The Use of Navigation Satellites Signals for Measurement the Absorbance of the Forest Canopy

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Abstract— The results of measurement of the electromagnetic wave attenuation by the forest canopy at L-band are presented. The soil moisture mapping with reasonable accuracy in a global scale is only possible using the data of satellite radiometers at L-band frequency (SMOS and SMAP remote sensing programs). In the process of soil moisture retrieval from remote sensing data it is necessary to know the state of ecosystems on the Earth's surface. Forests are one of the dominant terrestrial ecosystems of Earth covering a large area of the surface. The attenuation coefficient of the forest canopy has high value even at L-band frequency. In the absence of forest canopy attenuation data the error of retrieval of the soil moisture for woodlands areas will have very high values. For this reason the emissivity model of Earth surface needs a priory data of the emissive and attenuate properties of the forest cover. One of methods of measurement of forest canopy attenuation coefficient at L-band frequency is using the signals of Global Navigation Satellite System (GNSS). Measurement showed that for elevation angle of 50 and 35 degrees the attenuation has a value range of -6 -10 dB and -10 -15 dB respectively. This makes it possible to claim that under certain conditions the soil radiothermal emission can make a noticeable contribution to the overall emission of surface covered forest. The results obtained in the measurement can be used in SMOS and SMAP sub-pixel data processing.

1. INTRODUCTION

To carry out analysis of the heat and moisture flux in the global scale it is possible to use the data of microwave satellite radiometer. At this moment, two satellite with L-band radiometer on board are functioning in orbit. Their data are suitable for the retrieval of soil moisture with acceptable accuracy in global scale. The first of these is the Soil Moisture and Ocean Salinity Mission (SMOS) launched on November 2, 2009. The second is Soil Moisture Active and Passive (SMAP) launched on January 31, 2015. The microwave emission at L-Band mainly depends on soil moisture content and water content on the vegetation layer. The vegetation layer over the soil surface attenuates soil emission and adds its own contribution to the emitted radiation. For this reason the remote retrieval of soil moisture by microwave satellite data is a very difficult process. These effects at low frequencies can be approximated by a simple model (τ-ω model). Emission from the two-layer medium consists of three terms: 1) the vegetation emission; 2) the vegetation emission reflected by the soil surface; 3) soil emission attenuated by the vegetation canopy. In this case radio brightness temperature is calculated by equation:

$$T_B = (1-\omega)\cdot(1-\gamma)\cdot(1+\gamma R)T_V + (1-R)\gamma T_S; \tag{1}$$

where ω is the single scattering albedo of the canopy; T_S, T_V is temperatures of the soil surface and canopy respectively, R is the soil reflectivity, $\gamma = \exp(-\tau/\cos\theta)$ is the transmissivity of the vegetation layer, τ is the optical depth. The vegetation attenuation factor can be computed from the optical depth related to the total vegetation water content (VWC) [1]. The optical depth of the standing vegetation may be calculated by equation:

$$\tau = A\cdot VWC \tag{2}$$

where A is empirical parameter. The values of $A = 0.12 + / - 0.03$ are representative for most agricultural crops. However, estimation of VWC at global scale is very difficult. The SMOS Level 2 algorithm uses optical depth data parameterized as a function of the LAI [2]. The following equation is considered in LMEB (L-band Microwave Emission of the Biosphere):

