Application of the Correlation Theory of Thermal Regime and Thermal Radio Emission for Atmosphere

Konstantin P. Gaikovich

***Abstract*—The results obtained by application of the earlier developed stochastic theory of temperature distribution and thermal radio emission of medium (half-space) to atmosphere are presented. It was obtained that the exponential autocovariance function of the surface temperature is in good agreement with that determined from meteorological data (such covariance functions are inherent in random processes generated by the Poisson process). The theory offers a good qualitative explanation of the frequency and height dependencies of statistical parameters, and for some of these parameters there is a good quantitative agreement. The theoretically predicted effect of the time shift of the correlation functions maxima was discovered in the data. The theory was generalized for the spatial inhomogeneities of atmosphere, and the vertical correlation length of random atmosphere inhomogeneities was obtained as the geometric mean from the diffusion length and the horizontal correlation length of surface temperature.**

***Index Terms*—Author, please supply your own keywords or send a blank e-mail to keywords@ieee.org to receive a list of suggested keywords.**

I. Introduction

The earlier developed stochastic theory considered the thermal conductivity equation and formulas of [1] and [2] with random boundary conditions. In [1], on the basis of a simultaneous solution of the emission transfer and the thermal conductivity equations, it proved possible to obtain expressions for the brightness temperature of the radio emission as integrals of the boundary conditions evolution (surface temperature or heat flux) and next, in [2], perform an inversion of these expressions to obtain formulas for the temperature distribution (profile) of a medium (half-space) as integrals of the brightness temperature evolution. These formulas together with the thermal conductivity equation have also been used to develop the above-mentioned stochastic theory of the temperature regime and the thermal radio emission of medium, assuming the surface temperature as a random stationary function of time with the average value $\langle T_0 \rangle$, the mean-square deviation σ, and the autocovariance function $B_{T_0T_0}(\tau) = \langle (T_0(t) - \langle T_0 \rangle)(T_0(t+\tau) - \langle T_0 \rangle) \rangle$ [4], [5]. This theory gives necessary covariance functions and statistical parameters as linear integrals of the surface temperature covariance function. The integral expressions obtained were of the convolution type; hence, it was convenient to apply the spectral approach for the following analysis [5], which completed development of the correlation theory of the thermal regime and the thermal emission of a homogeneous half-space. All the statistical parameters of temperature and emission have been expressed as one-dimensional integrals depending on the medium parameters: electromagnetic absorption coefficient γ and thermal diffusion coefficient a^2. For the exponential covariance function of the surface temperature, some results have been obtained in the explicit form, and numerical simulation has been carried out [5]. In this paper, the developed theory is applied for the atmosphere. It is also generalized for the case of a horizontally inhomogeneous atmosphere.

The results of the theory application to atmosphere can be used in radiometer methods of temperature profile remote sensing by measurements of thermal radio emission at millimeter wavelengths [6]–[10]. **au: what is volume number for [10]? am assuming it is a journal article** The covariance matrix is used in the statistical regularization method as well as in calculation of the statistical extrapolated temperature profile as the most suitable first guess.

II. Problem Formulation

A possibility of applying a theory to real media (atmosphere, soils), as it has been already mentioned in [4], very much depends on the condition of homogeneity for the medium parameters a^2 and γ. There definitely exist homogeneous soils. As for the atmosphere, the eddy diffusivity coefficient largely varies with altitude and time. Nevertheless, the research here is much easier owing to availability of meteorological data, so it is possible to verify applicability of a theory on the basis of comparison with the empirical statistics.

It should be mentioned from the very beginning that the exponential autocovariance function of surface temperature

$$B_{\mathrm{T_0T_0}}(\tau) = \sigma^2 \exp(-\tau/\tau_0) \tag{1}$$

where there is only one time parameter; τ_0 (correlation time) is in good agreement with that determined from meteorological data. Covariation function (1) corresponds to the structure function

$$D_{\mathrm{T_0T_0}}(\tau) = D_\infty(1 - \exp(-\tau/\tau_0)). \tag{2}$$

In Fig. 1, the structure function of deviations of the surface temperature from its mean values (to eliminate the seasonal trend) is presented. The statistical ensemble of the near-surface temperature measurements in the continental conditions (Russia, Nizhny Novgorod) for 70 years of observations with one-day interval has been used. The estimation of the statistical error is 0.8 K^2. The minimum rms deviation of (2) from the empirical

