# The Error of the Method of Angular Sections of Microwave Sounding of Natural Environments in the System of Geoecological Monitoring

**FedoseevaE.V.[1], Kuzichkin O. R.[2]**

*[1]Vladimir State University named after Alexander Grigoryevich and Nikolai Grigorievich Stoletovs, Vladimir, 600000, Russia*
*[2]1Belgorod State Research University, Belgorod, 308015, Russia*

**Abstract**
The article deals with the problems of application of microwave methods in systems of geoecological monitoring of natural environments and resources of the agro-industrial complex. It is noted that the methods of microwave radiometry make it possible, by the power of the measured intrinsic radio-thermal radiation of the atmosphere, when solving inverse problems using empirical and semi-empirical models, to determine such parameters of the atmosphere as thermodynamic temperature, humidity, water content, moisture content, precipitation intensity, and the presence of different fractions of clouds.In addition to assessing the meteorological parameters of the atmosphere and the geophysical parameters of the underlying surface based on the data of microwave radiometric measurements, it is possible to promptly detect and study pollution of both the atmosphere and the earth's surface. A technique has been developed for the analysis of sources of measurement error and their numerical evaluation, because they have a significant effect on the accuracy of solving inverse problems of reconstructing the values of the physical parameters of the probed media.To analyze the degree of influence of the limited spatial selectivity of the antenna of the microwave radiometric system on the measurement error, we calculated the relative measurement error of the ratio of radio brightness contrasts in two angular directions. It has been determined that in the system of geoecological monitoring of natural environments, the effect of background noise is maximal with small changes in the radiobrightness temperature during angular scanning and high sensitivity of the receiving equipment.

***Key words*:**
*radio wave radiometry, geoecological monitoring, angular section, natural resources, radiobrightness temperature, method error*

## 1. Introduction

At present, to solve the problems of rational use of natural resources in agro-industrial complex (AIC) when applying the concept and technologies of precision farming, systems of geoecological monitoring are used [1-5]. They make it possible to assess geoecological changes in natural resources on the territory of the agro-industrial complex, as well as to carry out their technological control in order to form a predictive assessment of the possibility of negative scenarios and irreparable depletion of resources.

Microwave radiometry is one of the applied methods of geoecological monitoring of natural environments, which makes it possible to remotely estimate the structure and physical parameters of the controlled environment using measurements of its own radio-thermal radiation. The use of radiometry in precision farming technologies solves a number of applied problems, the solution of which makes it possible to increase the efficiency of the use of natural resources in the agro-industrial complex. For example, to control irrigation and control the moisture saturation of soils, it is important to control the intensity of possible precipitation.At the same time, the methods of microwave radiometry allow, according to the power of the measured intrinsic radiothermal radiation of the atmosphere, when solving inverse problems using empirical and semi-empirical models, to determine such parameters of the atmosphere as thermodynamic temperature, humidity, water content, moisture content, precipitation intensity, the presence of different fractions of clouds [6]. In addition to assessing the meteorological parameters of the atmosphere and the geophysical parameters of the underlying surface based on the data of microwave radiometric measurements, it is possible to promptly detect and study pollution both of the atmosphere and the earth's surface [7].

From the point of view of organizing geoecological monitoring of AIC facilities, everything is built on the main three levels of vicinal, local and regional. Moreover, from the vicinal measuring complexes of the monitoring system, they transmit primary digital data to the vicinal server, where all information is processed, analyzed and transmitted to the local servers [8-10]. Local-level servers perform service functions for collecting and primary processing of measurement information coming from vicinal observation points.In addition, they are entrusted with the task of preliminary analysis of measurement information, assessment of its reliability and management of vicinal complexes of geoecological control [11]. Application of microwave radiometry

Manuscript received June 5, 2021
Manuscript revised June 20, 2021
https://doi.org/10.22937/IJCSNS.2021.21.6.8

methods provides a unique opportunity to create an interlevel measurement interface by combining In this case, the interaction of the servers of the local level with the servers of the regional level is based on the estimated data obtained from the measuring channels of microwave radiometry. Regional servers are administratively tied to the regional parts of the unified information and analytical subsystem of geoecological monitoring, but in terms of information content to the selected zones of manifestation of natural and man-made processes and their connection with the objects of the agro-industrial complex [12]. Information integration of regional servers is carried out, as a rule, through the protocol procedures for inter-network interaction at the regional level of the hierarchical structure of geoecological monitoring.

