Joint USA-Russia Field Experiment in Alabama on Microwave Radiometry of Soil-Vegetation System

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Abstract -- Long-Term "Agreement on Collaboration in the Field of Remote Sensing of the Earth" has been signed in December 2002 between the Institute of Radioengineering and Electronics (IRE), Russian Academy of Sciences (RAS), and NASA Center for Hydrology, Soil Climatology and Remote Sensing (HSCaRS), Alabama A&M University (AAMU). Among the topics of collaboration are "Experimental investigations of the characteristics of microwave radiation from land, water surfaces and the atmosphere".

IRE RAS contributed to this collaboration with portable (book size) microwave radiometers, a portable (palm size) data acquisition system (DAS), and programs for data collection, calibration, processing and thematic interpretation.

HSCaRS AAMU contributed to this collaboration with the laboratory and field facilities, a mobile platform (rover) and in situ measurements. The radiometers delivered to the test site area (Huntsville, AL) were light-weight devices operating at the wavelengths of 6 cm, 18 cm, and 21 cm. The radiometer antennas provided a beam-width of about 30º.

The first phase of "radiation vs soil moisture" experiments took place in December 2003. Three characteristic types of bare soil with different moisture content values in the presence of short and not dense grass have been selected. Antennas were located at the on-ground platforms.

The second phase of "radiation vs soil moisture" experiments took place in June 2004 in the same location. Within a second phase of experiments, the radiation data were collected from a truck which served us as a prototype of a specialized mobile platform.

In October 2004, the team began the third phase of experiments using the specialized mobile platform (rover type), equipped with three radiometers, DAS and GPS receiver. All measurements included observations of radiometer response on changes in soil moisture and characteristics of vegetation. The paper discusses the experimental data and model predictions.

Keywords- soil moisture, vegetation, microwave radiometry

I. INTRODUCTION

Microwave radiometry, or passive microwave remote sensing, is one of the radio-physical methods used for remote observations of the environment. It is based on measurements of the natural electromagnetic radiation of environmental objects like lands, waters, snow, ice, and the atmosphere in the millimeter to decimeter wavelength range [1-4].

Investigations of water and land surfaces are taking place in the 0.5 to 50 cm band of electromagnetic wavelengths, in practice, in between 2 and 3 cm (X-band), 5 and 6 cm (C-band) and 18 and 30 cm (L-band). Inside these bands, the land surface radiation is primarily a function of the free water content in soil but it is also influenced by other parameters, such as depth to a shallow water table (first of all in L-band), vegetation biomass (first of all in X- and C-band), and salinity and temperature of the soil [1-14]. Regarding open water areas, microwave radiation is dependent on temperature, salinity and roughness of the water surface. All relationships are wavelength dependent.

The measure of the intensity of radiation at microwaves is a brightness temperature, T_b, which is a product of emissivity,κ, and thermodynamic temperature, T_e, within the effectively emitting layer (skin-depth) of the object,

$$T_b = \kappa\, T_{e.}$$

The thermodynamic and brightness temperatures are measured in Kelvins where,

$$T(K) = t(°C) + 273.$$

The emissivity is a function of dielectric permittivity of the objects of observation.

For a land surface, the dielectric permittivity is first of all a function of soil moisture. The higher a soil moisture content, the higher the permittivity of soil the lower the emissivity intensity of radiation/brightness temperature of the given land area.

For a water surface, the dielectric permittivity is first of all a function of electric conductivity of water areas (first of all in L-band) that is dependent on a concentration of salts, acids, on a presence of oil films and many other chemical substances. For example, the higher salinity of water, the higher the dielectric permittivity of water solution, the lower the emissivity/intensity of radiation/brightness temperature of the given water area.

Within the 2 to 30 cm microwave band, for t=10-30^{o}C, the radiation characteristics of several surface types of environment are shown in Table 1.

Table 2 shows the sensitivity of radiation in the X-band (2-3 cm) and L-band (18-30 cm) to the changes in free water content in bare soil, soil density, salinity and temperature of the soil surface [1, 2]. These data show that the main parameter affecting the intensity of a bare soil radiation, practically independent of spectral band, is the soil moisture. Based on this sensitivity it is feasible to estimate the value of soil moisture without *a priori* data on the soil parameters.

