Estimation of the correlation of radiation and the radar backscattering coefficient of soil cover in X-band based on experimental research

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Abstract. The article considers the problem of integrated processing of remote sensing data of radar and radiometric data. The angular dependences of the radio brightness temperature and the back reflection coefficient in the X-band of a homogeneous soil cover are obtained. The correlation between these values is determined.

1. Introduction

Experimental studies of the relationship between the radiating and reflecting characteristics of natural environments is very significant both in interpreting remote sensing data and in identifying the physical mechanisms of this relationship. The need to determine the correlation between the brightness temperature ($T_b$) of thermal radiation and the backscattering coefficient arises when it is necessary to solve various problems of remote sensing using complex methods of active and passive radar. These are the tasks of improving the quality of radar and radiometric images, estimation the electro physical and geometric parameters of the underlying environment, etc. [1]. Currently, much attention is paid to programs aimed at the global study of the surface of the land and ocean using active and passive location methods. This is the program of the European Space Agency “Soil Moisture and Ocean Salinity” (ESA SMOS Mission), the American National Aerospace Administration (NASA SMAP Mission), which are aimed at restoring soil moisture values by comparing spatially combined radar and radiometric data in the L-band [2]. In support of these programs, large-scale airborne and ground-field studies of the reflective and radiating properties of various types of soil coverings, differing in soil composition, temperature and humidity conditions depending on the region of study and its climatic features, are carried out [3]. At present, there are practically no works on synchronous radar and radiometric measurements in the X range for obtaining data on their correlation in control plots. Thus, the determination of the correlation between the reflected signals and the self-radiation signals of various types of the earth's surface will contribute to solving remote sensing problems using complex methods of active and passive radar. In this paper the results of experimental investigation of the radiating and reflecting properties of a soil cover in X-band are presented. The degree of correlation was estimated by comparing the angular dependences of the measured data approximated by polynomials of various degrees. Thus, a new method is proposed for assessing the degree of statistical connection between the radio brightness temperature and the backscattering coefficient.
2. Test site, instruments and methods of measurement

The object of research is a potato field in the Ivolginsky hollow, located in the suburban area of Ulan-Ude. The soils of this basin have scientific interest as a model training ground for mountain-basin soil formation, the specificity of which is characteristic of sharply continental regions of Inner Asia [4]. The studied soil type consists of 33% of sand and 66% of clay. With known values of temperature and humidity, it is possible to determine the dielectric constant using the refraction model, which in general has the following form

\[ \sqrt{\varepsilon_c} = \sum \sqrt{\varepsilon_j W_j}, \]

where \( \varepsilon_c \) is the dielectric constant of the mixture; \( W_j, \varepsilon_j \) - volumetric contents and complex dielectric constant of the components that make up the mixture.

Studies of the reflective properties of the soil cover were carried out using a bistatic radar, with separate receiver and transmitter units, on each of which has a parabolic antenna with a diameter of 640 mm. The radar has the following technical characteristics: transmitter - carrier frequency 9.95 GHz, pulse duration 9 ns, radiated peak power 30 watts. The center frequency of the receiver gain band is 9.95 GHz, the dynamic range is with a gain control of 70 dB. The antenna gain is \( \sim 33 \) dB, the antenna beamwidth is five degrees. Structurally, each antenna is mounted on its support, which allows to measure on various linear and cross polarizations. The radiometer R-3 was used for radiometric measurements, which have the following main technical characteristics: average frequency 11.2 GHz, frequency band 1 GHz, fluctuation sensitivity threshold 0.1 K. The device is equipped with a horn antenna with a 10×12 cm aperture with a beam width of twenty degrees. The first series of experiments was carried out at the beginning of the summer season. The surface of the test section has a periodic structure in the form of parallel ridges about 20 cm high (Figure 1a). The second series of experiments was carried out in October. In this case, the surface was more uniform, with an average height of irregularities of 5–6 cm.

![Figure 1](image-url)

**Figure 1.** Object of study and measuring instruments installed on the car match: 
- a) soil cover, b) radiometer, c) radar

The surface survey was performed using the drone MavicPro to determine the topographic relief. According to the survey results, the average roughness parameters were estimated with standard deviation of small-scale irregularities 3.36 cm. During the experiments, the soil temperature in the surface layer was measured up to depth 3 cm at the same time. In summer measurements, the soil temperature was 26°C, and in autumn measurements, the soil temperature was 8°C, correspondingly. In both cases, the weight moisture of soil was determined by thermostat-weight method. The soil samples in the surface layer were select, taking into account that the thickness of the effectively emitting
layer in this range is not more than 3 cm. The average weight moisture of the soil for the summer season (June) was 9.6%, for autumn (October) - 5.63%, correspondingly.

