Microwave Radiometry of Rice Fields

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Abstract: Microwave radiometric method is discussed as applied to monitoring of rice growth. The following questions are considered in the paper.

- Modeling of microwave emission from rice fields.
- Experimental studies of microwave emission from rice fields.
- Rice biomass retrieval from microwave radiometric measurements.
- Examples of monitoring of rice growth with airborne and ground based radiometers.

Keywords: Microwave Radiometry, Rice Fields

1. Introduction

Rice is the most important food agricultural crop for the Asian region. Therefore, the Asian Association on Remote Sensing has decided to launch a special Rice Satellite for monitoring rice crop growth in the region. The satellite will be equipped with multi-configuration Synthetic Aperture Radar (SAR) to obtain high-resolution radar images of rice fields over the region. The thematic interpretation of these images will inevitably require the availability of test sites and conducting ground truth measurements at these sites. These measurements should include the determination of different rice biometric parameters, particularly, the biomass of rice crops and its temporal dynamics. Traditional methods of biomass estimation are connected with sampling and, therefore, with partial destruction of the crop. Moreover, to obtain an acceptable accuracy of biomass estimation for the given rice field, the number of samples should be big enough. Numerous measurements during the growth period at a test site are very labor-intensive, and could seriously damage the crop. Microwave radiometric method could be a successful instrument for conducting calibration measurements at the test sites. In this respect, the following questions are considered in the paper.

- Modeling of microwave emission from rice fields.
- Experimental studies of microwave emission from rice fields.
- Rice biomass retrieval from microwave radiometric measurements.
- Examples of monitoring of rice growth with airborne and ground based radiometers.

2. Microwave Radiometric Models for Rice Fields

Characteristics of microwave emission from a surface are the brightness temperature T_b or the emissivity κ. Microwave radiometry is based on retrieving algorithms, which solve the inverse problem of reconstructing the environmental parameters (such as soil moisture, vegetation biomass, etc.) from the measured radiation characteristics (brightness temperatures). Three types of the retrieving algorithms are usually used. The first one is based on the use of experimental regression relations between geophysical or biophysical parameters and radiation characteristics. A disadvantage of this approach is its limited applicability (in many cases, the regression relations are valid only for test sites or regions where they were obtained). The second type of algorithms (which has been successfully developed in the last few years) is based on the use of neural networks. For this approach to provide good results, it is necessary to train the corresponding neural network by a statistically representative sampling. However, such training is not always possible. The third type of algorithms, which is most widely used, is based on an inversion of radiation models. The models relating the radiation parameters to environmental ones are developed on the basis of certain theoretical assumptions concerning an object to be modeled, e.g., vegetation canopies, bare soils, water surface, etc.

The emissivity of a vegetation canopy is found by the use of numerical solutions to the transfer equation or the use of known solutions to this equation for particular cases of one-dimensional and isotropic phase function. The procedure for computing the emissivity of the vegetation is usually based on the complementary between emissivity and reflectivity, so that the former can be evaluated once this latter is known. Details of the computing procedures have been given, particularly, in [1]. Their brief outlines are the following. A) The vegetation canopy is modeled as a thick layer of elementary lossy scatterers of finite dimensions, i.e., disks and cylinders, over the rough soil surface. The layer is subdivided into elementary sub-layers, whose optical thickness is determined by the condition that the interactions among the scatterers within the same elementary layer are negligible. The scattering and transmission matrices of each sub-layer are then evaluated on the basis of the absorption and scattering properties of the individual vegetation elements. B). Absorption and scattering from an element of vegetation are expressed in terms of its absorption and bistatic scattering cross sections, which depend on the shape, dimensions, and permittivity of the element, as well as on the sensor parameters, i.e., frequency, observation angle, and polarization. The cross sections are computed with respect to local coordinate systems relative to the identified elements of vegetation; so that subsequent transformations in terms of the Eulerian angles and averaging over these angles are required to take the distributions of orientation of the scatterers into account C). The terrain is analogously characterized by its scattering matrix, whose elements depend on the dielectric constant and on the roughness of the surface. For a given surface, the scattering model is selected according to the frequency and observation angle. D). The scattering and transmission matrices of adjacent layers are obtained in terms of the respective matrices by "doubling" (matrix doubling method is described in detail by Eom and Fung [2]) and the process is reiterated to combine successively all the sub-layers into which the canopy was subdivided, until the scattering and transmission matrices of the whole layer are computed. Analogously, the soil is included through another "doubling" operation and, finally, the bistatic scattering coefficient of the terrain covered by vegetation is obtained. E). The emissivity of the vegetation canopy is computed by the energy conversation.

