g/g < m_g = 0.299g/g < m_{g2}(20ºC) = 0.352g/g, ρ_d = 0.576g/cm^3, plot 3), all three soil water components (m_g = 0.602g/g > m_{g2}(-20ºC)= 0.345g/g, ρ_d = 0.594g/cm^3, plot 4; and m_g = 0.563g/g > m_{g2}(20ºC) = 0.352g/g, ρ_d = 0.596g/cm^3, plot 5).

The samples shown in Fig. 3 contain only bound water (m_g = 0.056g/g < m_{g1}(20ºC) = 0.089g/g, ρ_d = 0.86g/cm^3, plot 1), bound water and transient bound water (m_{g1}(-20ºC) = 0.088g/g < m_g = 0.161g/g < m_{g2}(-20ºC) = 0.188g/g, ρ_d = 0.782g/cm^3, plot 2; m_{g1}(20ºC) = 0.089g/g < m_g = 0.161g/g < m_{g2}(20ºC) = 0.254g/g, ρ_d = 0.782g/cm^3, plot 3), all three soil water components (m_g = 0.416g/g > m_{g2}(-20ºC)= 0.188g/g, ρ_d = 0.942g/cm^3, plot 4 and m_g = 0.416g/g > m_{g2}(20ºC) = 0.254g/g, ρ_d = 0.942g/cm^3, plot 5). In the case of frozen soil samples, the unbound soil water is present in the form of wet ice.

It is worth noting that, in the cases of AS and BLS, the respective soil water conductivities were derived by fitting the measured values of soil LFs in the range of low frequencies, applying the methodology of [2]. The respective values of the derived electrical conductivities for the bound water, σ_b, transient bound water, σ_t, unbound water, σ_u, and wet ice, σ_{wi}, , are given in Tab. 1.

Assessment of the errors was conducted using the coefficient of determination R^2 and standard deviation *RMSE*. For the AS data shown in Fig. 2, these estimates have made: $R^2_{\varepsilon'}$ =

0.996 and $R^2_{\varepsilon''}$ = 0.985, $RMSE_{\varepsilon'}$ = 0.161 and $RMSE_{\varepsilon''}$ = 0.249. For the BLS, these estimates have made: $R^2_{\varepsilon'}$ = 0.997 и $R^2_{\varepsilon''}$ = 0.996, $RMSE_{\varepsilon'}$ = 0.215 и $RMSE_{\varepsilon''}$ = 0.106.

Tab.1 The values of electrical conductivity for the AS and BLS.

Water comp. / Param.	Bound water, σ_b		Transition bound water, σ_t		Unbound water, σ_u, σ_{wi},	
T (°C)	20	-20	20	-20	20	-20
AS	0	0	0.04	0.03	0.24	0.046
BLS	0	0	0.09	0	0.21	0

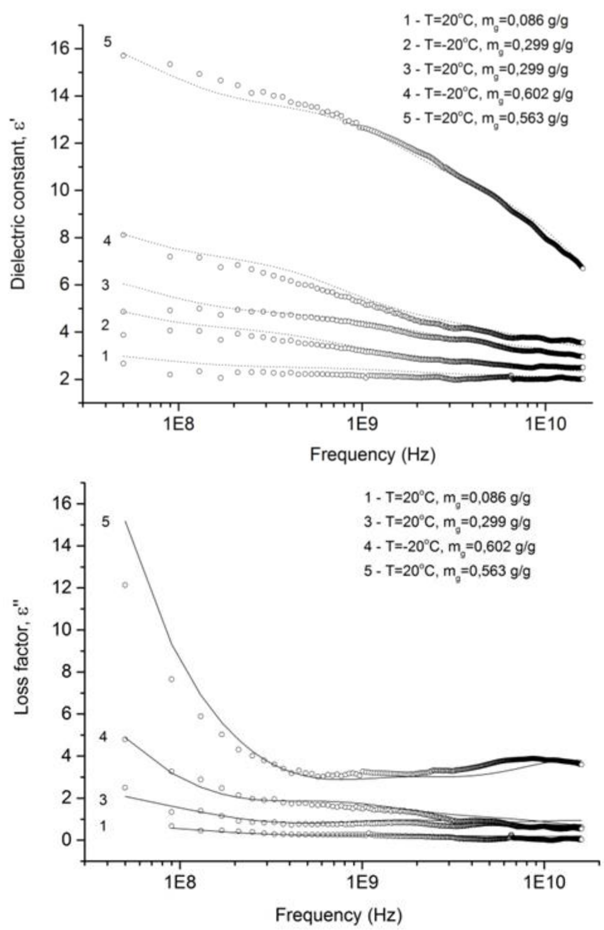

Fig. 2 Spectra of dielectric constant, ε´ (a), and loss factor, ε″ (b), measured for the AS (symbols) and predicted (solid lines) with the use of the TD MRSDM developed for the YS. Shown data represent both thawed (T=20°C) and frozen (T=−20°C) soils, having only bound water (m_g=0.086), bound water and transient water (m_g=0.299), bound water, transient water and liquid water at T=20°C or wet ice T=-20°C (m_g=0.563 and m_g=0.602).

