Forest dielectric characteristics for navigation satellites signals in L 1 range

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Abstract. A structural dielectric model of the forest is presented taking into account the wood Biomass distribution. The multi-scale structural formations of the individual trees and the stand as a whole as a hierarchical system of non-interacting components of the mixed dielectric are discussed. Layers of crowns and trunks are distinguished as anisotropic dielectric media with gradient boundaries. The possibility of using the orientation parameter of the order of branches in the crown layer to estimate the gradients of the effective permittivity of the inhomogeneous distribution and its spatial anisotropy is analyzed. A comparative analysis of the features of the effective dielectric permittivity of pine and birch forests is carried out. The possibilities of using a layered anisotropic dielectric forest model to describe the transformation of GPS and GLONASS signals in order to restore the biometric characteristics of the forest are considered.

1 Introduction

The development of methods for recovering physical characteristics of tree stands using GLONASS and GPS signals has prospects of creating an effective forest monitoring system by a universal user resource - global navigation satellite systems (GNSS) [1]. Available GNSS signals are presented as an effective tool for continuous local monitoring of forests which allows obtaining data about the physical characteristics and state of the tree stands cover with a sampling frequency of 1 Hz in the L-band operating frequency range. Scanning of the stand with multidirectional microwave streams allows restoring the distribution of phytomass and the moisture of the stand of forested areas of up to 3 hectares on the vicinity of the antenna location. The duration of diurnal and seasonal processes of changes in water content in trees and air in the forest canopy compared to the duration of GNSS probing signals (1 ms) is essential. The hardware-software complex for recording changes in the characteristics of transmitted and scattered GNSS signals in the tree stands provides obtaining attenuation coefficients from localized areas of forests [2].

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The presence of models of electromagnetic waves interaction of microwave range with a stand allows restoring quantitative values of taxation parameters and moisture content of forests from linear attenuation coefficients. The solution of the restoration task involves the development of adaptive models that take into account the structural and species diversity of individual trees and the stand as a whole and as a hierarchical system radio physical of components of a mixed dielectric.

In this work, a version of the development of a dielectric model of a stand adapted for the characteristics of GNSS signals of the L1-band is presented.

2 Special features of the dielectric forest model for GNSS signals

Tree stands are randomly inhomogeneous medium with tree elements of various shapes, sizes and spatial orientation [3-4]. A universal approach to describing the electro physical properties of different types of forests is possible when considering a forest as a multiphase dielectric medium with losses characterized by an effective dielectric permittivity (EDP). The forest as a two-component continuous dielectric medium, which includes multi-scale tree elements and air. It can be considered as a mixed inhomogeneous dielectric. Experimental data on the elements dependence of the complex permittivity tensor of wood $\varepsilon = \varepsilon' + i\,\varepsilon''$ of different types of forests on humidity and temperature for radio frequencies in the range of 20-1011 Hz are presented in the monograph [5]. The difference in dielectric properties of wood is observed for orientations of the electric field strength vector along the tree in the radial and tangential directions. In practical applications tensor elements corresponding to the longitudinal direction (*L*) and the cross one (*C*) are used. The anisotropy of wood is characterized by the value of $\Delta\,\varepsilon$:

$$\Delta\,\varepsilon = \varepsilon\,(L) - \varepsilon(C). \tag{1}$$

The dielectric permittivity of leaves and needles of different types of forests depending on humidity varies for the real part of ε' from one to 40 and for the imaginary part of ε'' from 0.2 to five [6-7]. The electro physical model of tree stand as an aggregate of individual trees with a relatively low density of tree elements distribution in the volume of a stand suggests taking into account the dielectric properties of individual tree elements in a given frequency range. Anisotropy of wood determines the gradients of anisotropy as a separate tree and a forest as a whole. The random distribution of trees in space forms a heterogeneity of biomass of related groups of trees, the dimensions of which exceed by one order the characteristic dimensions of a single tree.One of the prospective areas of mathematical modeling of forest ecosystems is a tier-mosaic approach to the structuring of the forest [8]. Figure 1 illustrates the geometric structure of trees and layers of the tree stand. Within the framework of this approach, it is possible to create a dielectric model of tree stand that allows describing the patterns of space-time changes of its electro physical parameters that are sufficient to the evolution processes of the biometric characteristics of the forest.