Surface	T_b (K)	κ
Metal	0	0
Water surface	90 – 110	0.3 – 0.4
Very wet soil	160 – 180	0.55 – 0.65
Very dry soil	250 – 270	0.85 – 0.93

Table 1. Microwave Radiation Characteristics of Some Typical Surface Types

Wavelength (cm)	Spectral Band	$\Delta T_b / \Delta W$ (K/g/cm^3)	$\Delta T_b / \Delta D$ (K/g/cm^3)	$\Delta T_b / \Delta S$ (K/ppt)	$\Delta T_b / \Delta T$ (K/^{o}C)
2 – 3	X	- 200	- 15	0.05	0.5
18 – 30	L	-(200 to 300)	- 10	- 0.5	0.1

Table 2. Sensitivity of a Bare Soil Microwave Radiation to Variations in Soil Moisture (W), Dry Soil Density (D), Salinity of Water in a Soil (S), and Surface Temperature (T)

It has also been seen that even for rather high values of biomass, up to 2 to 3 kg/m^2, the plant canopy is still transparent in the decimeter wavelength range.

The centimeter and decimeter wavelength microwave radiometers are not influenced by the conditions of illumination, by the presence of fog, smoke, clouds, however 0.3 to 0.8 cm wavelength radiometers are useful in meteorological investigations as far as they can provide the researchers with the information about water content in clouds and about the areas with rainfall.

II. MICROWAVE RADIOMETERS

The Geoinformatic/IRE RAS microwave radiometers are portable light weight devices operating at the wavelengths of 6 cm, 18 cm and 21 cm (Figure 1).

Figure 1. External view of the Geoinformatic/IRE RAS microwave radiometers, operating at the wavelengths of 6 cm, 18 cm and 21 cm.

As shown in Figure 1. The red panels: antennas (the biggest one belongs to 21-cm radiometer, the black and grey boxes are receivers. The white box is a common power supply unit and connecting cables.

III. RESULTS and DISCUSSION

The first phase of "radiation vs soil moisture" experiments took place in the area of the Alabama A&M University Winfred Thomas Agricultural Research Station on December 7, 2003. Three characteristic types of bare soil with different moisture content values in the presence of short and not dense grass have been selected. Antennas were located at the on-ground platforms. In each area, the radiometric measurements were conducted four times (by changing the height and the angle of the antenna position). In situ soil samples were taken three times in each area.

The examples of data collected by a 21 cm radiometer over the dry area are presented in Figure 2.

A series of data presented in Figure 2 contains original radiometer data in output voltage collected over a dry soil area (soil moisture is about 2 to 4 %). One can see the changes in output data when measuring the sky radiation (minimum signal), and radiation from very dry and vegetation covered soil.

Similar data were collected by these three radiometers over a very wet soil with paddles of water on the land surface (averaged soil moisture is about 18-20%). A screening effect of vegetation was seen at the 6 cm wavelength data.

A lower level of radiation is seen for more wet soil, in accordance to theoretical predictions [1-14].

Based on these measurements, the aggregated "brightness temperature at 21 cm wavelength vs volumetric soil moisture data" dependence was obtained (Figure 3). It indicates a good agreement with theoretical predictions for uniformly moistened soil. In particular, the experimental data of radiation sensitivity to changes in volumetric data of soil moisture, namely, - 207.83 K/cm3, lay in a range of theoretical estimates, namely, - (200-300) K/cm3, presented in [1-3] and shown in Table 2 above.

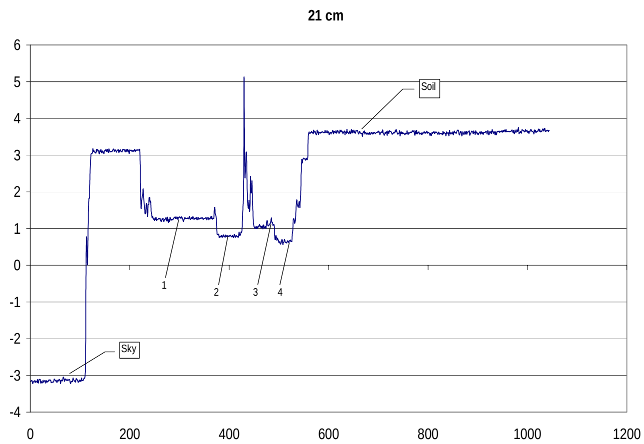

Figure 2. Signals (in volts) at the output of 21 cm radiometer when observing sky, dry land and selected dry soil areas.