The possibilities of remote sensing of natural environments are significantly expanded when scanning the studied area both in azimuth and in corner of the place. Such measurements make it possible to form a volumetric model of the geophysical parameters of the probed natural space. Measurements of this kind are used in profilers, the results of which are used to construct altitude profiles of temperature, humidity and water vapor content [13], in which, at the present stage of development, in addition to semi-empirical regression models, neural networks are widely included, providing additional opportunities for solving problems of parameter estimation.The presence in the investigated spatial area of dissimilar natural environments, for example, the atmosphere and the earth's surface, is not a significant factor limiting the possibilities of microwave radiometric studies. Under such conditions, a comprehensive assessment of physical parameters is carried out, taking into account the conditions for the formation of its own radiothermal radiation of each medium [14].

The possibilities of remote sensing of natural environments using microwave radiometric systems determine the prospects for their widespread implementation in the creation of an operational network for continuous microwave radiometric monitoring of the atmosphere and the earth's surface and the creation of modern mobile autonomous systems in solving problems of both increasing the measurement accuracy and developing methods for solving inverse problems of assessing physical parameters of the investigated media [15,16].

### 1.1. Model of the angular error of microwave sounding of natural media

An important issue of organizing such microwave measurements is the analysis of sources of measurement error and their numerical evaluation, since they have a measurement information.

significant effect on the accuracy of solving inverse problems of reconstructing the values of the physical parameters of the probed media. Comprehensive analysis showed the presence of various sources of error in microwave radiometric measurements and differently affecting its value [17, 18]. According to the analysis, one of the factors that significantly affects the measurement results and strongly depends on the measurement conditions is the estimation error [19] or compensation [20] of the contribution to the input signal of the microwave radiometric system of background radiation received over the scattering region of the antenna pattern.

When solving applied problems of remote sensing, various approaches are possible, depending on the problems being solved, so it is possible to use relative measurements of the radiobrightness temperature for several close angular directions. For example, to estimate the optical thickness of a horizontally homogeneous or locally inhomogeneous atmosphere, measurements are used in two directions, and when measuring the dielectric constant of a smooth surface, measurements are required in three angular directions [6, 13].

The models for determining the parameters include the relative measurements of the radiobrightness temperatures as an empirical quantity, i.e. radiobrightness contrasts of the studied areas with respect to a certain reference benchmark area, the radiobrightness temperature of which can be determined or modeled with high accuracy. Thus, the estimated value when making measurements using the angular section method is the ratio of radiobrightness contrasts

$$\delta(\Delta T_{rb}) = \frac{\Delta T_{rb1}}{\Delta T_{rb2}} = \frac{(T_{aref} - T_{a1}) - \beta\eta(T_{bref} - T_{b1})}{(T_{aref} - T_{a2}) - \beta\eta(T_{bref} - T_{b2})}, \quad (1)$$

where $T_{aref}$ is the antenna temperature when receiving radio noise radiation from the reference area; $T_{bref}$ is the averaged value of the radiobrightness temperature of the radio noise radiation of the space corresponding to the scattering region of the antenna pattern when directed to the reference region.

The relative measurement error of the radiobrightness contrast ratio is the sum of the relative measurement errors of each contrast

$$\delta(\delta(\Delta T_{rb}))^2 = \delta(\Delta T_{rb1})^2 + \delta(\Delta T_{rb2})^2, \quad (2)$$

and if we neglect the difference in the values of the errors in the assessment of the radiobrightness contrast in two angular directions, then the relative error is

$$\delta(\delta(\Delta T_{rb})) = \sqrt{2}\delta(\Delta T_{rb}), \quad (3)$$

those in $\sqrt{2}$ times greater than the relative measurement error of the radiobrightness contrast.

When performing numerical estimates of the error, it is necessary to take into account the fact that the difference in the background noise $\Delta T_b = T_{bref} - T_b$ depends on the measurement conditions and, accordingly, on the choice of the reference area.