Scaling of the basic elements of the tier-mosaic electro physical model for the tree stands in the L1- band is determined by the wavelength of the probing signal $\lambda \approx 0.2$ m.

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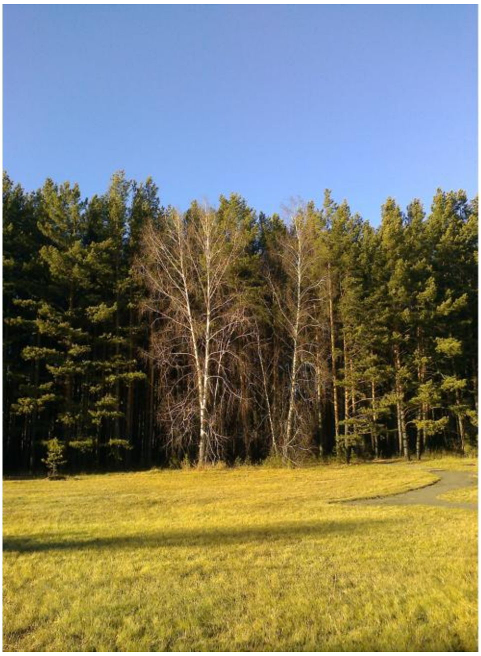
a)


b)

Fig. 1. Structural levels of pine and burch tree stand: a) free bound, b) bound after cutting down.

Mature boreal forests in the conditions of the ground location of the receiving antenna allow us to distinguish the following levels of basic elements:

- level 1, needles, leaves, branches with the diameter of $d \ll \lambda$;
- level 2, branches and trunks with the diameter of $d \geq \lambda$;
- level 3, crown, tree trunk with vertical extent of $h \gg \lambda$;
- level 4, layers of crowns and tree stands with a length vertically, $H(cr)$ and $H(st) \gg \lambda$.
- level 5, groups of trees on sites up to 100 m^2

The type of a single tree, its taxonomic indices, dielectric properties of its elements determine the electro physical characteristics of the stand.

The isolated layers of the tree stand differ in terms of the volume density of the phytomass, the anisotropy of the effective permittivity, the magnitude and direction of the electro physical characteristics gradients in the vertical and horizontal directions.

A tree as an "atomic" element of the tree stand is the main structural unit of any forest and separate trees are described by structural levels 1-3. Specific differences in these structural levels are observed at any age of the trees. The tree trunk together with the large branches for a single tree represents an ordered system that can be characterized by an orientation parameter of order S [9] with respect to the vertical direction:

$$S = \langle 3 \cos 2\theta - 1 \rangle / 2 \tag{2}$$

Here θ is the angle between the branches and the vertical tree trunk. The averaging is carried out along the orientation of the whole ensemble of branches. The dispersion of the quantity S is proportional to $\cos^4 \theta$. *I*t affects on cross section dispersion of this system.

The tree trunks of are oriented almost strictly vertically so the layer of trunks has a value of S that is close to one. The value of the difference in the real parts of the longitudinal and cross components of the permittivity $\Delta\varepsilon' = \varepsilon'(L) - \varepsilon'(C)$ of wood with a moisture content of 40% for spruce and larch at 20 ° C [5] are 2.8 and 9.6 respectively. Consequently, the tree trunk layer has sufficient anisotropy to affect the right circular polarization of GPS and GLONASS signals.

Crones of trees have some tiers of branches, which differ noticeably in angle θ. The angles of the inclination of the branches for different types of trees as can be seen from Fig. 1 vary in the range from 30° to 90°. The gradients of the order parameter of the crown branches from the upper boundary of the crowns to the bottom one characterize the change in the magnitude of the anisotropy of the crowns. In the case of equally probable orientation in the space of the crown branches, the real part is $\varepsilon' = [\varepsilon'(L) + \varepsilon'(C)] / 2$, $\Delta\varepsilon' = 0$, and the crowns are a dielectric isotropic medium.

