Observed Effects of Humus, Salt Contents and Soil Contamination on the Microwave Emissivity of Soils

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Abstract – Multi-temporal multi-frequency passive techniques have been employed in order to make comparative research of microwave emissivity of soil plots with different salt, humus and impurity content. It has been established that humus, salt and impurity has an effect on the soil structure at the saturated state and on pace of soil water evaporation. Soils polluted with mineral oils most dry up fast of oll, salted soils slowly dry up. The experiment with radiometers, 2.7, 6.0 and 8.2 GHz, revealed the changes in radiobrightness temperature are related which the concentration of the substances listed above. At evaporation in a surface layer of soils with various contaminations there are various gradients of moisture. Because of that the radiobrightness temperatures on different wavelengths can hardly differ. In the article it is shown, that it is possible to distinguish the plots with different humus, salt contents and soil contamination under identical meteorological conditions by the remote sensing method.

Keywords: Microwave remote sensing, Soil dielectric permeability, Humus, Soil degradation

1. INTRODUCTION

Almost all of the Russian agricultural lands are the subject of degradation processes that limit crop productivity. Over 97 % tillage lands have a negative balance of humus. Annually the soil humus contents decreases by 0,01-0,05% (Pankova, 2000). On the irrigation lands soil salinization occurs. Near by the large cities the soils are polluted by smoke emission. In this connection there is a necessity of land surface monitoring both on the global and location scales. Dehumufication (the process of humus loss) and salinization cause the soil color changes witch reveal the processes that might be visible or near infrared ranges (Wividi, 1996).

The basis for use of microwave remote sensing techniques is the dependence of microwave emissivity of soils on it dielectric properties. At microwave frequencies the radiobrightness temperature of a bare soil surface is determined by the soil moisture, influencing to a dielectric permeability, soil temperature and the surface structures. When the surface roughness smaller than the wavelength, radiobrightness in decimetric range is most sensitive to the water content of a first few centimeters of the soil and no more than one centimeter in centimetric range.

Therefore it is possible to reveal the factors degradation of soils if they influence upon dynamics of moisture in a surface layer due to precipitation and the subsequent drying process.

2. DIELECTRIC PERMEABILITY OF POLLUTED SOILS

Salinity impacts the real part of a dielectric constant of soils only at negative temperatures and increases imaginary part of a dielectric constant of water for the wavelength over 10 cm at positive temperatures.

We installed influence of a humus contents, ashes and petroleum contaminations on a dielectric permeability of soils. The increase of a humus contents results in increasing of a boundary water share and in decreasing dielectric permeability at large moisture (Mironov, 2003). As we see in Fig. 1*a*, the increase of boundary water quantity results in lengthening of a line with small declination appropriate lower permeability of boundary water. The adding of ashes in soil with the low contents of clay (sandy loam) makes the same influence (Mironov, 2004). The contamination of soil by petroleum does not change boundary water quantity but reduces a curve declination of dielectric permeability relation in the field of a free water (Fig.1*b*).

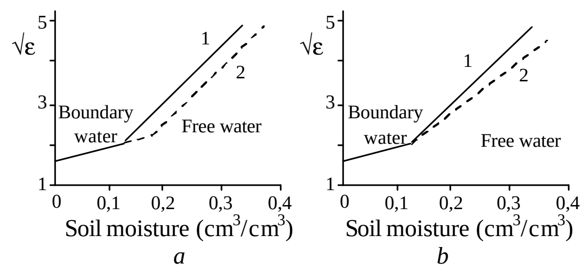

Figure 1. Influence of increase of the humus contents both ashes (*?*) and of contamination by petroleum (*b*) on a refraction coefficient $\left(\sqrt{e}\right)$ of soils;
1 - initial relation; 2 - changed relation.

The change of a dielectric permeability *e* results in change of emissivity χ and radiobrightness temperature T_b pursuant to the formulas:

$$c = 1 - \left(\frac{\sqrt{e}-1}{\sqrt{e}+1}\right)^2, \qquad T_b = cT,$$

where T = effective temperature of soil.

However stronger influence on dynamics of temperature renders change of hydrological properties of soils

3. EMISSIVITY AND RADIOBRIGHTNESS DYNAMIC

3.1. Experiment description

The experimental researches were developed in 1998-2004 summery seasons in the Omsk region (Western Siberia, Russia). It has been studied the comparative dynamics of radiobrightness temperature of soil plots with different salt and humus content at frequencies of 2.7, 6.0 and 8.2 GHz.