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The author is with the Department of Semiconductor Physics, Institute for Physics of Microstructures, Novgorod 603600, Russia.
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structure function (see Fig. 1) amounts 0.75 K^2 at $\tau_0 = 3.0$ days, $D_\infty = 55.85$ K^2, so it is within the statistical estimation error. Hence, the autocovariance function (1) should be used with the value $\sigma\sqrt{D_\omega/2} = 5.3$ K. So, it was proved possible to use the corresponding formulas [5] in the following analysis. It is a remarkable result because such a covariance function is inherent in random processes which are generated by the Poisson process, so the atmosphere weather temperature variability could be considered as the process of this kind. It means that the value of τ_0 determines both the mean time of the temperature weather stability and its rms variances relative to this mean value.

For the exponential surface temperature covariance function (1) in [5] three basic covariance functions have been obtained: the interlevel temperature covariance function $B_{\mathrm{T_2T_1}}(z_2, z_1, \tau)$, the interwavelength radio brightness covariance function $B_{\mathrm{T_{B_1}T_{B_2}}}(\lambda_1, \lambda_2, \tau)$, and the cross-covariance function $B_{\mathrm{T_BT}}(\tau)$ for the radio brightness at wavelength λ and the temperature at depth level z, as shown in (3)–(5) at the bottom of the page, where $r_z = \sqrt{\Gamma_z/\tau_0}$, $r = \sqrt{\Gamma/\tau_0}$, $r_\tau = \sqrt{\tau/\tau_0}$ (dimensionless parameters), $\Gamma = 1/(\gamma \mathrm{a})^2$ is a time scale of the skin-depth heating (the skin-depth is $d = 1/\gamma$), and $\Gamma_z = z^2/a^2$ is the time scale of the heating of the layer with the depth z.

The above expressions determine the values of the rms variances of temperature and radio brightness $\sigma^2_{\mathrm{T}}(z) = B_{\mathrm{T_1T_2}}(z, z, 0)$, $\sigma^2_{TB}(\lambda) = B_{\mathrm{T_{B_1}T_{B_2}}}(\lambda, \lambda, 0)$, of the autocovariance functions $B_{\mathrm{TT}}(z, \tau) = B_{\mathrm{T_1T_2}}(z, z, \tau)$, $B_{\mathrm{T_BT_B}}(\lambda, \tau) = B_{\mathrm{T_{B_1}T_{B_2}}}(\lambda, \lambda, \tau)$, and of the corresponding correlation functions of temperature and radio brightness $\mathrm{R_{T_1T_2}}(z_1, z_2, t) = B_{\mathrm{T_1T_2}}(z_1, z_2, \tau)/(\sigma_{\mathrm{T}}(z_1)\sigma_{\mathrm{T}}(z_2))$, $\mathrm{R_{T_{B_1}T_{B_2}}}(\lambda_1, \lambda_2, \tau) = B_{\mathrm{T_{B_1}T_{B_2}}}(\lambda_1, \lambda_2, \tau)/(\sigma_{T_B}(\lambda_1)\sigma_{T_B}(\lambda_2))$, $\mathrm{R_{T_BT}}(\tau) = B_{\mathrm{T_RT}}(\tau)/(\sigma_{T_B}(\lambda)\sigma_{\mathrm{T}}(z))$. If thermal emission is received from the direction at the elevation angle θ, then in all of the above expressions the substitution $\gamma \to \gamma/\sin\theta$ should be made.

From (3)–(5), it follows that the respective autocovariance functions should depend on two of the dimensionless parameters, and the rms variances should depend only on one of them. For the exponential covariance function (1), some statistical parameters can be expressed in the explicit form. In particular,

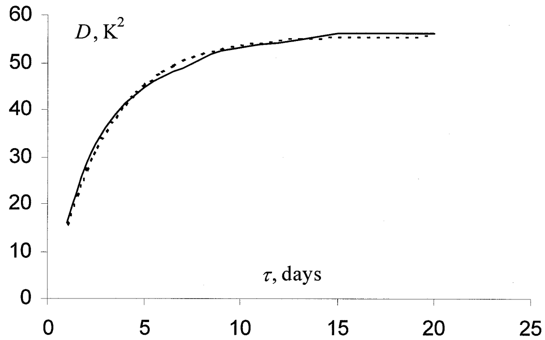

Fig. 1. Time structure function of surface air temperature obtained (solid line) by the 70-year meteorological statistics and (dashed line) its approximation by expression (2).

we have (6)–(8) (shown at the bottom of the page) where ${}_1F_1$ is the singular hypergeometric function, $\alpha = \sqrt{\tau_0/\Gamma} = 1/r$, $\Lambda = a\sqrt{\tau_0}$, and T_0 is the surface temperature. The parameter Λ defines the depth scale of random temperature variations penetration into medium.