In the recent years, described model simulations were successively compared with experimental emissivities measured over fields of different crops. The advantage of this approach is that the model is able to include multiple scattering effects and shows the flexibility, since the dimensions, the orientation and the position of the scatterers may be properly selected in order to represent realistically a given crop geometry. In principle, the model is valid in the whole microwave spectrum, provided the suitable approximations are adopted to compute the cross sections of the single elements. However, the use of simple geometrical shapes, such as disks and cylinders, is acceptable at low frequencies but gradually loses validity when the frequency increases, since the microstructure of the elements becomes more and more important.

The use of numerical simulations is not always convenient for practical applications. Due to this reason, experimentalists often use some simplified analytical models for the emissivity of vegetation canopies, which are based on known analytical solutions to the transfer equation and which approximate to the numerical solutions with an acceptable accuracy. These models are usually obtained on the basis of some assumptions that impose limitations on the considered scattering medium.

The emissivity of a vegetation canopy is usually found with the use of three component model [3]. The brightness temperature of vegetated soil at a given polarization is found in this model as

$$T_b = T_v(1 - r - t) + \kappa_s T_s t + T_v(1 - r - t)(1 - \kappa_s)t \qquad (1)$$

where T_v is the temperature of the vegetation, T_s is the temperature of the soil, r is the reflectivity, t is the transmissivity, κ_s is the emissivity of the soil. For practical applications, the reflectivity and transmissivity of the vegetation layer are represented in simple analytical forms. In the single scattering approach, (1) reduces to the form:

$$T_b = (1-\omega)(1-e^{-\tau})T_v + \kappa_s T_s e^{-\tau} + (1-\omega)(1-e^{-\tau})T_v(1-\kappa_s)e^{-\tau} \qquad (2)$$

which is known and referred as the τ - ω model [4]. This form of the model today is generally accepted for the description of microwave emission from the Earth's surface in the presence of vegetation canopies. Numerous papers analyzed the applicability of this model and have found the model to be appropriate for the description of microwave emission from vegetation canopies.

In experimental studies, the most researchers use to find the parameters of the τ - ω model from regression analysis of experimental data. The optical depth is found in these studies as $\tau = bW / \cos\vartheta$, where W is the vegetation water content, ϑ is the observation angle, and the coefficient b and the single scattering albedo ω are estimated by fitting the model to the measured values of brightness temperatures. One can see that in this approach the retrieved single scattering albedo represents the reflectivity of the optically thick vegetation layer r_0 rather than the albedo of the unit volume of vegetation. With this semi-empirical approach, the brightness temperature of a vegetation canopy is expressed in a simple form:

$$T_b = T\{\kappa_s e^{-2\tau} + (1-r_0)(1-e^{-2\tau})\} \qquad (3)$$

Kirdiashev *et al*. [3] have introduced the concept of the vegetation transfer coefficient (the slope reduction factor) as

$$\beta = t^2 = e^{-2\tau} = \frac{\Delta T_b}{\Delta T_{bs}} \qquad (4)$$

where $T_{bs} = \kappa_s T$ is the brightness temperature of soil. This coefficient shows the decrease of the brightness temperature contrast ΔT_b, because of the presence of a vegetation canopy above a soil, comparing with that for the bare soil ΔT_{bs}. In other words, β-factor is the ratio of the slope of the emissivity-soil moisture function with a vegetation cover to the bare soil slope. A value of 1 indicates no effect while a small value means that most of radiometric sensitivity to soil moisture has been lost. In terms of the β-factor, the brightness temperature of vegetated soil is written as

$$T_b = T_{bs}\beta + (1 - r_0)(1 - \beta)T \qquad (5)$$

The models (2), (5) have rather high accuracy that was confirmed by numerous theoretical and experimental studies. The models are very convenient for the sensitivity analysis and for the development of inversion algorithms. Parameters of the models (the brightness temperature of soil, the optical depth, the reflectivity of optically thick vegetation layer, the physical temperature of vegetation and soil) are linked to geophysical parameters (soil moisture, soil roughness, vegetation water content, etc.). That makes it possible to retrieve the geophysical parameters from microwave radiometric measurements.