The creation of an adequate model for the distribution of navigation satellites signals in a forest canopy requires the determination of the geometric characteristics of the tree stand: the height of trees, the diameter of the trunks and the number of trees per unit area of the forest of the effective height of the forest canopy and crown. An example of forest taxation parameters of larch stand plantings near the station "Pogorel'skii Bor" of V.N. Sukachev Institute of Forest of FRC KSC SB RAS is shown in Figure 2. The experimental site of 800 m^2 contained 66 trees of different diameters and heights with crowns of different lengths. The choice of the effective thickness of the crown layer is possible with the assumption of a gradient of the crowns biomass along the vertical at the upper and lower boundaries.

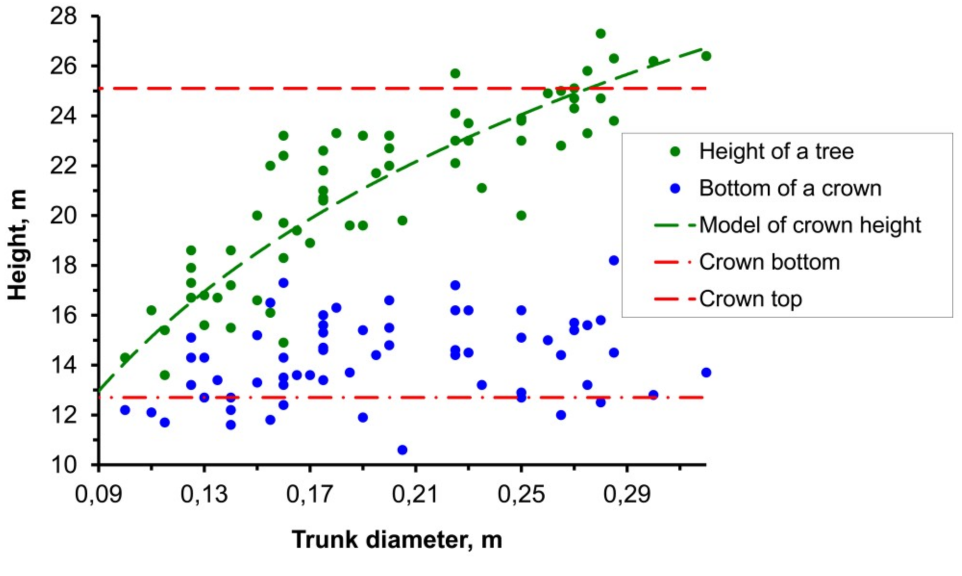

Fig. 2. Dependence of the vertical extent of tree crowns on larch on larch forest.

The boundary of the top crowns layer is formed by a trees different heights with greater depth of vertical gradient of wood distribution. The specificity of the two-layered dielectric model of the stand pertains to the mutual intersection of the layers of the trunks crowns. In fact, it is possible to introduce a third, gradient transition layer containing trunks and branches with similar in meaning diameters. The fifth-level heterogeneity retain the features of the EDP discussed above with variations, which are due to different tree densities in local groups of trees. Fig. 3 presents a satellite image and a tree distribution plan for birch and pine forests showing the presence of localized groups of trees on sites with a typical size of 10-20 m.