III. Application for Atmosphere

For the exponential covariance function (1) a numerical simulation has been carried out in [5]. The theory and the empirical parameters were compared using the data provided by a routine meteorological sonde service over three months (every day measurements at the same diurnal time). Temperature was measured at 70 height levels from the surface up to 30-km height with an accuracy of 0.1 K. Two datasets have been in use: the continental data (Russia, Nizhny Novgorod, winter conditions) and the tropical ocean data (tropical Pacific). Thus it was possible to calculate the correlation functions only at the values of the time shift τ with a one-day step. It made possible to ignore the diurnal trend of mean values.

The radio brightness was calculated from the sonde data (taking into account the height dependence of the absorption coefficient γ) in the frequency range 54–60 GHz (in the atmosphere oxygen absorption band) in the zenith direction. In this range the skin-depth of the radio brightness formation changes from 0.25 km at 60 GHz up to 1.8 km at 54 GHz, and the absorption coefficient is nearly height-independent. Thus, it was

$$B_{T_2T_1}(r_{z_2}, r_{z_1}, r_\tau) = \frac{8\sigma^2}{\pi} \int_0^\infty \exp\left(-\frac{r_{z_1}+r_{z_2}}{2}\,\omega\right) \cos\left(\frac{r_\tau^2}{2}\,\omega^2 - \frac{r_{z_1}-r_{z_2}}{2}\,\omega\right) \frac{d\omega}{\omega^4+4}, \tag{3}$$

$$B_{T_{B_1}T_{B_2}}(r_1, r_2, r_\tau) = \frac{32\sigma^2}{\pi} \int_0^\infty \frac{\left[\frac{r_r r_2}{2}\,\omega^2 + \frac{r_1+r_2}{2}\,\omega + 1\right]\cos\left(\frac{r_\tau^2}{2}\,\omega^2\right) + \frac{r_2-r_1}{2}\,\omega \sin\left(\frac{r_\tau^2}{2}\,\omega^2\right)}{(r_1^2\omega^2+2r_1\omega+2)(r_2^2\omega^2+2r_2\omega+2)} \frac{d\omega}{\omega^4+4}, \tag{4}$$

$$B_{T_BT}(r, r_z, r_\tau) = \frac{16\sigma^2}{\pi} \int_0^\infty \exp\left(-\frac{r_z}{2}\,\omega\right) \frac{\cos\frac{r_\tau^2\omega^2 - r_z\omega}{2} - \frac{1}{2}\,r\omega\left[\sin\frac{r_\tau^2\omega^2-r_z\omega}{2} - \cos\frac{r_\tau^2\omega^2-r_z\omega}{2}\right]}{r^2\omega^2+2r\omega+2} \frac{d\omega}{\omega^4+4} \tag{5}$$

possible to use the surface value of the absorption coefficient for the calculation in (3)–(5). The thermal diffusion coefficient a^2 (the eddy thermal diffusivity is mainly responsible for its value) was, therefore, the only free parameter in the theory and its effective value (which physically is some weighted mean over height) could be determined by using any of the expressions (3)–(5) to achieve the minimum deviation from the corresponding parameters calculated using a meteorological dataset.

