THE DEVELOPMENT OF A TECHNIQUE FOR ESTIMATING THE ATMOSPHERIC TRANSMISSION

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A practical technique for estimating atmospheric transmission in the spectral regions 3–5 μm *and* 8–12 μm *is studied. Standard meteorological observations data are the input parameters of this technique. The errors in the diagnostics of the atmospheric transmission due to the use of the standard meteorological devices are given.*

Many modern opto-electronic devices (OED) operate through the atmospheric communication channel. Thus, the effect of the medium, in particular, its transmission, should be taken into account at the design stage in order to fulfill such most important requirements imposed on the OED as the achievement of a specified range of action. The proposed engineering technique for the diagnostics of the atmospheric transmission in the spectral regions 3–5 μm and 8–12 μm enables the designer to perform such estimates for a wide class of OED in the middle and far-IR ranges.[1,2]

The area and conditions of application of the above technique are:

1) the ground layer of the atmosphere (horizontal viewing paths),

2) the Atlantic-continental European climatic zone of the USSR (according to Alisov's classification[3]),

3) the weather conditions are characterized by an air temperature $T > -12°C$, in the case of absence of hydrometeors and lithometeors.[4]

The broadband atmospheric transmission function (ATF), i.e., integral characteristic, is selected as the transmission characteristic in the spectral region $\Delta\lambda = \lambda_2 - \lambda_1$. In the region $\Delta\lambda$ the ATF is given by the relation

$$\tau_{\Delta\lambda} \simeq \tau^{m}_{\Delta\lambda} \cdot \tau^{a}_{\Delta\lambda}, \qquad (1)$$

where $\tau^{m}_{\Delta\lambda}$ is the atmospheric transmission function associated with absorption losses due to the atmospheric gases including absorption by the water vapor continuum and $\tau^{a}_{\Delta\lambda}$ is the ATF due to aerosol extinction losses.

The value $\tau^{m}_{\Delta\lambda}$ is determined by integrating the product of the transmission functions of the main atmospheric gases over the wavelength spectrum. As applied to the problem of calculating the signal-to-noise ratio at the output of the OED (see, e.g., Ref. 1) the indicated product of ATF's is additionally normalized as follows:

$$\tau^{m}_{\Delta\lambda} = \frac{\int\limits_{\lambda_1}^{\lambda_2} \frac{\partial B(\lambda,\ T)}{\partial T} \cdot S(\lambda) \cdot \prod\limits_{i=1}^{N} \tau_{\lambda}^{m_i} \cdot \lambda d\lambda}{\int\limits_{\lambda_1}^{\lambda_2} \frac{\partial B(\lambda,\ T)}{\partial T} \cdot S(\lambda) \cdot \lambda d\lambda}, \qquad (2)$$

in order to take the spectral selectivity of the radiation from the observed object and the spectral characteristic of the photodetector into account. Here $\tau_{\lambda}^{m_i}$ is the spectral transmission of the *i*th gas: for the region $\lambda \in$ 3–5 μm $i = 7$ (H_2O, CO_2, CH_4, CO, O_3, N_2O, and the water vapor continuum) and for $\lambda \in$ 8–12 μm $i = 6$ (H_2O, CO_2, CH_4, O_3, N_2O, and the water vapor continuum), $S(\lambda)$ is the instrument function, which is equal to unity in the region $\lambda \in \lambda_1 - \lambda_2$ and is equal to zero outside of this region, $B(\lambda,\ T)$ is the spectral density of the emissivity of a blackbody having the radiative temperature T_0 ($W \cdot cm^2 \cdot \mu m^{-1}$), which is equal to 238 K in the calculations.

The presence of the radiation wavelength λ in the integrand of Eq. (2) follows from the definition of the detecting power of the photodetector, whose theoretical characteristics are given in Ref. 1. In the case of a fixed optical path (R = const) the spectral transmission of water vapor $\tau_{\lambda}^{H_2O}$ and the water vapor continuum τ_{λ}^{c} can be considered to be functions of the absolute humidity, and $\tau_{\lambda}^{CO_2}$, $\tau_{\lambda}^{O_3}$, $\tau_{1}^{CH_4}$, τ_{λ}^{CO}, and $\tau_{\lambda}^{N_2O}$ can be considered to be functions of the volume concentrations of the corresponding gases, which are assumed to be constant under conditions of the application of this technique.

Therefore, the transmission coefficient (molecular component) $\tau^{m}_{\Delta\lambda}$ under the condition R = const may be represented as a one-parameter function with the absolute humidity a (g/m^3) as its argument.

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The calculation of the ATF (3–5 μm and 8–12 μm spectral region) for a wide range of variation in the absolute humidity a (from 0 to 25 g/m^3) and for a rather detailed set of paths from 0.5 to 10 km were performed. At that the spectral transmissions of atmospheric gases (H_2O, CO_2, O_3, CH_4, CO and N_2O) were calculated using the technique presented in Ref. 5. The estimates of the transmission of the water vapor continuum in the region $\lambda \in$ 3–5 μm were also made according to data of Ref. 5, and in the region $\lambda \in$ 8–12 μm – according to the empirical model in Ref. 6.