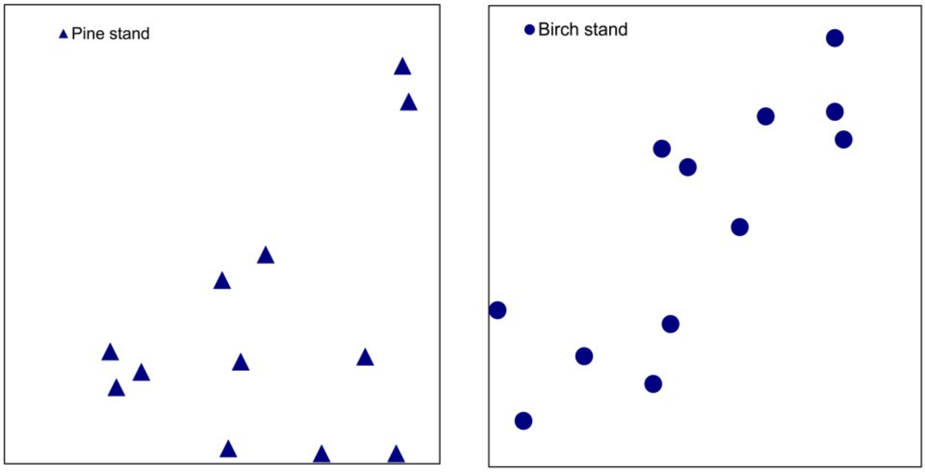

Fig. 3. Trees distribution at the experimental site.

Experimental researches of forests by radio transmission method using GNSS signals [2] revealed not monotonous dependencies of the relative amplitude on scanning trace. Scanning the forest with GNSS signals detects localized groups of trees over the anomalies dependence of the signals amplitude on time.

Figure 4 shows the recording of GLONASS 24 satellite signals when scanning pine and birch forests. Reducing the amplitude of the signal after passing through the tree stand allows us to establish the boundaries of localized groups of trees. Colors are: black (1) - correspond to signal trajectories passing in pine forest, green (2) scanning unforested-space, red (3) – birch forest.

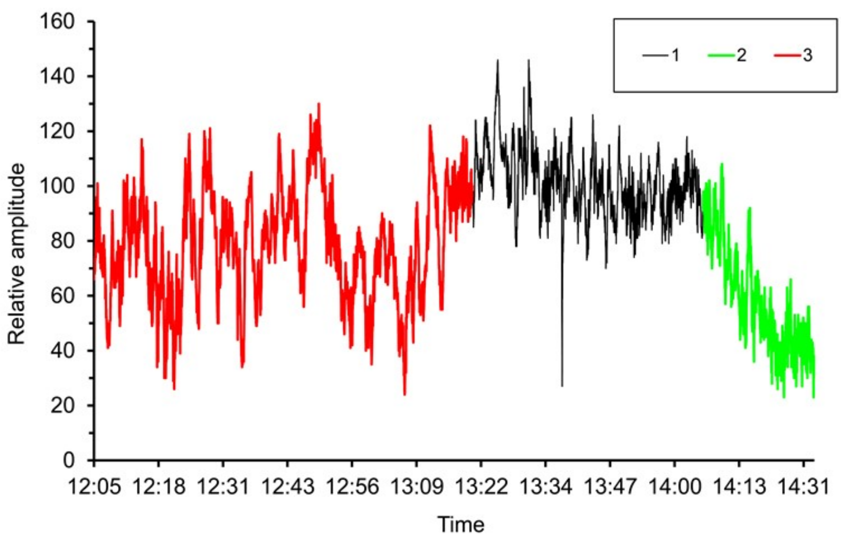

Fig.4. Fluctuations in the amplitude of GNSS signals in pine forest (1), unforested-space (2), and in birch forest (3).

3. Conclusion

A five-level structural dielectric model of the forest has been proposed taking into account the gradients of the biomass distribution and the complex effective permittivity of the tree stand.
The multi-scale structural formations of individual trees and the tree stand as a whole are distinguished which form a layer mosaic-tiered system of non-interacting components of the mixed dielectric.
The possibility of taking into account the anisotropy of the EDP in the tree crown layer with the use of the orientation order parameter of the branches is considered.
The assessments of the EDP gradients of the tree stand are made due to the inhomogeneous distribution of trees phytomass in the volume of the forest.
The possibility of using the orientational order parameter of the branches in the crown layer for estimating the gradients of the inhomogeneous EDP distribution and its spatial anisotropy is analyzied.
The prospects of using an anisotropic layered model of tree stand for describing the transformation of GPS and GLONASS signals in the forest with the purpose of restoring his biometric characteristics are discussed.

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