3. Experimental Studies of Microwave Emission from Rice Fields

The influence of soil on microwave emission can be completely cancelled for such a specific crop like rice. For this crop underlying surface is water with well known microwave radiation properties. Vorobeichik *et al.* [5] performed measurements of rice crops emissivity with onboard and car-mounted radiometers during 1980-83 in Krasnodar Region. The radiometers operated at the wavelengths 2.25 and 18 cm. Spatial resolution at the earth surface was 20-100 m and 0.5-1 for airplane and car measurements, respectively. Radiometers were calibrated with internal calibrators and by the radiation level of open water surface. A black body and metal plate were used as external calibrators in measurements from the car. Measured emissivities were compared with averaged over antenna footprint values of rice above water wet biomass. In airplane measurements, 10-20 samples of biomass were taken over a rice field. In car measurements, the plants were removed directly from the area of antenna footprint. Biometric measurements were conducted by specialist of the Krasnodar Institute of Rice. Wet rice biomass, gravimetric moisture, relative weight of different plant components, and conductivity of vegetation sap were determined for different rice sorts during growth period. A dependence of the emissivity on the rice wet biomass is presented in Fig.1. This dependence was a stable one for three complete vegetation cycles for investigated rise sorts. It implies that the dependence can be used for operational control of rice biomass.

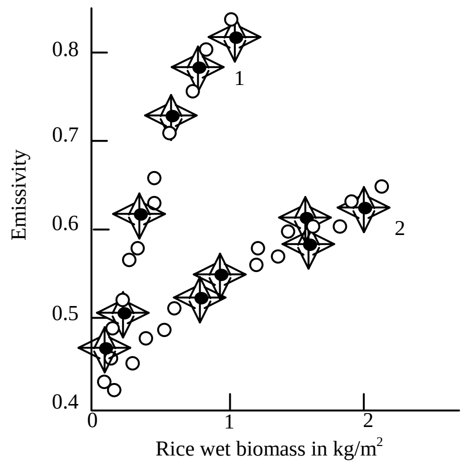

Fig.1. Emissivity of rice crop versus its above water wet biomass at 2.25 (1) and 18 (2) cm. Points are car measurements. Crosses are airplane measurements and show a statistical spread of remote and ground truth data.

4. Rice Biomass Retrieval from Microwave Radiometric Measurements

The feasibility of vegetation biomass determination from microwave radiometric measurements was displayed first in the work by Kirdiashev *et al.* [3] Equation (5) was solved to find the coefficient β (and vegetation water content) from radiometric measurements at a single frequency for the same canopy with different T_{bs} (different soil moisture conditions). This approach was further used by many researchers for estimating vegetation optical depths. For two-frequency measurements, the model analysis of microwave radiometric algorithms as applied to vegetation biomass retrieval was performed by Chukhlantsev and Shutko [6]. These algorithms are based on the model (5) for microwave emission from the Earth's surface in the presence of vegetation cover. From measurements of brightness temperature of soil-vegetation system at two different configurations (two wavelengths), one can get using equation (5):

$$\frac{\beta_1}{\beta_2} = \frac{T' - T_{b1}}{T' - T_{b2}} \left(1 + \frac{\Delta T_{bs}}{T' - T_{bs1}} \right) \tag{6}$$

where $\Delta T_{bs} = T_{bs1} - T_{bs2}$, $T' = (1 - r_0)T$, and indices 1 and 2 relates to the first and second measuring configuration, respectively. If conditions of measurements are chosen by such a way that

$$\Delta T_{bs} \approx 0\,, \tag{7}$$

an estimate of transfer coefficient ratio can be obtained from (6):

$$\frac{\beta_1}{\beta_2} \cong \frac{T' - T_{b1}}{T' - T_{b2}} \tag{8}$$

On the other hand, the ratio of transfer coefficients is

$$\frac{\beta_1}{\beta_2} \cong \exp[-2(b_1 - b_2)W] = \exp[-2(b_1 - b_2)mQ] \tag{9}$$

where m is the vegetation gravimetric moisture in wet weight basis and Q is the wet vegetation biomass. An estimate of vegetation biomass (the weight of vegetation per unit area) can be obtained, thus, from radiometric measurements at two configurations:

$$Q = -\frac{1}{2m(b_1 - b_2)} \ln \frac{T' - T_{b1}}{T' - T_{b2}} \tag{10}$$

The temperature of vegetation can be equaled to the air temperature or can be measured by an infrared sensor. The values of reflectivity r_0 for different types of vegetation canopies are known [7].