Analytic dependences of the ATF on the absolute humidity and the optical path length were constructed on the basis of generalizations of these results:

$$\tau^{m}_{3-5} = \exp -\left[0.145R^{0.529}\cdot\ln(a/217) + 1.19R^{0.465}\right], \tag{3}$$

$$\tau^{m}_{8-12} = \exp\left[\frac{0.011\ln R - 0.0156a - 0.049}{R^{-0.881}}\right]. \tag{4}$$

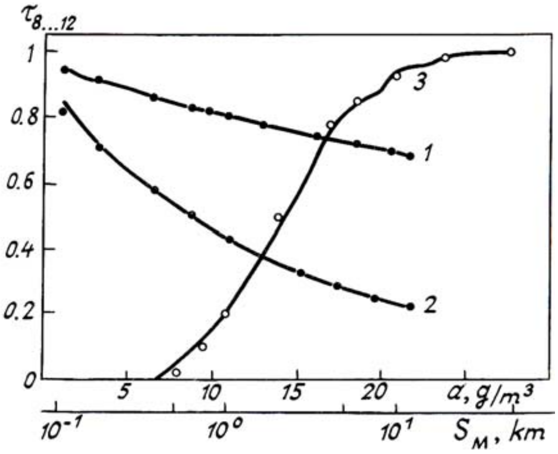

FIG. 1. Models of the broadband atmospheric transmission function ($\lambda \in$ 8–12 μm): molecular component at R = 1 km (curve 1), molecular component at R = 5 km (curve 2), aerosol component at R = 1 km (curve 3), calculations according to formula (5) (filled circles), the calculations according to formula (7) (empty circles).

The retrieval estimates of the ATF ($\lambda \in$ 8–12 μm) are shown in Fig. 1 by filled circles vs the corresponding dependences (curves 1 and 2) plotted on the basis of the initial data. Figure 1 shows that the analytic dependence is found to be in good agreement with the initial data.

The aerosol component of the extinction is the most variable component of the ATF. It is a function of many geophysical factors, and, in addition, it exhibits both diurnal and seasonal variability of its spectral characteristics, depending also on the geographical factor.[4,7]

The aerosol extinction losses can be accounted for by an empirical dependence of the form

$$\tau^{a}_{\Delta\lambda} = \exp\left[-\frac{3.91}{S_m}\cdot\mu_{\Delta\lambda}\cdot R\right], \tag{5}$$

where S_m is the meteorological visibility range (MVR), $\mu_{\Delta\lambda}$ is the average normalized coefficient of aerosol extinction in the region $\Delta\lambda$. The values of $\mu_{\Delta\lambda}$, determined from the gradations of MVR under the considered weather conditions, were obtained on the basis of a regional empirical model.[7] This empirical dependence $\tau^{a}_{8-12}(S_m, R = 1\text{ km})$ Is plotted in Fig. 1 (curve 3).

The value of $\mu_{\Delta\lambda}$ is assumed to be discrete in Eq. (6) and is constant within the limits of the specific gradation of MVR. Thus, the dependence $\tau^{a}_{\Delta\lambda}(S_m)$ can undergo sharp variations at the boundaries of the MVR gradations. This is a disadvantage of the models of this type. On the basis of the initial experimental data a second version of the two-parameter model $\tau^{a}_{\Delta\lambda}(S_m, R)$ not encumbered by this disadvantage was developed

$$\tau^{a}_{3-5}(S_m, R) = \exp\left[\frac{0.488\ln S_m - 2.26}{S_m}\cdot R\right], \tag{6}$$

$$\tau^{a}_{8-12}(S_m, R) = \exp\left[\frac{0.346\ln S_m - 1.665}{S_m}\cdot R\right]. \tag{7}$$

The results of the corresponding calculations according to formula (7) are denoted by empty circles in Fig. 1, corresponding to the empirical dependence $\tau^{a}_{8-12}(S_m, R = 1\text{ km})$ (curve 3). These models of the ATF agree well.

TABLE I. The relative error of the ATF ($\Delta\tau_{\Delta\lambda}$, %)

Device	S_m, km				
	1	2	3	4	5
M-71	112	35	23	16	12
PDB-3	85	32	23	16	12

It should be noted that the proposed technique for diagnostics of the atmospheric transmission in the IR range is suitable for engineering estimates. This technique can be recommended for use in the field experiments, because the input parameters to this technique are the data of standard meteorological observations. The relative errors in the ATF ($\Delta\lambda \in$ 3–5 μm and (8–12 μm) calculated by the technique under consideration for different values of the MVR and a path length R of 1 km are shown in Table I. They were calculated assumed that the MVR were recorded using standard equipment (an M-71 nephelometer or a PDB-3 base photometer (see Ref. 8)), and the air temperature and humidity characteristics were obtained using an MB-4M aspiration psychrometer MB-4M (see Ref. 9).

In conclusion, it should be noted that errors in the recording of MVR using standard meteorological equipment made up the main contribution to the error in the estimates of the atmospheric transparency.

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