If the reference area is located in the same half-space with the controlled areas, for example, when determining the optical thickness of cumulus clouds, the reference area is an area of a cloudless sky, or in the case of sounding the earth's surface - areas covered with vegetation or water surfaces, then approaches to the estimation of the error in measurements of the radiobrightness temperature can be used when performing absolute and relative measurements given in [8-10], and for the case of measuring the ratio of radiobrightness contrasts and, accordingly, all conclusions on the effect of background noise on the measurement results in the relative method of radioheatlocating control are also valid for the method of angular sections, only the value of the relative error increases in $\sqrt{2}$ times.

If the reference region is located in different half-spaces that significantly differ in radiative properties, for example, when studying a homogeneous atmosphere - cloudless or with stratus-like clouds, and the earth's surface with vegetation is chosen as the reference region, the radiobrightness temperature of which is close to the thermodynamic temperature, then the contribution of the difference in the background the noise $\Delta T_b$ of the reference and the studied area into the value of the radiobrightness contrast in the first approximation can be estimated by the formula

$$\Delta T_{brb} = (\beta_{up} - \beta_{down})(\overline{T}_b^u - \overline{T}_b^d)/(1-\beta) = \Delta\beta\Delta\overline{T}_{bud} / (1-\beta), \quad (4)$$

where $\beta_{up}$, $\beta_{down}$ are the fractions of the total scattering coefficient of the antenna, characterizing the reception through the scattering region of the antenna pattern from the upper and lower half-spaces; $\Delta\beta = \beta_{up} - \beta_{down}$.

When controlling the parameters of a sufficiently homogeneous medium filling the half-space, the difference in the background noise has approximately the same value as the radiobrightness contrast. Then the formulas for estimating the coefficients of the influence of errors in the composition of the total relative error in measuring the relative radiobrightness contrast have the form

$$K_\beta = \frac{(\Delta T_{rb} - \Delta\beta\Delta T_{bud})\beta}{(1-\beta)\Delta T_{rb}} \approx \frac{(1-\Delta\beta)\beta}{(1-\beta)}, \quad (5)$$

$$K_{\Delta T_b} = \frac{\Delta\beta}{(1-\beta)}, \quad (6)$$

$$\delta_{\Delta T_b} = \Delta T_b / \Delta T_{rb} \approx 1. \quad (7)$$

To be able to assess the effect of the difference in background noise on the measurement error of the ratio of radiobrightness contrasts, data on the values of the scattering coefficients $\beta$, $\beta_{up}$, $\beta_{down}$ and $\Delta\beta$ are needed. In figure 1 shows the graphical dependences $\beta$, $\beta_{up}$, $\beta_{down}$ and $\Delta\beta$ on the width of the main lobe of the antenna pattern with a circular radiating aperture, the field distribution over which is parabolic with a pedestal and the irradiation level of the aperture edge -10 dB from the level in the center of the aperture.

According to the data in Fig. 1, the values of the scattering coefficients $\Delta\beta$ are taken in the range from 0.25 to 0.1 with the corresponding values $\beta$ from 0.25 to 0.33, and the coefficient of influence of the difference of the background noise in the directions to the study area and the reference area (Figure 2) has values in the range from 0.1 to 0.25, and under the condition $\Delta T_b \approx \Delta T_{rb}$ the value $K_{\Delta T_b} = \frac{\Delta\beta}{(1-\beta)}$ is equal to the component of the relative error due to the influence of background noise.

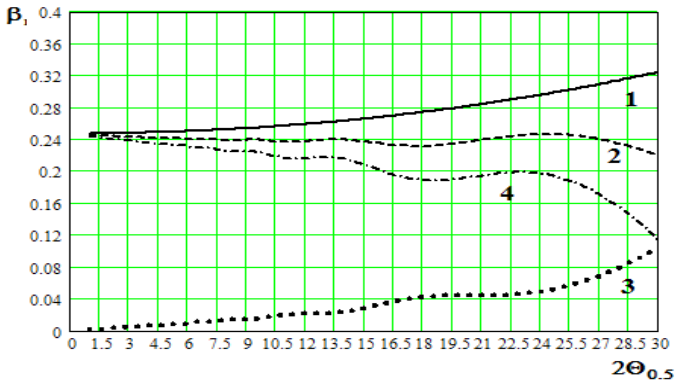


**Fig. 1.** Dependence of the scattering coefficients $\beta$ (1), $\beta_{up}$ (2), $\beta_{down}$ (3) and $\Delta\beta$ (4) of an antenna with a circular radiating aperture on the width of the main lobe of the antenna pattern