For this purpose, the correlation function between temperature and its surface value at a zero time shift was chosen because in the temperature and radio brightness variances (that could also be used in this end) the contribution of unaccounted-for components of the temperature variability should be more considerable. These components are convection, advection, IR-emission and latent heat sources. One may expect the effect on the chosen interlevel correlation function to be similar to some of this components, in particular, to convection which, like the eddy diffusion, smoothes the temperature overfalls. The influence of convection, at least partially, should be accounted for in effective value of a^2. At nonzero time shifts the unaccounted-for atmosphere variability should diminish the empirical correlation functions as compared to their theoretical values. The results for the continental and tropical datasets turned out similar, so only the continental case is presented below

Fig. 2 shows the empirical and theoretical [from (3)] correlation function $R_{\mathrm{T_0 T}}$ between the temperature and its surface value versus height for three different values of time shift $\tau = 0$, ± 1 at the best fit (at $\tau = 0$) value of the effective thermal diffusivity $a^2 = 11.6$ m^2/s, which may be considered as a reliable value. At $\tau = 0$ there is a good agreement with the theory up to the height of about 1.5 km. At higher levels, the contribution of the unaccounted-for atmosphere variability components increases, as easily seen from Fig. 3, where the relative rms temperature variances are shown. The theoretical and empirical variances are in a agreement up the height of about 1 km. The correlation function height dependencies $R_{\mathrm{T_0 T}}$ at $\tau = \pm 1$ day agree qualitatively with the theory. One can see that the maximum of the empirical correlation function at $\tau = 0$ is located at the same height level as the maximum of the theoretical correlation function. Besides, at the time shift $\tau = 1$ day, there is a height where the empirical correlation function exceeds its values for $\tau = 0$. One can see that the effect of a time shift in the correlation maximum, which has been predicted in [5], is discovered in real meteorological statistics. From the physical point of view, it happens because the temperature variations transfer from the surface into medium not instantly but by means of thermal conductivity. This qualitative agreement between the theory and the experiment is the main result of the paper.

The main difference between the empirical and theoretical functions at $\tau = \pm 1$ is that the former decrease due to the influence of unaccounted-for variability factors. So, another important result is that the theory permits to determine a relative contribution of the thermal conductivity in the temperature and radio brightness variances and, thus, the contribution of other factors. The height where this contribution in temperature variances becomes essential could be considered physically as the upper bound of the atmosphere boundary layer where the surface influence is predominated. From results shown in Fig. 3, this boundary height is somewhere between 500 and 1000 m (depending on the chose of the numerical criterion). It is possible to compare our results with another known definition of the boundary layer depth as the height of diurnal temperature wave extinction $h_b = a\sqrt{T_d/\pi} = 565$ m (T_d is diurnal period), using our value of the best fit turbulent diffusivity coefficient. So, these definitions lead to similar results.

In Figs. 4 and 5, the empirical and theoretical [from (5)] correlation functions $R_{\mathrm{T_R T}}$ between radio brightness and temperature at $\tau = \pm 1$ day for the frequencies 60 GHz (in the center of the oxygen absorption band) and 54 GHz (on the slope of the band) are shown. For the 60-GHz fequency (Fig. 4), these functions are similar to those for correlation of the temperature with its surface value (see Fig. 2), but the cross-correlation func-

$$\sigma_{T_B}^2 = \sigma^2 \left(\frac{4\alpha^2}{\pi} \frac{\ln \alpha}{\alpha^4 - 1} + \frac{\alpha^2(\alpha - 1)}{(\alpha^2 + 1)(\alpha + 1)} \right) \tag{6}$$

$$\begin{aligned} B_{T_B T_0}(\tau) =& \sigma^2 \frac{\alpha}{1+\alpha} \exp\left(-\left|\frac{\tau}{\tau_0}\right|\right) = \sigma^2 \frac{\alpha}{1+\alpha} e^{-r_\tau}, \qquad \tau \geq 0 \\ =& \sigma^2 \Bigg\{ \exp\left(-\frac{\tau}{\tau_0}\right) + \frac{1}{\tau_0} \exp\left(-\frac{\tau}{\tau_0}\right) \frac{1}{\left[(\gamma a)^2 + \frac{1}{\tau_0}\right]} \left[\gamma a \sqrt{\tau}\, {}_1F_1\left(\frac{1}{2}, \frac{3}{2}, \frac{\tau}{\tau_0}\right) \right. \\ & \left. + \exp\left(-\left[(\gamma a)^2 + \frac{1}{\tau_0}\right]\tau\right) erfc\left(\gamma a \sqrt{\tau}\right) - 1 \right] - \frac{1}{\tau_0} \exp\left(\frac{\tau}{\tau_0}\right) \frac{1}{\left[(\gamma a)^2 - \frac{1}{\tau_0}\right]} \left[\gamma a \sqrt{\tau_0}\, erfc\left(\frac{\tau}{\tau_0}\right) \right. \\ & \left. - \exp\left(\left[(\gamma a)^2 - \frac{1}{\tau_0}\right]\tau\right) erfc\left(\gamma a \sqrt{\tau}\right) \right] \Bigg\}, \qquad \tau < 0 \end{aligned} \tag{7}$$