$$\tau = B_1\cdot VWC + B_2 \tag{3}$$

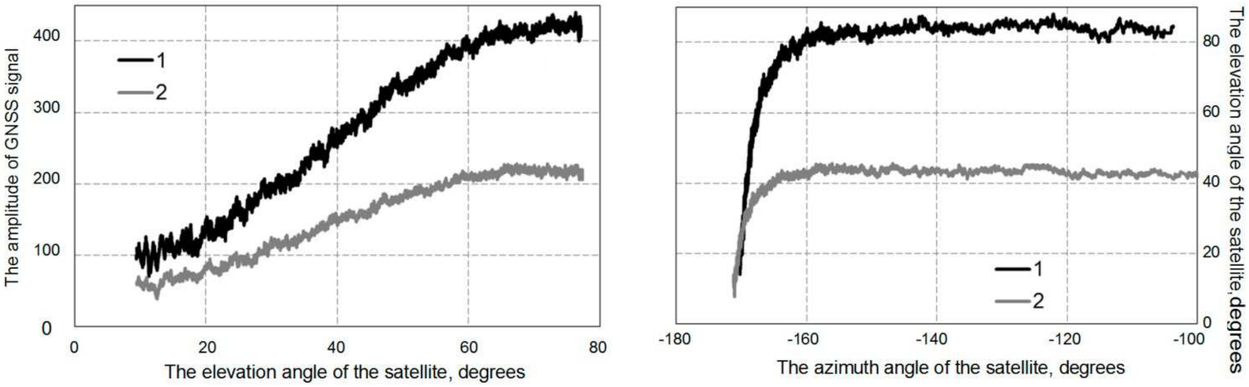
where parameters B_1 and B_2 are function of the canopy type. At L-band for majority of low vegetation types the values of ω are close to 0. The account of the attenuation and emission of the forest canopy in the SMOS Level 2 algorithm occurs in a similar way [3]. However, the authors of SMOS Level 2 algorithm assert that "A pure empirical approach, based on τ and ω parameters fitted over experimental data is not appropriate to forests, because presently available radiometric measurements are limited" [2]. Thus it can be argued that the problem of wave attenuation of forest canopy at the L-band frequency remains poorly studied. In recent decades, GNSS signals are widely used to measure the surface characteristics at L-band frequency [4, 5]. In this paper it is proposed to use of GNSS signals for measuring the attenuation coefficient of electromagnetic waves propagating through the forest canopy.

2. RESULT OF STUDY

The frequencies of the GNSS signals and the satellites' radiometers at L-band are very similar. For this reason the characteristics of forest canopy measured with GNSS signals may be used in the SMOS data processing. We carried out measurements with using GPS/GLONASS receiver MRK-32, industrial produced (Russia, Krasnoyarsk, "Radiosvyaz") which is equipped by antenna, receiving Right Hand Circular Polarization (RHCP) wave. The test site was situated at South part of Omsk region. The measurements were performed for the birch forest.

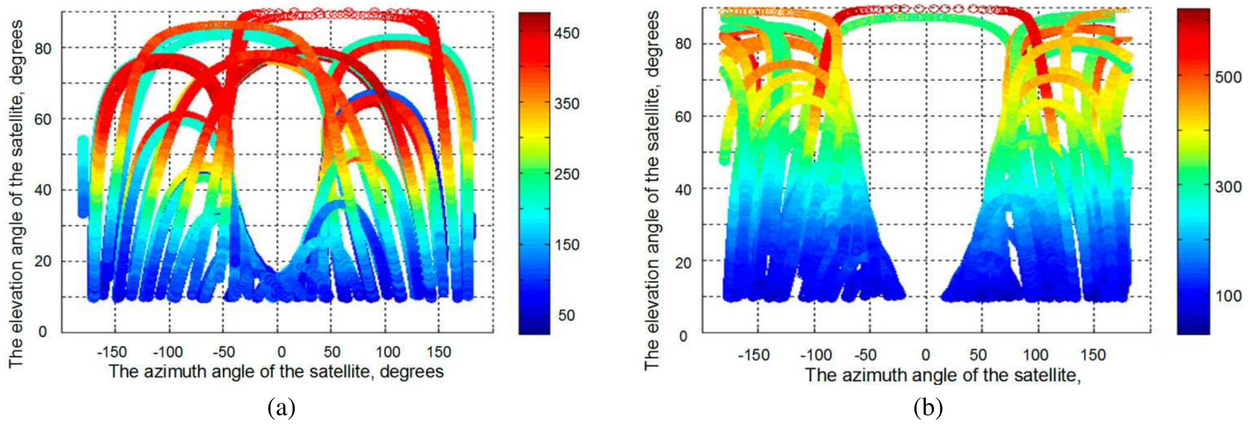
The amplitude of GNSS satellite signal even in an open area is not constant and depends on: the elevations and azimuth angle of the satellite, the states of the atmosphere and ionosphere et al. Also the amplitude of the GNSS signal depends on the serial number of the satellite (Fig. 1, Fig. 2). For this reason, comparing signals from satellites with different numbers and received at different times is impossible.

The level of GNSS signals was measured under forest canopy (A_{tree}) and in the open area (A_{free}). In temperate latitudes the azimuth of GNSS satellites, under which they can be seen on



(a) (b)

Figure 1. The dependence of GNSS amplitude signal on coordinates of satellites GLONASS10 (1) and GLONASS24 (2).