5. Examples of Monitoring of Rice Growth with Airborne and Ground Based Radiometers

The most favorable situation is the radiometric observation of vegetation canopies when underlying surface is water (rice, rush). In this case, the error of vegetation biomass retrieval is minimum one. Besides, emission properties of water surface are studied well that allows obtaining estimates of biomass from microwave radiometric measurements at a single frequency [5]. The biomass estimate is determined from measured brightness temperature by

$$Q = -\frac{1}{2mb_1} \ln \frac{T' - T_{b1}}{T' - T_{bw}} \tag{11}$$

where T_{bw} is the brightness temperature of open water surface. Biomass estimates can be also obtained using algorithmic dependences of emissivity on the under-water biomass (see Fig.1). Exploration of the technique proposed was conducted for rice crops during 1980-83 in Krasnodar Region [5, 6]. A radiometer operating at a wavelength of 18 cm was installed onboard a light bi-plane Antonov-2. The flight height was 50-100 m providing the 35-70 m spatial resolution at the surface. To specify the dependence of coefficient b on the rice biomass and to validate the results obtained, several test sites were chosen where biomass sampling was performed. Biometric measurements were conducted by specialist of the Krasnodar Institute of Rice. Samples were taken by cut under-water vegetation from small square areas with a size of 0.5×0.5 m^2. To increase the accuracy of ground measurements, 12-21 samples were taken within a test site. The accuracy of biomass retrieval from radiometric data was estimate by comparing retrieved data with ground measurements at check sites with different rice species and crop heights varying within 60-90 cm. Results of the comparison are presented in Fig.2.

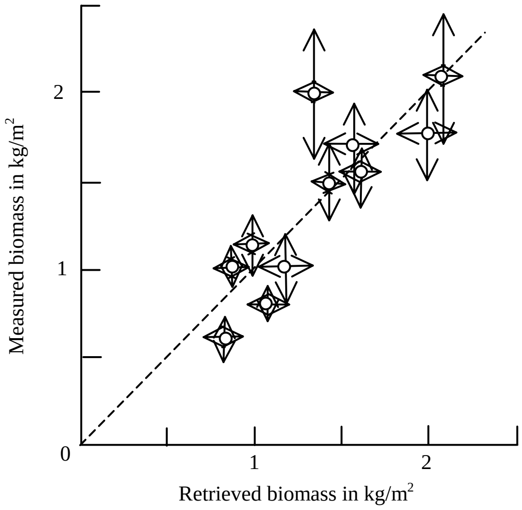

Fig.2. Measured and retrieved biomass of rice crops.

Horizontal segments are due to spatial variations of radiometric signal over the check site. Vertical segments represent root mean square of biomass variations within the site. It is seen that the accuracy of biomass retrieval is 10-20% that is compared with the accuracy of traditional ground measurements.

The described method of rice biomass retrieval was further developed by Yazerian [8] for rice crop monitoring and rice yield prediction. The method can also be used for validation and calibration of satellite sensors with high spatial resolution (optical sensors, synthetic aperture radars) that are specialized for satellite monitoring of rice growth and global rice yield forecast. Radiometric observations can also be useful for monitoring of lakes and rivers overgrowing with rushes and canes.

5. Conclusions

The results presented show potentials of using airborne microwave radiometers for calibration and validation of Rice Satellite data. Further work is needed to clarify the following questions.

a) characteristics of microwave radiometers required;

b) organization of calibration measurements at test sites;

c) relationship between SAR and microwave radiometric data.

References

[1]. Ferrazzoli P., Luzi G., Paloscia S., Pampaloni P., Shiavon G., and Solimini D. (1989). Comparison between the microwave emissivity and backscattering coefficient of crops. *IEEE Trans. Geosci. Remote Sensing*, **27**:772-777.

[2]. Eom H.J. and Fung A.K. (1986). Scattering from a random layer embedded with dielectric needles. *Remote Sens. Environ*., **19**:139-149.

[3]. Kirdiashev K.P., Chukhlantsev A.A., and Shutko A.M. (1979). Microwave radiation of the Earth's surface in the presence of vegetation cover. *Radio Eng. Electron. Phys*., **2**:37-56.

[4]. Kerr Y.H. and Njoku E.G. (1990). A semi-empirical model for interpreting microwave emission from semiarid land surfaces as seen from space. *IEEE Trans. Geosci. Remote Sensing*, **28**:384-393.

[5]. Vorobeichik E.A., Petibskaia V.S., Chukhlantsev A.A., and Yazerian G.G. (1988). Microwave radiation of the rice fields. *Radiotekhnika i Elektronika*, **33**:2420-2421 (in Russian).

[6]. Chukhlantsev A.A. and Shutko A.M. (1987). Application of microwave radiometry for determining biometric parameters of vegetation canopies. *Issledovanie Zemli iz Kosmosa (Research of the Earth from Space)*, **No. 5**:42-48 (in Russian).

[7]. Van de Griend A.A. and Wigneron J.P. (2004). On the measurement of microwave vegetation properties. *IEEE Trans. Geosci. Remote Sensing,* **42**:2277-2289.

[8]. Yazerian G.G. (2000). *Monitoring of hydro-economic systems by means of microwave radiometry (by the example of Kuban rice fields). PhD thesis*, Institute of Radioengineering and Electronics RAS, 110 pp. (in Russian).