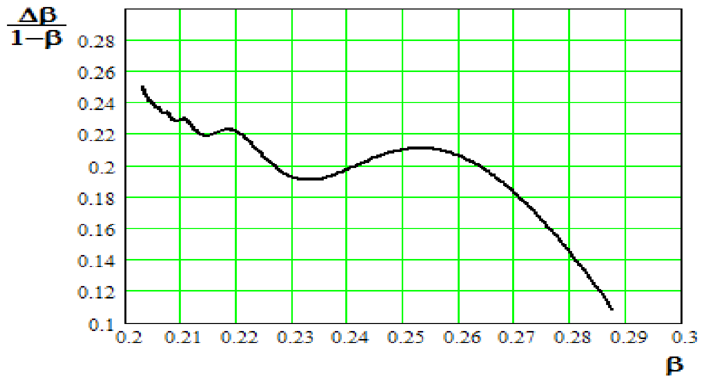


**Fig. 2.** Dependence of the influence factor $K_{\Delta T_b} = \dfrac{\Delta\beta}{(1-\beta)}$ of the difference in background noise on the magnitude of the dissipation factor of the antenna

## 1.2. Estimation of the relative error based on the angular section model

To analyze the degree of influence of the limited spatial selectivity of the antenna of the microwave radiometric system on the measurement error, we calculated the relative measurement error of the ratio of radiobrightness contrasts in two angular directions under the condition $T_0 - T_{rbref} = 100K$ , $\mu = 0.85$ . The results of calculating the error in measuring the radiobrightness temperature by the angular section method are shown in Figures 3 - 8.

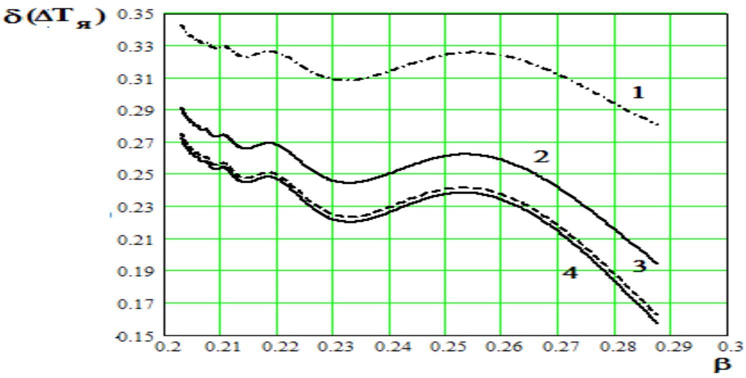


**Fig. 3.** Dependence of the relative measurement error of the ratio of radiobrightness contrasts on the value of the scattering coefficient $\beta$ , provided that the absolute value of radiobrightness contrasts in two directions is equal to 10 K (1), 20 K (2), 50 K (3), 100 K (4) at the sensitivity of the radiometer is 1 K