The soil samples taken from the soil plots have been tested for the amount of salt and humus content. The results of the salt tests and the particle-size test of the soil plots given in Table 1.

It is seen that the soil samples No. 1-3 are non-salted soils. The particle-size composition of soil plots is not much different. There is small difference in the clay particles content (particles size <0.01 mm) having the most essential influence on hydrology characteristics. The essential difference of the soil plots No. 1, 2 consist in the humus content and for the soil plots No. 3, 4 consist in the salt content.

Table 1. Parameters of soil plots

Plot	Humus (H, %)	Salt (S, %)	Soil texture (%)		
			sand	silt	clay
1	6,6	0,082	26,1	37,9	36,0
2	0,6	0,064	12,0	43,9	44,1
3	6,1	0,076	26,1	26,0	47,9
4	6,1	1,278	26,1	26,0	47,9

Measurement techniques were not distinguished from those described in paper (Bobrov, 1999). The measurement error of brightness temperature difference for adjacent plots did not exceed 0.3-1 K.

About 30 experimental cycles have been developed, each of these was begun with intensive irrigation of soil plots and was going till the complete drying up. The measurements of brightness temperature T_b used to begin after the water infiltration, soil samples were taken 2-3 hours after irrigation (after free water flowed down).

3.2. Effect of soil salinity

The comparative research of emissivity dynamic of plots No 3, 4 has shown that after irrigation emissivity of salt plot (No 4) it is changes slower, than emissivity of plot No 3. It follows from the data adduced in Fig. 2.

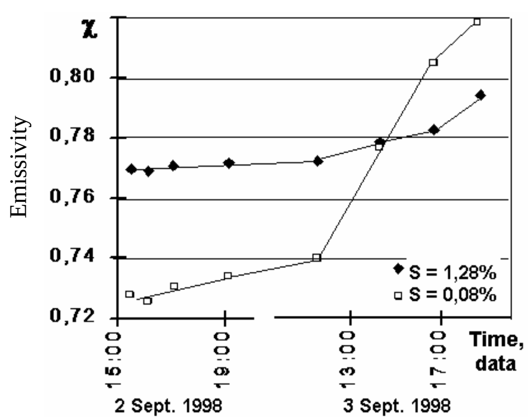

Figure 2. Emissivity dynamics of salted (S=1.28%) and non-salted (S=0.08%) soils at frequency 6.0 GHz after intensive irrigation.

After irrigation the brightness temperature T_{b4} of plots No 4 was usually higher, than brightness temperature T_{b3} of plots No 3. At first, it was conditioned that water poorly penetrates into salted soil aggregate and poorly destroy it than that on the surface of non-salted humus soil. Therefore the surface roughness and emissivity of salted soil are more than these of non-salted soil. Secondly, owing to the higher water-retention of non-salted soil, the moisture of top-layer (and dielectric constant) during two-three hours after irrigation was higher than that of salted soil.

During one-two days after irrigation the brightness temperature of soil plots was being increased. At the same time the top layer of salted plot got dry more slowly than that of non-salted plot. Therefore the radiobrightness contrast of salted and non-salted plots $DT_{bS} = T_{b4} - T_{b3}$ was being decreased, then the sign was changed (see Fig. 2). The contrast maximum observed during the experiments, came to 30 K (at 1,2% of salt content difference). Five-seven days later, the top-layers got dry up and the brightness contrast nearly disappeared.

Such features of emissivity dynamics are explained by low rate of evaporation from a surface of the salted soil. After moistening of the salted soil up to a condition of saturation owing to swelling the soil capillary tubes are closed. It reduces speed of motion of soil water up on capillary tubes almost up to zero. In pure soil with the high humus content a large part of course soil interstices is present, which able fast to free at evaporation quickly. It results in a gap of a fluid pole in a capillary and decelerates evaporation from underlying soil. The typical soil moisture profiles direct after irrigation and two days later are shown in Fig. 3.