4. CONCLUSIONS

As a result of this work, it was shown that TD MRSDM, developed in [1] for the tundra soil collected in the Yamal peninsula (50% of organic matter) can be used for predicting the dielectric constant and loss factor of the Alaska shrub tundra soil (80% of organic matter) and Siberian boreal pine litter (90% of organic matter), both soils being in a thawed or frozen state. Built on this basis, the dielectric model can be used in the soil moisture range from zero to the maximum field capacity, in the frequency range from 50 MHz to 15 GHz, and in the temperature range from -30°C to + 25°C.

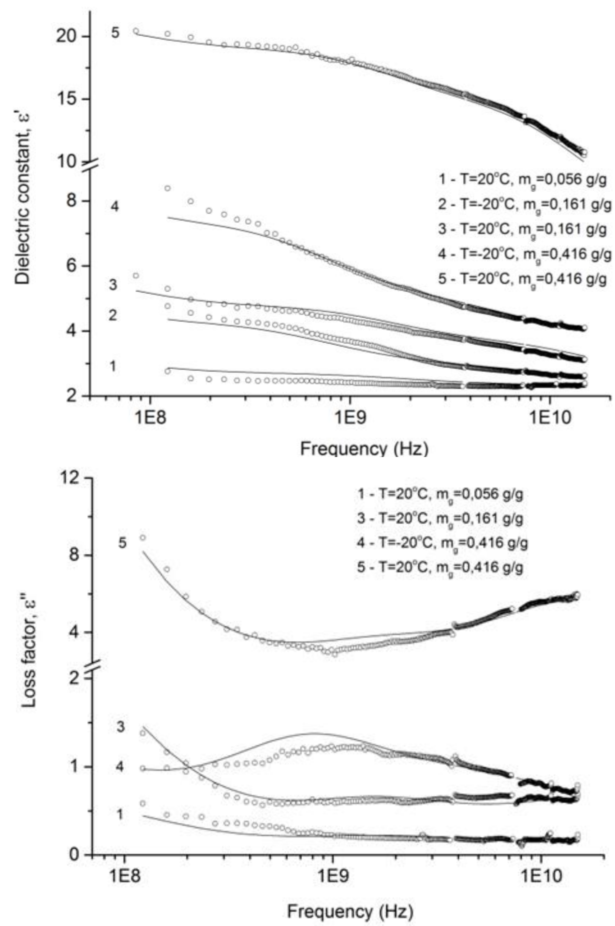

Fig. 3 Spectra of the dielectric constant, ε´ (a), and loss factor, ε″ (b), measured for the boreal pine litter (symbols) and predicted (solid lines) with the use of the TD MRSDM developed for the YS. Shown data represent both thawed (T=20°C) and frozen (T=−20°C) soils, having only bound water (m_g=0.056), bound water and transient bound water (m_g=0.161), bound water, transient water and liquid water at T=20°C or wet ice T=-20°C (m_g=0.416).

5. REFERENCES

[1] V.L. Mironov, I.V. Savin and K.V. Muzalevsky, "Temperature Dependent Multi-Relaxation Spectroscopic Dielectric Model for Thawed and Frozen Organic Soil at 0.05-15 GHz," *in proc. IGARSS*, 26-31 July, Milan, ITALY, pp. 2031-2034, 2015.

[2] V.L. Mironov and I.V. Savin, "A temperature-dependent multi-relaxation spectroscopic dielectric model for thawed and frozen organic soil at 0.05–15 GHz," *Physics and Chemistry of the Earth*, Parts A/B/C, Available online 14 March, (2015) [doi:10.1016/j.pce.2015.02.011].

[3] V.L. Mironov, R.D. De Ro and I.V. Savin, "Temperature-Dependable Microwave Dielectric Model for an Arctic Soil," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 48, no. 6, pp. 2544-2556, June 2010.

[4] V.L. Mironov, I.V. Savin, " Temperature Dependable Microwave Dielectric Model for a Pine Litter Thawed and Frozen," *PIERS Online,*. V. 7., № 8, pp. 781–785, 2011.