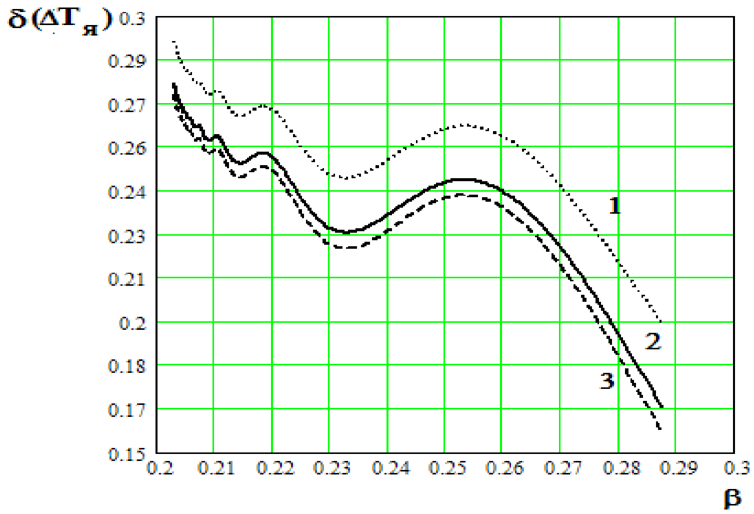


**Fig. 4.** Dependence of the relative measurement error of the ratio of radiobrightness contrasts on the value of the scattering coefficient $\beta$, provided that the absolute value of radiobrightness contrasts in two directions is equal to 10 K (1), 20 K (2), 50 K (3) at a radiometer sensitivity of 0.5 K

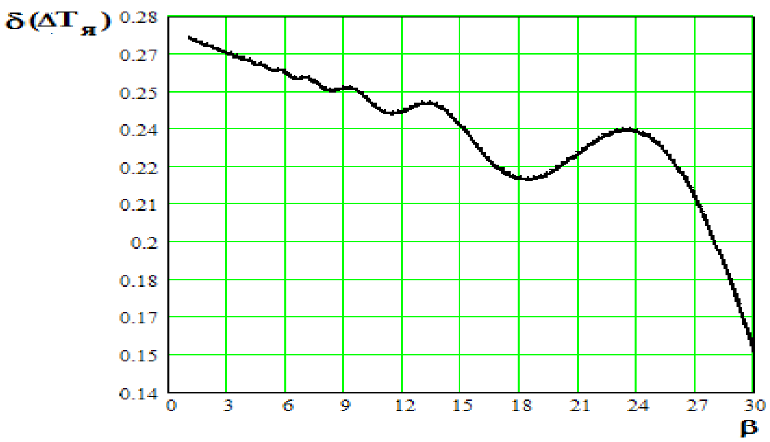


**Fig. 5.** Dependence of the relative measurement error of the ratio of radiobrightness contrasts on the value of the scattering coefficient $\beta$ at a radiometer sensitivity of 0.1 K

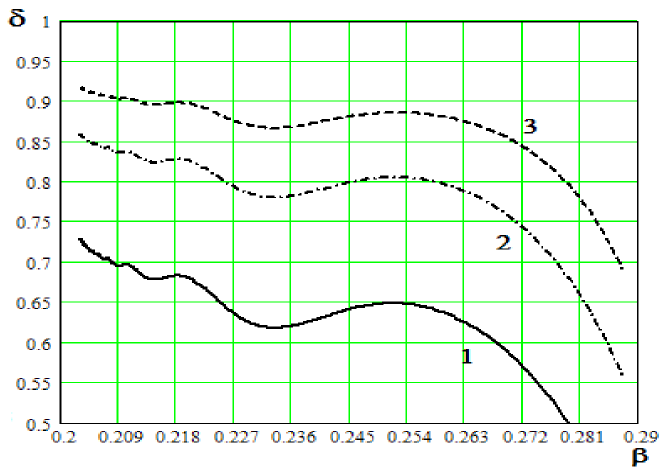


Fig. 6 . Dependence of the fraction of the error caused by the influence of background noise in the total value of the relative measurement error of the ratio of radiobrightness contrasts on the value of the scattering coefficient $\beta$, provided that the absolute value of the radiobrightness contrasts in two directions is 10 K at the sensitivity of the radiometer 1 K (1), 0.5 K (2), 0.1 K (3)