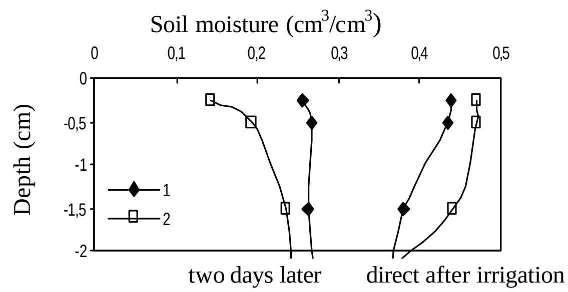

Figure 3. Soil moisture as a function of depth. 1- salted soil (S=1.28%); 2 - non-salted soil (S=0.08%).

3.2. Effect of humus content

The soils with the low humus contents with other conditions being equal have a smaller porosity and have capillary tubes of smaller diameter than those rich in humus soil. On thin capillary tubes the water is pull up from steep layers and a gap of a fluid pole in a capillary occurs at smaller moisture. In the previous section it was shown that the fast drying up layer on a surface of rich in humus soil hinders in evaporation from more steep layers. Therefore in soils rich in humus a higher moisture gradient arises in a layer the depth 1-2 cm than those in soils poor in humus. It results in distinction in emissivity at different wavelengths.

In Fig. 4 the dynamics of brightness temperature at frequencies 2.7 and 8.2 GHz of soil plots No 1 and No 2 in experiment conducted 5 July 2004 is shown. The irrigation by water layer of 22 mm was made one day prior to it. The brightness temperatures of both plots at different frequencies were almost identical direct after irrigation. As it is visible from Fig. 4 the brightness temperatures at frequency 2.7 GHz remains identical to both plots approximately till 19:00. To the end of a day the moistening owing to water draw from steep layers begins to exceed evaporation and brightness temperature at frequency 2.7 GHz is reduced. Thus at frequency 8.2 GHz it is much higher for a plot No 1 (rich humus soil).

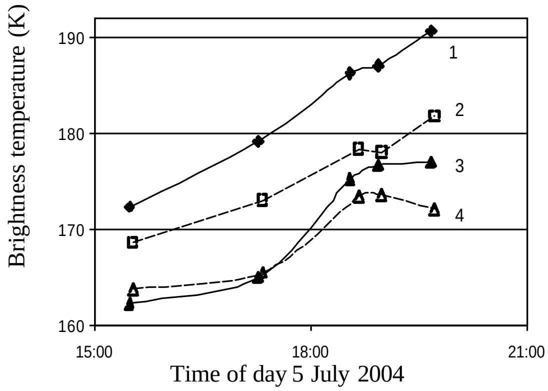

Figure 4. Brightness temperatures dynamics of rich in humus soil (curve 1, 3) and poor in humus soil (curve 2, 4) at frequencies 8.2 GHz (curve 1, 2) and 2.7 GHz (curve 3, 4) one day later after intensive irrigation.

To characterize distinctions in brightness temperatures at different frequencies (which are cased by the distinctions in moisture gradients) it conveniently use the normalized difference:

$$NDT = \frac{T_2 - T_1}{T_2 + T_1}$$

where T_1 = brightness temperature at frequency 8.2 GHz, T_2 = brightness temperature at frequency 2.7 GHz.

In Fig. 5 the dynamics of *NDT* for soil plots No 1 and No 2 in experiment conducted 4-6 July 2004 is shown.

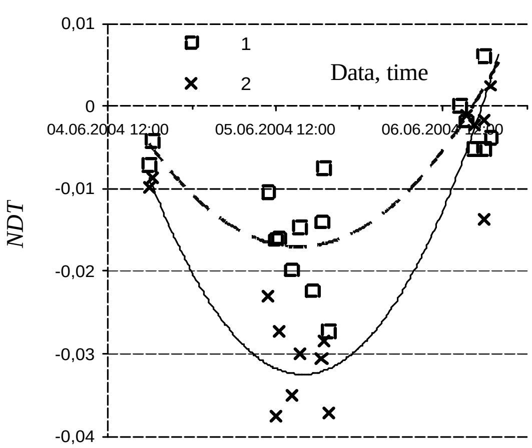

Figure 5. *NDT* dynamics of poor in humus soil (1) and rich in humus soil (2). Solid and dashed curve is approximation of the data by a second degree polynomial.

