

Assessment volume of a forest biomass by the attenuation of the navigation signals the frequencies L1

Anatoly Sorokin^{1,2}, Anatoly Ostylovsky², Aleksandr Borisov³, Viktor Ivanov³, Daniil Makarov¹, Dmitry Kharlamov¹

¹Federal Research Center KSC SB RAS, Akademgorodok, 50, Krasnoyarsk, 660036, Russian Federation

²Siberian Federal University, 79, Svobodny, Krasnoyarsk, 660041, Russian Federation

³Institute of Forest, KSC SB RAS, Akademgorodok, 50, Krasnoyarsk, 660036, Russian Federation

Abstract. The method for assessment the volume of a forest stand based on measurements of the attenuation of navigation satellites signals in the L1 range and morphological features of forest species is presented. The dielectric model of a mixed dielectric with the natural structural features of the species of the forest stand was used. The option of restoring the biomass volume of the forest stand according to the radioscapy data on the mixed forest test site is considered. The practical applications of the method of continuous local monitoring of the forest stand condition in forest science are discussed.

1 Introduction

The physics of the interaction of radio waves with the forest is an actual area of research in fundamental and applied sciences. Forests are randomly heterogeneous environments with tree elements of various shapes, sizes and spatial orientations [1]. The electrophysical properties of the stand as a multicomponent medium are determined by the molecular structure of wood, including water, and the macroscopic distribution of tree elements in the volume of the stand.

It is possible to continuously monitor the state of the stand by radioscapy using signals from navigation satellites [2]. The electrophysical characteristics of the stand are determined by the amount of stand biomass by fractions, the moisture content of wood, needles, leaves and the spatial distribution of trees.

The sounding of forests with signals from various satellites of the GPS and GLONASS navigation systems with a frequency of 1 Hz provides scanning of the forest stand on an area of up to 1 ha. Coordinate binding of scanning flows of pulse signals allows determining the localization of changes in biomass and its moisture [3].

2 Method for determining the bulk density of stand biomass

The signals of each navigation satellite cover half the surface of the globe. The location of the antenna in the tree stand on the soil surface with a vertically oriented axis of the radiation pattern makes it possible to record the probing flux of an individual satellite in the analytical volume V in the form of a cone with an angle of 160° and a vertex on the antenna. In this volume, we distinguish conical channels with a solid angle corresponding to the first Fresnel zone. In this volume, the antenna registers signals scattered by the forest stand with a path difference of not more than $\lambda/4 \approx 5$ cm. The contributions of signals with a greater difference in stroke will be noticeably smaller and this volume mainly determines the value of the recorded signal after passing through the stand. The azimuth and elevation angle of the satellite, in conjunction with the coordinates of the antenna's location, allow us to calculate the coefficients of specific attenuation in the stand with coordinate reference [3].

Tree stand as a statistically heterogeneous mixed dielectric medium with local conductivity for radio waves of the L1 range is a scattering and absorbing medium. The total signal power loss during propagation in the forest is determined by absorption and multiple scattering on wood, needles, leaves [1].

In the volume V_F of the conical channel with the solid angle of the first Fresnel zone in the layers of small thickness δ , perpendicular to the wave vector of the signal, with the volume fraction of wood μ and attenuation coefficient ν , the signal power loss will be determined by the product $\nu\mu\delta$.

The passage of the signal from the upper edge of the stand to the antenna through the number of layers $H / \delta \sin\phi$ gives the attenuation coefficient of the signal $(1 - \nu\mu\delta)^{H/\delta \sin\phi}$. The passage to the limit as $\delta \rightarrow 0$ leads to the expression for attenuating the signal power P_0 at the input to the stand to the value P at the receiving antenna:

$$P = P_0 \exp\left(\frac{\nu\mu H}{\sin\phi}\right) \quad (1)$$

The obtained exponential law is similar to the known laws of absorption and scattering of electromagnetic waves of the optical range in various media [4]. The volume V_F is determined from the angular coordinates of the navigation satellite and the average height of the stand. The average value of the fraction of the volume of biomass in this volume is determined by the expression μV_F , where:

$$\mu = \frac{\ln \frac{P_0}{P}}{\nu H} \sin\phi \quad (2)$$

3 Radioscopy of the forest stand.

The key point to identify the possibilities of the method of determining the volume of the stand is the selection of test objects. The characteristics of the transmitted signals of navigation satellites in the forest stand vary depending on the species composition, age of the trees, the diameter of the tables, the size and structure of the crowns, the structure of the distribution of trees in the study area [4]. Carrying out measurements, data analysis and identifying the relationship between changes in the characteristics of transmitted radio waves through the forest canopy with specific biometric indicators of the stand requires the maximum reduction in the number of factors influencing the attenuation of signal power. Such objects can be stands that are clean in composition with uniform spatial distribution of trees, without glades and clearly defined grouping. Desirable absence of undergrowth, undergrowth and shrub layer. Important is the pronounced layers of crowns and trunks of the forest stand.