During the experiments, a monostatic single-position location scheme was used, when the radar and radiometer were sequentially installed on a car match with a height of 22 meters. (Figures 1b, c). This made it possible to cover the range of incidence angles from 30° to the region of grazing angles. The direction of surface irradiation was carried out along the ridges, with a field length along the scanning line of 1350 meters. The angle of incidence during radar measurements was set every 2.5° along one azimuth angle directed to the object of study. Radiometric measurements were carried out after the radar measurements with of the R-3 radiometer on the same automobile tower. In the general case, the solution to the problem of obtaining reliable experimental data during radiometric measurements consists in eliminating the influence of background noise radiation received by the system through the side lobes of the antenna pattern. In this case, the relative contribution of such radiation depends on the angle of incidence due to the redistribution of the regions of the upper and lower half-space relative to the region of the main and first side lobe of the bottom beam, especially in the region of the grazing angles. From here follows the task of minimizing angular noise during measurements at various angles. Relative calibration of the radiometer was carried out at two registration points — intrinsic radiation of the sky and radiation of the soil in nadir at a given thermodynamic temperature. Conversion of signal level values to brightness temperature was carried out according to calibration data. The angle of inclination of the terrain along the test site does not exceed three degrees, which does not require appropriate geometric adjustment of the measurement results.

3. Angular dependences of the backscattering coefficient and radio brightness temperature of the soil cover
The results of measurements of the backscattering coefficient $\sigma^0$ and brightness temperature $T_b$ are presents in the form of angular dependences $\sigma^0$ on linear and cross polarizations. In the case of air temperature close to the temperature of the soil and its lower moisture content during summer measurements, the general course of the curves of the angular dependences $\sigma^0$ and $T_b$ on linear polarizations practically is coincides (Figure 2). On the left along the ordinate axis, the values of radio brightness temperature in K are plotted, on the right, the values of the back reflection coefficient in dB, accordingly [5].

![Figure 2](image-url)  
*Figure 2. Angular dependence of the backscattering coefficient and brightness temperature on the soil cover at different polarizations*

It is may be to note the qualitative difference in the patterns of reflected signals at different polarizations. The spread range of the backscattering coefficient on the horizontal and cross polarizations has a quasiperiodic character due to the regular structure of the underlying surface. On the
vertical polarization a smoothed curve is observed, which indicates a smaller dependence of the reflection on this polarization from the surface geometry. As follows from the data obtained, the level of the reflected signal on the vertical polarization, in the studied range of angles, exceeds on average by 3–4 dB the signal level on the horizontal polarization. To assess the degree of statistical relationship, a polynomial approximation of the curves of the angular dependences of the experimental data $\sigma^0$ and $T_b$ was carried out. A rather high approximation coefficient between these curves was obtained. The correlation dependence of the radar and radiometric data between the approximation curves $\sigma^0$ and $T_b$ was estimated. A comparison of the approximation curves of the angular dependences of the indicated values shows their coincidence, at least in the range of angles from 45° to 88°. The correlation coefficient is 0.98 for vertical polarization and 0.83 for horizontal. In contrast to summer measurements, the angular dependences $\sigma^0$ and $T_b$ during autumn measurements on horizontal polarization show a weak correlation at incidence angles of less than 70°. On vertical polarization, the coincidence of the curve is observed at angles of more than 55°, and at smaller angles the opposite picture is observed.

4. Conclusions

The main aim of this work was to conduct experimental testing of a method for measuring radio brightness temperature and backscattering coefficient using mobile lifts. This method has great potential and allows you to explore various types of land covers, including forest media. A uniform technique for measuring scattered signals and radiothermal radiation on the earth's surface is one of the direct methods for solving the problems of combining radar and radiometric data. The degree of statistical relationship of these parameters was estimated on a comparison of the obtained angular dependences approximated by polynomials of different degrees. This approach provides a more reliable results. The calculation results show that the greatest degree of correlation is observed at small differences of air and soil cover temperatures. The correlation decreases with an increase in the temperature difference of the studied media. Hence, the problems appears of determining the conditions, including soil moisture, surface roughness, etc., under which the degree of correlation will be sufficient to solve the problems of complexity using the proposed method. Thus, for a more reliable assessment of the degree of correlation, further studies are needed, including other soil types. In conclusion, we note that the experimental assessment of the degree of statistical relationship between the characteristics of the scattered signal and thermal radiation is one of the reliable approaches to solving the problem of combining active and passive radars.

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