The sign of *NDT* is related with the sign of a gradient of moisture. Usually the moisture of soil decreases in direction to a surface. Such moisture gradient is negative. Depending on irrigation intensity and rate of evaporation the maximum values of a module *NDT* are achieved in 6 - 30 hours and exist for approximately the same time. The more evaporation the shorter is this period. The *NDT* values make from - 0.25 to - 0.5 for rich in humus soils and from 0 to - 0.3 for poor in humus soils. In each particular experiment after irrigation by a water layer more than 16-18 mm a residual of *NDT* values made more than 0,2. At weak irrigation, when the soil is moistened on depth less than 5 cm, difference in *NDT* values is significant less though values can be large. In Fig. 6 the data of experiment at weak irrigation conducted after loosening of plots are adduced.

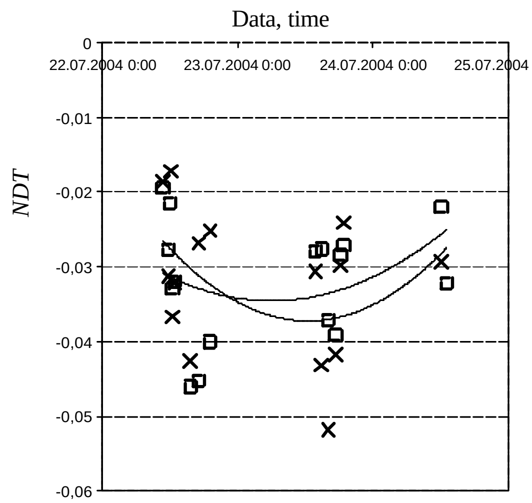

Figure 6. *NDT* dynamics of poor in humus and rich in humus soils at weak irrigation after loosening of plots. Labels are same as in Fig. 5.

The data adduced on Fig. 5 and 6 testify that the main reason of difference in values *NDT* is the difference in a porosity of soil surface layers.

3.3. Effect of petroleum contamination

The petroleum is hydrophobic fluid therefore the petroleum contamination results in noticeable change of hydrological properties of soils. The contamination implemented by motor oil pollution of dry soil with a rough surface. Some watering - evaporation experimental cycles are conducted at contamination of a plot by an equivalent oil layer of 27 mm distributed on a surface. As a result of oil absorption into the soil layer has been polluted up to the thickness 3-4 cm. Thus the polluted soil surface aggregates ceased to absorb water and did not break up at irrigation. Whereas the pure soil surface aggregates at intensive irrigation fail, thus the roughness degree is reduced.

In Fig. 7 dynamics of brightness temperature of pure soil plots No 1 and polluted by oil soil plots with the same soil parameters during evaporation after intensive irrigation is shown. Directly after of irrigation brightness temperatures of plots were almost identical (about 290 ?). At once after irrigation of plots by water layer of 20 mm the brightness temperature of pure soil at all wavelengths has decreased to 160-170 K whereas brightness temperature of the polluted plot at short wavelengths (frequencies 6.0 and 8.2 GHz) has decreased less.

Such distinction in the emissivity of the polluted and pure plots is stipulated by two circumstances: at first, the surface of a pure plot has become more smooth, secondly, it has become more moistened as the surface layer of the polluted soil because of strong hydrophobic properties was a little moistened, and the large part of a water was absorbed by the underlying not polluted soil. In the polluted soils there is a sharp jump of moisture on a low bound of the polluted layer.

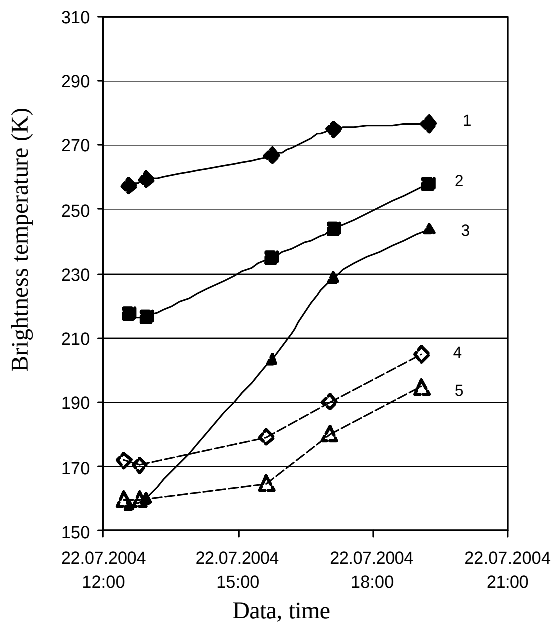

Figure 7. Brightness temperatures dynamics of pure soil plots No 1 (curve 4, 5) and polluted by oil soil plots (curve 1, 2, 3) at frequencies 8.2 GHz (curve 1, 4), 6.0 GHz (curve 2) and 2.7 GHz (curve 3, 5) at once after intensive irrigation. The thickness of a polluted layer is equal to 3-4 cm.