(a) (b)

Figure 2. The dependence of GNSS amplitude signal on coordinates of satellites GLONASS (a) and GPS (b). The level of signal is shown in color. Azimuth 0° is direction to "north", azimuth 90° is direction to "east", azimuth 180° is direction to "south", azimuth −90° is direction to "west".

the celestial sphere, rarely corresponds to the direction "north" (Fig. 2). Therefore, the satellite signal was received at two positions of the antenna: on the northern edge of the forest and in the open place (Fig. 3). The times of measurement in each of the positions were 40 minutes. This allowed to compare of the GNSS signals passed through the forest canopy and received directly from the satellites in close conditions of ambient.

An electromagnetic wave passed through the forest canopy, equally: absorbed, scattered, multiply reflected and interfered. For this reason, the GNSS signal level may be attenuated to the level comparable to the limit of receiver sensitivity (Fig. 4(a)). This occurs when the satellite signal is shading by tree trunk. In some cases, the value of A_{tree} greater than A_{free} due to the interference signals passing through the forest canopy directly from the satellites and multiply reflected from the trees (Fig. 4(b)). This creates difficulties in the interpretation of measurement data. Nevertheless we managed to evaluate the range of the attenuation coefficient in forest canopy for some angles of SMOS sensing (elevation angle GNSS). We evaluated that range of the attenuation coefficient values for elevation angles of 55 and 35 degrees is a -6 -10 dB and -10 -15 dB respectively.

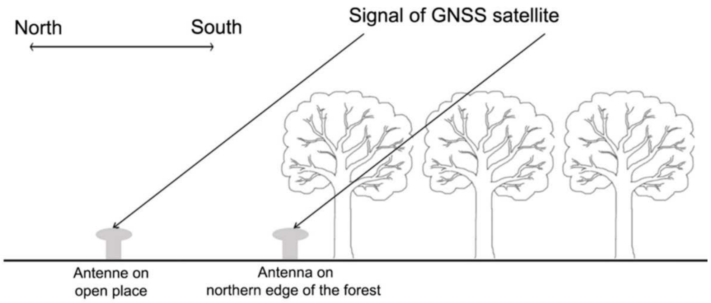
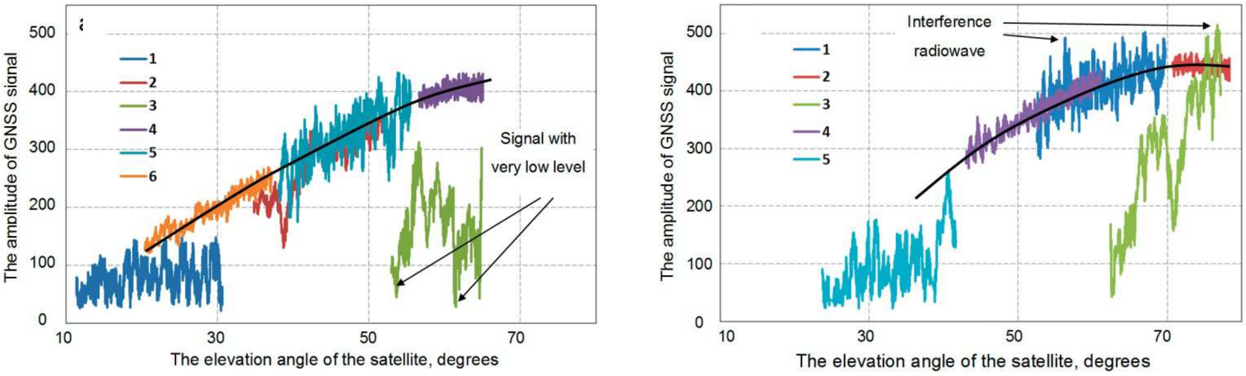


Figure 3. The change of the antenna position relatively to the edge of the forest at the time of measurement.