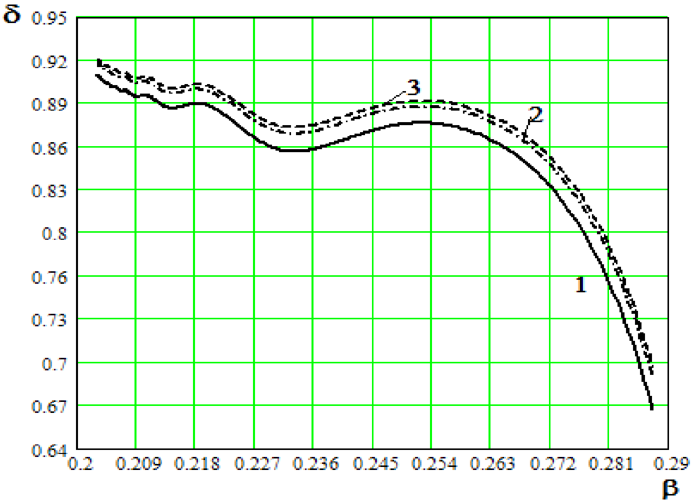


**Fig. 7 .** Dependence of the fraction of the error caused by the influence of background noise in the total value of the relative measurement error of the ratio of radiobrightness contrasts on the value of the scattering coefficient $\beta$, provided that the absolute value of the radiobrightness contrasts in two directions is 50 K at the sensitivity of the radiometer 1 K (1), 0.5 K (2), 0.1 K (3)

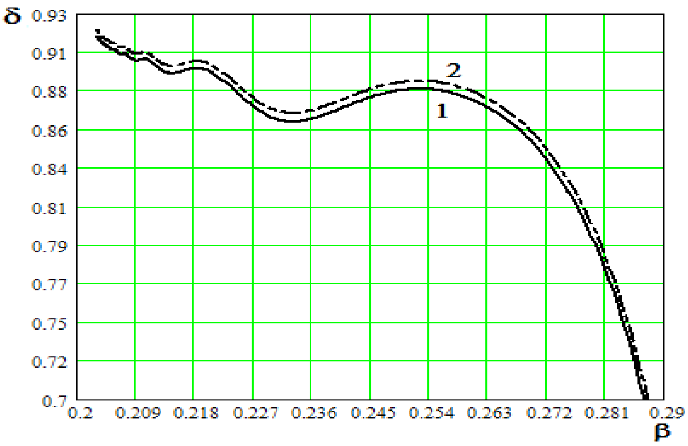


**Fig. 8.** Dependence of the fraction of the error caused by the influence of background noise in the total value of the relative measurement error of the ratio of radiobrightness contrasts on the value of the scattering coefficient $\beta$, provided that the absolute value of the radiobrightness contrasts in two directions is equal to 100 K at the sensitivity of the radiometer 1 K (1), 0.1 K (2)

## 2. Conclusions

An analysis of the obtained dependences of the relative errors in the measurement of the ratio of radiobrightness contrasts, which is implemented in the method of angular sections of radioheatlocating control of meteorological parameters, allows us to draw the following conclusions:

- for antennas with a large scattering coefficient $\beta$, the influence factor of the background noise, and, consequently, the share of the corresponding component in the total relative measurement error of the radiobrightness contrast ratio is smaller, which is explained by the smaller absolute value of the difference in the background noise for the direction of measurement and direction to the reference area;
- a similar dependence $\delta(\delta(\Delta T_{rb}))$ on the scattering coefficient $\beta$, but in this case the error is the smaller, the greater the difference in the radiobrightness temperatures in the angular directions and the higher the sensitivity of the radiometer;
- for large values of the difference in radiobrightness temperatures in angular directions (> 100K), the absolute value does not affect the measurement error;
- at a high sensitivity of the radiometer (<0.1K), the measurement error does not depend on the difference in radiobrightness temperatures in angular directions;

Thus, in the case of radioheatlocating control in the system of geoecological monitoring of natural environments, the effect of background noise is maximal at small changes in the radiobrightness temperature during angular scanning and high sensitivity of the receiving equipment. So, based on the data obtained, the limiting relative error in measuring the ratio of radiobrightness contrasts is determined, ultimately, mainly by the value $K_{\Delta T_b} = \frac{\Delta\beta}{(1-\beta)}$ and is 15% at $K_{\Delta T_b} = 0.11$ and 25% at $K_{\Delta T_b} = 0.2$ .

## Acknowledgements

This work was prepared as a part of the state task FZWG -2020-0029 "Development of theoretical foundations for building information and analytical support for telecommunication systems for geo-ecological monitoring of natural resources in agriculture".