The sensing depth at frequency 8.2 is less than a thickness of a polluted hydrophobic layer; therefore brightness temperature on this frequency decreases a little after irrigation. At frequency 2.7 GHz the sensing depth noticeably exceeds a thickness of a polluted layer and the moistened underlying layer of pure soil hardly influences on temperature. The increase of the polluted layer thickness results in easing of influence of moisture of the polluted soil on brightness temperature at frequencies 6.0 GHz and 2.7 GHz. The example adduced in Fig. 8 shows that the thickness of the polluted layer exceeds sensing depth at frequencies 8.2 and 6.0 GHz. Thus the brightness temperature measurement at different wavelengths allows to evaluate a thickness of the oil polluted layer.

3.3. Effect ashes of inclusions

Influence of ashes impurity is most hardly noticeably on sandy soils. Loamy soils polluted by ashes inclusions differ on brightness temperatures and *NDT* values only after intensive irrigation. The detection such polluted soils by a microwave remote sensing method is problematic.

4. CONCLUSIONS

In an outcome of conducted experimental researches the capability of effective detection of soil zones polluted with petroleum, and evaluation of a thickness of the polluted layer by a microwave radiometric method is established. The results of researches of soil with the various humus contents show that owing to differences in soil structure expressed on different porosity, various gradients of moisture can detect poor in humus soil 6-30 hours later after intensive irrigation.

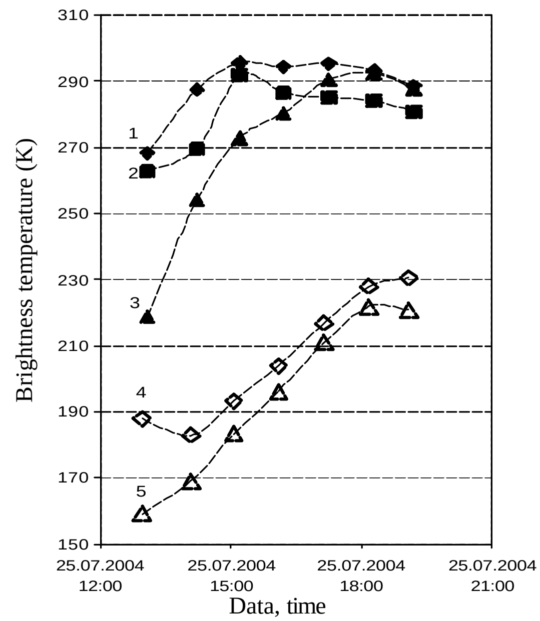

Figure 8. Brightness temperatures dynamics of pure soil plots No 1 and polluted by oil soil plots at once after intensive irrigation. The thickness of a polluted layer is equal to 5-6 cm. Labels are same as in Fig. 7.

5. REFERENCES

Bobrov P.P., "Estimating of soil salinity by passive microwave observations at G-band," Proceed. of IGARSS'99. Hamburg, Germany, pp. 1105-1107, 1999.

Bobrov P.P., "The study of evaporation, water content, and structural status of surface soil layer by microwave remote sensing methods," Eurasian Soil Science, vol 33, No. 5, pp. 501-505, 2000.

Mironov V. L. and P. P. Bobrov, "Soil Dielectric Spectroscopic Parameters Dependence On Humus Content," Proceed. of IGARSS'2003. Toulouse, France, vol II, pp. 1106-1108, 2003.

Mironov V.L., P.P. Bobrov and V.N. Mandrygina, "Bound Water Spectroscopy for the Soils with Varying Mineralogy," Proceed. of IGARSS'2004. Anchorage, Alaska, USA, vol V, pp. 3478 – 3480, 2004.

Pankova E.I. and A.F. Novikova, "Soil Processes on Agricultural Lands of Russia," Eurasian Soil Science, vol 33, No. 3, pp. 319-330, 2000.

Wividi D., "Monitoring of salt affected soils of the Indo-Gangetic alluvial plains using principal component analysis," Int. Journal of Remote Sens., vol 17, No.10, pp. 1907-1914, 1996.