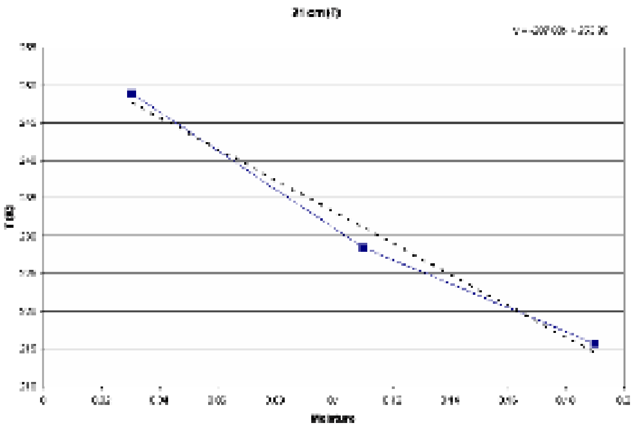

Figure 3. Brightness temperature at 21 cm wavelength vs soil moisture data in volumetric %

- dashed line – best fit for experimental data discussed above,
- solid line – one of the theoretical predictions)

The second phase of "radiation vs soil moisture" experiments took place in the area of the Alabama A&M University Winfred Thomas Agricultural Research Station on June 7, 2004. Within a second phase of experiments, the radiation data were collected from a truck which served us as a prototype of a specialized mobile platform.

The main goals of these experiments were as follows:

- to run the truck with microwave radiometers along the preliminary selected territory with low and high values of soil moisture content,
- to collect the GPS data along the truck trace (Figure 4)
- to collect the microwave radiometer data along the truck trace (Figure 5)
- work out a joint use of radiometers with a GPS receiver to overlay the radiometer data to the map/chart of the examined area and to conduct the data interpolation with different size of integration area (Figure 6).

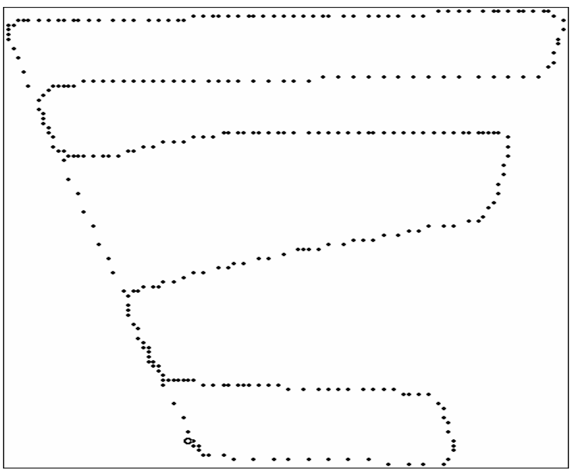

Figure 4. GPS-positioned truck trace for 21 cm wavelength data.

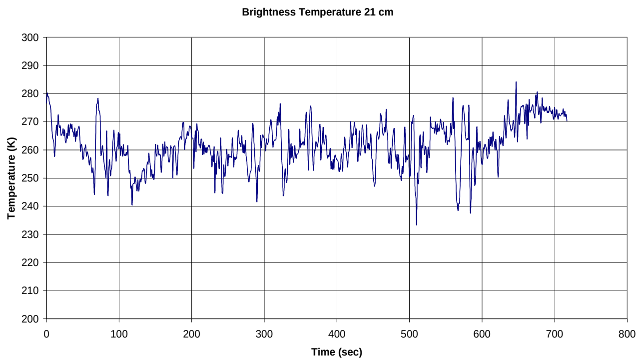

Figure 5. Brightness temperature data at the wavelength of 21 cm along the truck trace.

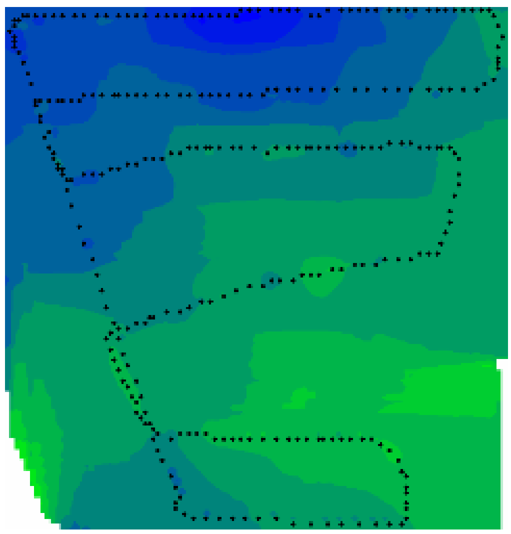

Figure 6. Map of brightness temperature data at 21 cm wavelength with fine element of interpolation.

The third phase of activities included accomplishments of similar to second phase issues but by using specialized mobile platform (rover type), equipped with three radiometers, DAS and GPS receiver. (Figure 7)

IV. SUMMARY

The effective mobile complex with 6 cm, 18 cm and 21 cm radiometers has been jointly developed. The spectra of microwave emission from bare and vegetation covered soils have been observed for dry and wet terrain. Also the mobile platform developed can be widely used for research and educational activities. The next phase of joint team's activity is in development of aircraft unmanned helicopter platform carrying 6 cm and 21 cm radiometer.

Figure 7. Specialized “Rover” based mobile platform with 3 radiometers, DAS and GPS system on board.

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