$$B_{TT_0}(z, \tau) = \sigma^2 \exp\left(-\left|\frac{z}{\Lambda}\right| + \frac{\tau}{\tau_0}\right) = \sigma^2 e^{-(r_z + r_\tau)}, \qquad \tau \geq 0 \tag{8}$$

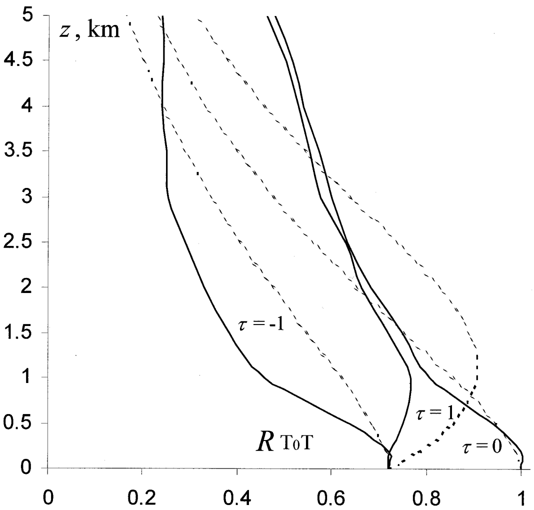

Fig. 2. Correlation function $R_{\mathrm{T_0T}}$ between air temperature at height level z and its surface value for time shifts $\tau = 0, \pm 1$ day. (Solid line) Theoretical functions. (Dashed line) Empirical functions.

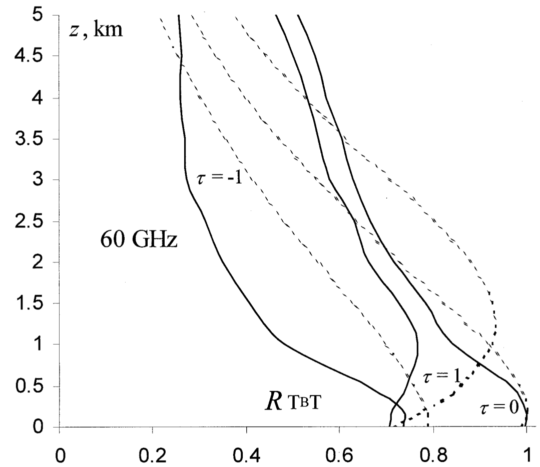

Fig. 4. Correlation function $R_{\mathrm{T_BT}}$ between the temperature at height level z and the radio brightness at the frequency 60 GHz (zenith direction) at time shifts $\tau = 0, \pm 1$ day. (Solid line) Theoretical functions. (Dashed) Empirical functions.

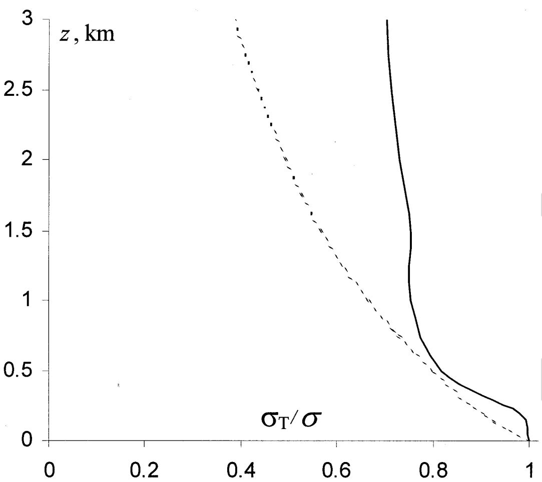

Fig. 3. Relation of rms variances of air temperature to rms variances of the surface temperature. (Solid line) Theoretical variances. (Dashed) Empirical variances.