## References

[1] V.S. Niklyaeva. Basics of agricultural production technology. Agriculture and plant growing. Ed.. - M.: "Bylina"..- 555 p. (2000)

[2] Evtefeev, Yu.V. Yu.V. Evtefeev, G.M. Kazantsev. Fundamentals of agronomy. - M.: FORUM..- 368 p. (2013).

[3] O. Hersent, D. Boswarthick, O. Elloumi. The Internet of Things: Key Applications and Protocols /— Willey.— 370 p. (2012).

[4] Poolayi, S., & Assadiyan, A. H. Governance of IoT in order to Move ahead of the calendar & live the future today. Journal Of Management And Accounting Studies, 8(3), (2020).

[5] O.R. Kuzichkin, R.V. Romanov, N.V. Dorofeev, A.V. Grecheneva. Organization and application of information and analytical support for geological monitoring of water use / // IIOAB Journal. - India vol. 11, Issue 1. - Pp 20-26. (2020).

[6] Stepanenko V.D., Shchukin G.G., Bobylev L.P., MatrosovS.Yu. Radiolocation in meteorology. - SPb.: Gidrometeoizdat. - 284 p. (1987) .

[7] Nekos AN, Nekos VE, Shchukin GG. Remote methods of research of natural objects. -SPb.: RGGMU. -318 p. (2009).

[8] Edited By V. S. Niklyaev. Fundamentals of agricultural production technology. Agriculture and crop production. – M.: "Bylina". - 555 p. (2000).

[9] I.A. Minakov, N.I. Kulikov, O.V. Sokolov and others. Ed. by I. A. Economics of agricultural industries / Minakov.- Moscow: Koloss. - 464 p. (2004).

[10] Yu.V. Evtefeev, G.M. Kazantsev. Fundamentals of agronomy: textbook / M.: FORUM. - 368 p. (2013).

[11] O. Kuzichkin, A. Grecheneva, A. Bykov Selection and justification of the location of the network of points of stationary observations in the local zones of karstological monitoring // 18th International Multidisciplinary Scientific Geoconference, SGEM.- Volume 18, Issue 1.2. - Pp. 629-636. (2018).

[12] O. Kuzichkin, N. Dorofeev, A. Bykov et al. Regression algorithms eliminate interference with the endogenous character geoecological monitoring of water resources // International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM. - Volume 17, Issue 52. – Pp. 749-754. (2017).

[13] Ware R., Carpenter R., Guldner J., Liljegren J., Nehrkorn T., Solheim F., and Vandenberghe F. Radio Science. -Vol. 38, no. 4. - Pp. 8079–8032. - DOI: 10.1029/2002RS002856. (2003).

[14] Karavaev DM, Shchukin GG. Microwave radiometric sounding of the system "atmosphere - underlying surface". Questions of radio meteorology. -SPb.: VKA im. AF Mozhaisky, Baltic Printing Publishing House. -Pp. 173–192. (2013).

[15] Rose T., Crewell S., Lohnert U., and Simmer C. Atmospheric Research. – 2005. -Vol. 75, no. 3. -Pp. 183–200. -DOI:10.1016/ j.atmosres12.005 .(2004).

[16] Battaglia A., Saavedra P., Simmer C. and Rose T. Rain, IEEE Geoscience and remote sensing letters. -Vol. 6, no. 2. -Pp. 354–358. -DOI: 10.1109/LGRS. 2013484. (2009).

[17] Westwater Ed. R, Crewell S., Mätzler C. Radio Science. –-No. 77. -Pp. 59–80. -DOI: 10.23919/URSIRSB.2004.7909438/ (2004).

[18] Fedoseeva E.V., Shchukin G.G. Metrological support of measurements in conditions of external noise interference. Monograph. - Murom. –110 p. (2012).

[19] Fedoseeva E.V., Shchukin G.G. Assessment of the influence of inaccuracy in the compensation of background noise on the error of relative radio heat location measurements // Scientific Bulletin of MSTU GA. - Issue 186. - P 58 - 61. (2012).

[20] Fedoseeva E.V., Shchukin G.G. The error of absolute radio heat location measurements with non-uniform background noise // Scientific Bulletin of MSTU GA. – Issue 186. – Pp. 43 - 48. (2012).