However, mixed coniferous-deciduous forests are interesting in that they have noticeable changes in the electrophysical characteristics of crowns associated with the appearance and decay of foliage against the background of persisting needles. Therefore, as

the first test object, a mixed pine-birch plantation plot located on the territory of urban forests near SFU was selected. A satellite image and a fragment of the stand are presented in Fig. 1.

Planting is represented by small areas of pine and birch forests. Pine forest stand (small grass pine stand) with an area of about 1.0 ha of class II bonitet has the following taxation characteristics: diameter at a height of 1.3 m 26.0 cm, height 23.5 m, fullness 0.9; stem wood stock - 290 m³. Birch forest stand (motley grass birch stand) with an area of 0.4 hectares of class III bonitet has the following taxation characteristics: diameter at a height of 1.3 m 25.0 cm, height 20.5 m, fullness 0.7, stem wood stock 170 m³.



Fig. 1. A fragment of the stand of pine and birch plantations.

Teenage, undergrowth and shrub layer are absent. Planting is represented by small areas of pine and birch forests. Pine stands with an area of about 1.0 ha of class II bonitet has the following taxation characteristics: diameter at a height of 1.3 m 26.0 cm, height 23.5 m, fullness 0.9, stem wood stock 290 m³. Birch forest stand with an area of 0.4 ha of class III bonitet has the following taxation characteristics: diameter at a height of 1.3 m 25.0 cm, height - 20.5 m, fullness - 0.7, stem wood stock - 170 m³.

The structure of the layers of crowns and tree trunks is physically significantly different in the density of distribution of wood substance in the volume of the stand. The effective dielectric constant will also be different. The attenuation of the signals of navigation satellites in the forest stand is determined by two main taxation indicators - the sum of the cross sections of trunks in the lower part of the stand at a height of 1.3 m and the biomass of tree crowns. These indicators can be obtained from the results of taxation using patterns of distribution of biomass in the stand. The calculation of the sum of the cross-sections of the trunks is quite simple to perform using the distribution of trunks by their diameter, and to estimate the biomass of the crowns it is necessary to use a rather complicated technique. The study of biomass is associated with the study of the interconnections of its various fractions in model trees. There are a large number of publications on the relationship of the mass of fractions of individual trees with a diameter of 1.3 m, height, cross-section of the trunk, as well as age [5-6].