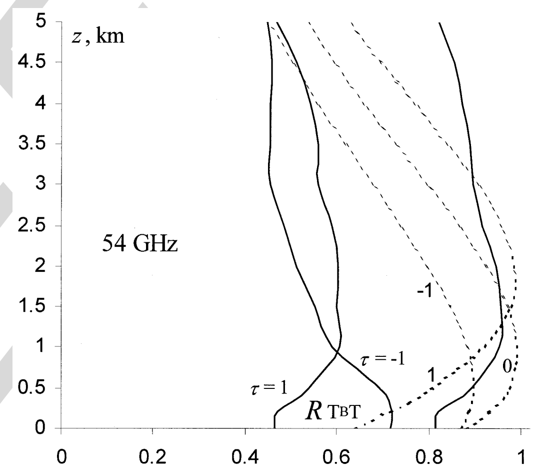

Fig. 5. Same as in Fig. 8, but for the frequency 54 GHz. **au: Fig. 8 is missing?**

tions for $\tau = \pm 1$ differ from each other at $z = 0$, then become equal at some height level above which their difference changes the sign. This effect is qualitatively correctly described by the theory. At 54 GHz, this difference is enhanced (see Fig. 5) as well as the height of the maximum at $\tau = 0$ because the emission at this frequency is formed in a thicker layer (1.8 km) than at 60 GHz (0.25 km), and it is more sensitive to temperature variances at higher levels.

And, finally, in Fig. 6 one can see the empirical and theoretical interfrequency correlation functions $R_{\mathrm{T_BT_B}}$ between radio brightness at 60 GHz and the brightness temperatures in the frequency range 54–60 GHz at $\tau = 0$ as well as the relative radio brightness variances $\sigma_{\mathrm{T_B}}/\sigma$ in the same frequency range. One can see that the theory is in a good agreement with the empirical correlation functions for the frequencies 56–60 GHz where it is about unity. There is a very good agreement between the theoretical and empirical radio brightness variances. Some excess in the value of the empirical variances should also be related to the unaccounted-for atmosphere variability factors, but low sensitivity of the radio brightness variances to these factors could be of use in determining the effective value of a^2 on from the radiometric measurements by a simple formula (6).

At time shifts $\tau = \pm\, 2$ days, the results are still in qualitative correspondence with the theory, but the influence of the unaccounted-for variability factors is greater.

These results show a possibility to use the theory [5] in radiometer methods of temperature profile retrieval by measurements of thermal radio emission in the oxygen absorption band [6]–[10]. It is an ill-posed problem, and one of the most effective methods of its solution is the statistical regularization method [6]–[8], which uses the temperature covariance matrix. The retrieval method based on the Tikhonov's theory [9], [10] may also involve a statistical extrapolated temperature profile as the most suitable first guess (the accuracy of the ill-posed problems solution depends strongly on the first guess quality). If one has a statistical ensemble of atmosphere sounding, it is convenient to use empirical statistics. But there are large areas on earth where there is no sonde statistics. Our approach permits to determine the value of the effective diffusion coefficient by ground-based

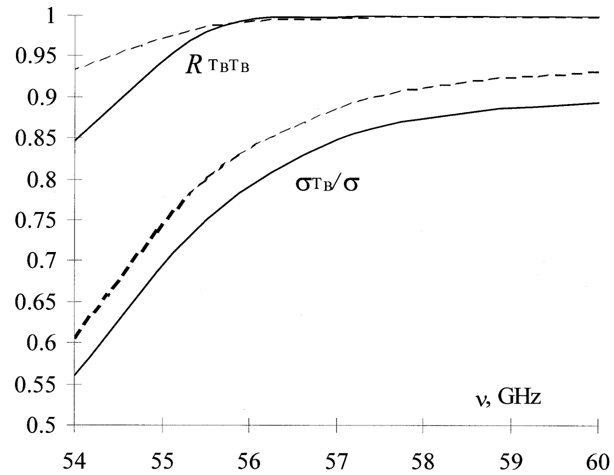

Fig. 6. Correlation function $R_{\mathrm{T_B T_B}}$ between the radio brightness at the frequency 60 GHz (zenith direction) and the radio brightnesses at frequencies in the range 54–60 GHz for zero time shift ($\tau = 0$) and relation of rms radio brightness variances in the same range to rms variances of the surface temperature. (Solid line) Theoretical functions. (Dashed line) Empirical functions.

radio brightness rms variations and to use this value for calculating the correlation matrix of temperature. This matrix is in good agreement with the empirical matrix at zero time shift. So, one can use this theoretical matrix in the statistical regularization method and for the calculation of the first guess in the Tikhonov's method.