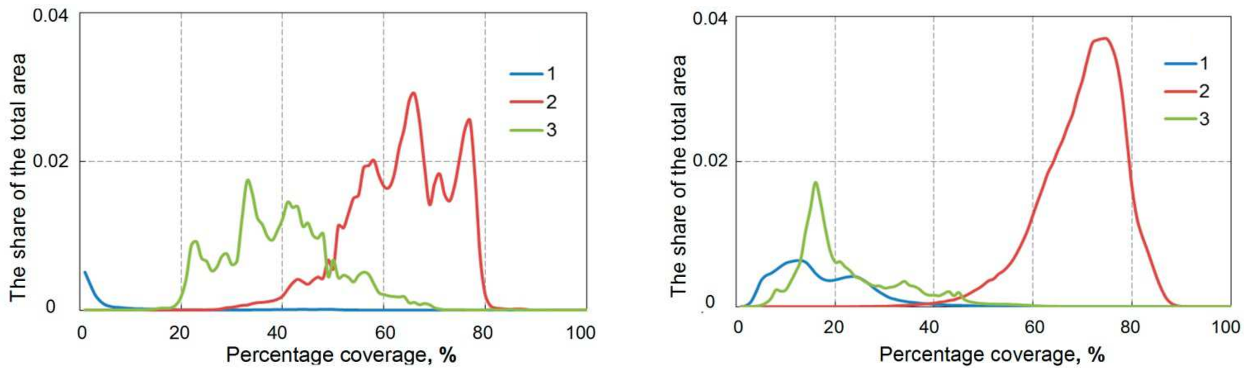


(a) (b)

Figure 4. The dependence of the amplitude of satellite signals GLONASS8 (a) and GLONASS23 (b) on the elevation angle of the satellite. 1, 3, 5 — signals passed through the forest canopy; 2, 4, 6 — signals measured in an open area. Black continuous line — approximation curve for the values of the amplitudes of the signal measured in an open area.

We analyzed the satellite data obtained for the South part of the Omsk region and North Kazakhstan. The area is situated between Longitude 70° to 77° East and Latitude 53° to 56° North. The northern part of this territory consists predominantly of wooded plains, which are gradually transiting into grassy plains in southern part. We used MOD44B data for determining the surface percentage coverage of forest within a pixel SMOS level 1C. In this product surface is classified by three categories: forest, non-tree vegetation and non-vegetation. The distribution of pixels MOD44B depending on the percentage of each of the three types of surface is shown in Fig. 5. The percentage of each type of surface on area is shown in Table 1. Table 2 shows the percentage of each of the surface types for some SMOS pixels. The data stated in the figure and in the tables are very close to each other.

We retrieved the data of soil reflectivity in an open area (R_{HC} in Table 4). For this we used the measured data of attenuation coefficient, surface percentage coverage of forest within a pixel



(a) (b)

Figure 5. The distribution of pixels MOD44B depending on the percentage of each of the three types of surface: forest (1), non-tree vegetation (2) and non-vegetation (3). The area is situated between Longitude 70° to 77° East and Latitude 53° to 54° North (a), between Longitude 70° to 77° East and Latitude 55° to 56° North (b).

Table 1. The percentage of each type of surface in total area.

No. of area	Latitude, range	Longitude, range	Percent of cover, %			
			Forest	Non-tree vegetation	Non-vegetation (open surface)	Water surface
1	53 ÷ 54	70 ÷ 77	1.8	59.5	35.1	3.7
2	54 ÷ 55	70 ÷ 77	4.2	63.4	30.2	2.3
3	55 ÷ 56	70 ÷ 77	12.4	67.7	18.4	1.6

Table 2. Percentage of each type of surface in the some pixels SMOS.

No. of area	ID of SMOS pixel	Latitude	Longitude	Percent of cover, %			
				Forest	Non-tree vegetation	Non-vegetation (open surface)	Water surface
1	4006893	53.43	75.77	1.9	62.6	34.4	1.1
2	4006397	54.55	72.75	4.0	55.9	33.1	6.9
3	4012032	55.48	74.57	10.8	68.0	21.0	0.2

Table 3. Comparison of R_H retrieved at different values of attenuation coefficient of forest canopy, sensing angle of 42° from the nadir, August 2016.

No. calculation	Latitude	Longitude	T_{bH}, K	Percent of cover, %				R_H	R_{HC}
				Forest	Non-tree vegetation	Non-vegetation (open surface)	attenuation, dB		
1	55,48	74,57	301	10,8	68,0	21,0	3	0,08	0,14
2							6	0,08	0,17
3							12	0,08	0,19

SMOS level 1C and reflectivity of all territory in SMOS pixel (R_H in Table 4). It is found that even in this case the R_H is slightly varying at different values of attenuation coefficient.

3. SUMMARY

We measured the electromagnetic wave attenuation coefficient for the forest canopy at L-band frequency. These values were used in the sub-pixel processing of SMOS data We processed data for pixels with percent of forest cover close to the maximum for the studied area. It is found that even in this case the R_{HC} is slightly varying at different values of attenuation coefficient.

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