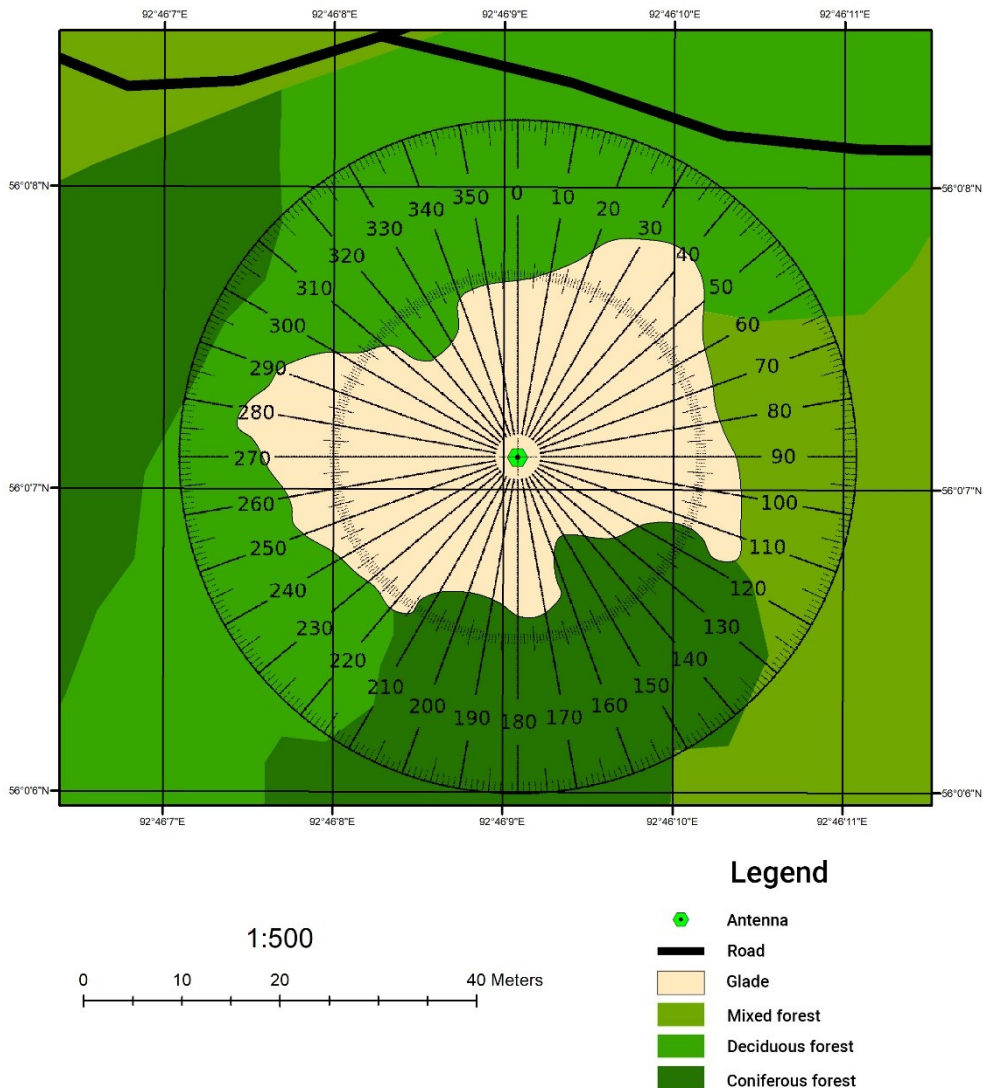


Fig. 2. Placement of mixed forest tree species on the test site.

Signals of the L1 range of GPS and GLONASS systems were recorded with MRK-32 equipment. The height of the antenna above the soil level is 0.25 m. The axis of the antenna pattern is oriented vertically. Antenna location coordinates $56^{\circ}00'07.6''\text{N } 92^{\circ}46'09.2''\text{E}$. The antenna was in the middle of the edge with a shift of 3 m to the southern border of the site.

The duration of the registration session is 3 hours. The sampling frequency was 1 Hz; during the indicated time interval, the forest massif scanned 13 satellites from each constellation. The location of the antenna provided the registration of GLONASS, GPS signals that passed through the forest and partially free space in the range of azimuth angles $0\text{-}360^{\circ}$ and elevation angles $10\text{-}90^{\circ}$. The maximum length of the signal path in the forest is

about 100 m. Graphs of changes in signal amplitude over time (frame scale, 1 s resolution) are shown in the figure 3.

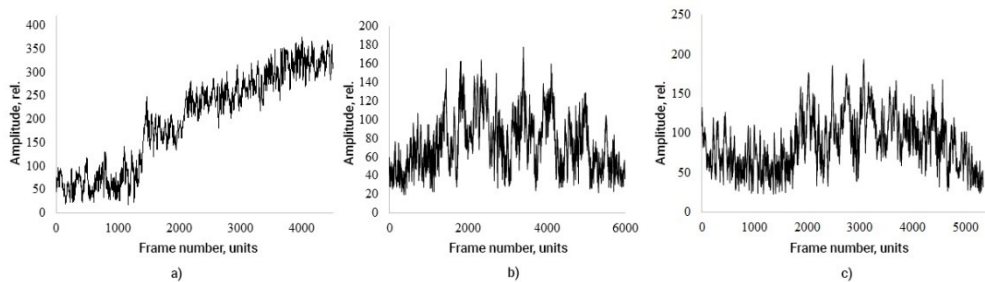


Fig. 3. Graphs of changes in signal amplitude over time: a) GLONASS 18 satellite, forest (frame numbers 1 - 2000) and free space (frame numbers 2000 - 4000), elevation angle ranges: 19° - 55° and azimuths: 230° - 260° ; b) GPS 3 satellite, forest range elevation angles: 16° - 34° , azimuths: 100° - 37° ; c) GPS 24 satellite, forest, elevation ranges: 21° - 31° , and azimuths: 260° - 320° .

4 Results and discussion

The uniquely determined position of the analytical volume VF of the conical channel allows revealing spatial dielectric inhomogeneities in the stand associated with variations in biomass and its moisture content. Temporal dependences of the amplitude of attenuated signals in the forest stand are used to determine the coefficients of specific attenuation assigned to the areas of different types of forests taking into account the known taxation characteristics. The sounding signal for satellite trajectories with elevation angles of 20° - 40° passes successively layers of crowns and trunks. Increasing the elevation angle of the satellite allows you to select signals attenuated only by the crowns, changing the azimuthal angle provides scanning of the stand area to 3 ha in the range of angles 0° - 360° . The associated values of ν and μ , if it is possible to calibrate using homogeneous stands, make it possible to restore ν at a known value of μ determined by taxation characteristics. In long-term monitoring of the stand, it is necessary to take into account changes in the dielectric constant, associated with seasonal cycles of moisture in the wood and needles, and the state of foliage. [7]

5 Conclusions

The fundamental possibility of the method of recovering fractions of the volume of wood, foliage or needles requires the development of a dielectric model based on data on the dielectric constant of wood, morphological and structural characteristics of the stand, and calibration of the probe signal. In reality, the creation of specialized receivers with software that allows you to process arrays of recorded signals to a user level within 3-4 hours. Placing the receiving antenna at different heights above the soil provides data on the crown layer. Practical applications of the method of continuous local monitoring of the stand state by signals of navigation satellites can be useful in forestry and forest pathology.

References

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