IV. Generalization of the Theory for Spatial Atmosphere Inhomogeneities

It is possible to use the analogy between the thermal conductivity equation and the two-dimensional (2-D) diffusion equation in the stationary case, which can be written as

$$\frac{\partial T}{\partial x} = \frac{k}{\rho V_x} \frac{\partial^2 T}{dz^2} \tag{9}$$

where the x direction is chosen in the horizontal plane in the direction of the wind speed $V_x = \text{const}$. The diffusivity length $d = k/\rho V_x$ plays the same role as the thermal diffusion coefficient a^2 in the thermal conductivity equation. If the surface temperature dependence $T_0(x)$ is given, the solution of (9) is expressed as

$$T(z, x) = \int_{-\infty}^{x} T_0(x') \frac{z}{\sqrt{4\pi d (x - x')^3}} \cdot \exp\left(-\frac{z^2}{4d(x - x')}\right) dx'. \tag{10}$$

Using (10) and the emission transfer equation, it is easy to obtain the formula for the radio brightness of inhomogeneous atmosphere and its inversion in the same way as has been done in [2] on the basis of simultaneous solution of thermal conductivity and emission transfer equations. Then, it is also possible to develop the stochastic theory of random spatial inhomogeneities using the complete analogy with the results of [3]–[5]. For example, in the case of the exponential spatial autocovariance function of surface temperature

$$B_{T_0 T_0}(\Delta x) = \sigma^2 \exp\left(-\frac{\Delta x}{r_0}\right) \tag{11}$$

where r_0 is the spatial correlation length in the x direction, the correlation function between the temperature at any given height level h and the surface temperature is expressed as

$$B_{TT_0}(\tau) = \sigma^2 \exp\left(-\left(\left|\frac{z}{L_x}\right| - \frac{\Delta x}{r_0}\right)\right) = \sigma^2 e^{-(r_z + r_x)}, \quad \tau \geq 0 \tag{12}$$

where the geometric mean $L_x = \sqrt{dr_0}$ is the length of the vertical correlation of random temperature inhomogeneities. It is an interesting result ensuing from this theory. One can see that the expression for the spatial covariance function (12) is similar to the expression for the time covariance function (8) from which it has been obtained. The same limitations as for the theory developed in [2]–[5] are also valid for this generalized theory. The conception of turbulent diffusion is used in the simplest form of well-known semiempirical theory (e.g., see [11]), where the turbulent diffusion coefficient is assumed constant. But it made possible obtaining of an exact analytical solution of the problem. More complicated forms of eddy diffusion equations [11] can be used only in a numerical analysis. The applicability of this theory can also be understood by comparison of the results with sonde statistics. It is clear that this theory describes situations when there is a dominating horizontal wind component with the mean value large enough for wind variations to be neglected. To reduce the influence of the height dependence of diffusivity and wind speed, one may assume some height level to be the surface level, so that at higher altitudes these parameters could be considered constants with stronger reason.

V. Conclusion

The results of application the earlier developed stochastic theory of temperature distribution and thermal radio emission of medium to real atmosphere are presented. For the exponential covariance function of the surface temperature (such covariance functions are inherent in random processes generated by the Poisson process) the validity of which was proved for real atmosphere, the comparison with the corresponding empirical parameters has been carried out using meteorological datasets. The predicted effect of the correlation maxima shift has been observed.

The results establish restrictions and applicability of the theory. It proved possible to discern the thermal conductivity contribution in the temperature and radio brightness variances. The theory provides good qualitative interpretation of the frequency and depth dependencies of statistical parameters; for some of these parameters, in particular, for temperature and radio brightness (in the oxygen absorption band) variances, and for the correlation functions at $\tau = 0$ in the atmosphere boundary layer (up to 1–1.5 km) there is a good quantitative agreement.

These results make it possible to use the theory [5] in radiometer methods of temperature profile retrieval by measurements of thermal radio emission without empirical statistics.

The theory based on simultaneous solution of the thermal conductivity and the emission transfer equations [2]–[4] has been generalized for the spatial (horizontal) atmosphere inhomogeneities, using the analogy between the thermal conductivity equation and the 2-D diffusion equation in the stationary problem. In particular, this generalization defines the vertical correlation length of atmosphere inhomogeneities as the geometric mean from diffusion the length and horizontal correlation length.

Further research should be focused on smaller spatial and time scales including diurnal dynamics. In the theory, study of an inhomogeneous medium is most important and it is possible through the numerical analysis using the general approach described in [4].

REFERENCES

[1] K. P. Gaikovich, A. N. Reznik, and R. V. Troitskii, "Microwave subsurface profile thermometry," in *Dig. IGARSS'91*. Espoo, Finland: Univ. Technol., 1991, vol. 3, pp. 1195–1198.

[2] K. P. Gaikovich, "Simultaneous solution of emission transfer and thermal conductivity equations in the problems of atmosphere and subsurface radiothermometry," *IEEE Trans. Geosci. Remote Sensing*, vol. 32, pp. 885–889, July 1994.

[3] ——, "Stochastic approach to results of simultaneous solution of emission transfer and thermal conductivity equations," in *Dig. IGARSS'95*, vol. 1, Florence, Italy, 1995, pp. 38–40.

[4] ——, "Stochastic theory of temperature distribution and thermal emission of half-space with random time-dependent surface temperature," *IEEE Trans. Geosci. Remote Sensing*, vol. 34, pp. 582–587, Mar. 1996.

[5] ——, "Spectral approach to correlation theory of thermal regime and thermal emission of the medium with random boundary conditions," *IEEE Trans. Geosci. Remote Sensing*, vol. 37, pp. 3–7, Jan. 1999.

[6] K. P. Gaikovich, N. N. Markina, A. P. Naumov, V. M. Plechkov, and M. I. Sumin, "Investigation of remote sensing possibilities of the low atmosphere in the microwave range and some aspects of statistical data use," *Int. J. Remote Sens.*, vol. 4, pp. 419–431, 1983.

[7] E. R. Westwater, W. B. Sweezy, L. M. McMillin, and C. Dean, "Determination of atmosphere temperature profiles from a statistical combination of ground-based profiler and operational NOAA 6/7 satellite retrievals," *J. Clim. Appl. Meteorol.*, vol. 23, pp. 689–703, 1984.

[8] J. Askne, G. Skoog, and E. Winberg, "Test of a ground-based microwave radiometer for atmospheric temperature profiling with meteorological applications," *Int. J. Remote Sens.*, vol. 6, pp. 1241–1256, 1985.

[9] A. V. Troitsky, K. P. Gaikovich, V. D. Gromov, E. N. Kadygrov, and A. S. Kosov, "Thermal sounding of the atmosphere boundary layer in the oxygen band center at 60 GHz," *IEEE Trans. Geosci. Remote Sensing*, vol. 31, pp. 116–120, Jan. 1993.

[10] E. R. Wetwater, A. S. Viazankin, K. P. Gaikovich, E. N. Kadygrov, and D. Y. Moiseev, "Radiometric monitoring of the temperature of the planetary boundary layer of the atmosphere" (in Russian), *Russian Meteorol. Hydrol. Meteorol. Hydrol.*, pp. 43–53, Mar. 1999. English Translation by E. R. Westwater.

[11] F. N. Frankel and P. A. Sheppard, Eds., *Atmosphere Diffusion and Air Pollution*. New York: Academic, 1959.

Konstantin P. Gaikovich was born on May 30, 1953, in Nizhny Novgorod, Russia. He graduated from Nizhny Novgorod State University, Nizhny Novgorod, in 1975. He received the Ph.D. degree and the Doctor of Science degree from the Radiophysical Research Institute, Nizhny Novgorod, in 1984 and 1994, respectively, both in physics and mathematics.

He is currently a Leading Research Associate with the Institute for Physics of Microstructures of Russian Academy of Sciences, Nizhny Novgorod. His research interests are physical inverse problems and images reconstruction, including the scanning microscopy (tunneling, near-field optical, atomic-force, and microwave), the subsurface radiometry of dielectric media (water, soils, living tissues), the noninvasive diagnostics of superconductors, and the remote sensing of the atmosphere using passive microwave and refraction measurements. He has written papers in the area of the planet radio astronomy and the gases spectroscopy. He has published more than 200 journal articles and conference papers.