MODEL DESCRIPTION OF TEMPERATURE DEPENDENCE OF THE H_2O ABSORPTION IN 8–14 μm ATMOSPHERIC WINDOW

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Temperature dependence of the water vapor absorption in the 8–14 μm *spectral range is studied on the basis of model calculations using the individual line approximation to estimate the absorption due to the* H_2O *rotation band and the average selective absorption. It is shown that at low temperatures the line wing absorption plays a major part as does the selective absorption at elevated temperatures. Thus, the inversion of the temperature dependence of the absorption in this spectral region is determined by the change in the relative role of the selective and continuum absorption.*

A knowledge of the water vapor absorption coefficient in the spectral regions corresponding to the atmospheric windows is necessary for climate models, calculations of the atmospheric heat balance, in problems of retrieving the atmospheric temperature and that of the underlying surface from satellite data on the outgoing terrestrial radiation, etc. In these cases the proper prediction of the temperature dependence of the absorption coefficient and absorption function in fairly wide temperature intervals appears to be of great importance. Nowadays the atmospheric transmittance, as a rule, is simulated on the basis of experimental data obtained primarily in fundamental papers by Burch and co–workers who revealed a strong negative temperature dependence. However, in Refs. 2 and 3 it was made clear that above 400 K the absorption coefficient tends to increase. Various temperature dependences appear when measuring the spectral absorption coefficient with a laser as a source. A review of these results is presented in Ref. 4. In Ref. 5 dealing with retrieval of the sea surface temperature from satellite measurements it is stated that the temperature dependence of the absorption coefficient at low temperatures is stronger than that predicted in Ref. 1. It is also pointed out that without a reliable knowledge of the absorption coefficient within atmospheric windows and, primarily, in the 8–12 μm range, the possibilities of using satellite measurements appear to be limited.

In the present paper the water vapor absorption in the 8–20 μm range is considered within the framework of the spectral line theory. The continuum absorption is treated as the result of absorption in the wings of rotational and vibration–rotational water vapor bands. In the case of the continuum absorption at relatively low temperatures the line shape is a sensitive function of temperature. At elevated temperatures it is the line intensity which is mainly affected. When the temperature increases, the contribution of the selective absorption also increases, which may cause the pattern of the temperature dependence to change (see Refs. 2 and 3).

This assumption is supported by model calculations of the water vapor continuum absorption using the individual line approximation for the rotational band and the average selective absorption coefficient. Although the calculations performed provide but only a qualitative description they do give a deeper insight into the physics of this phenomenon.

Thus, it is assumed that there is a single line centered at $\nu_0 = 250\ \text{cm}^{-1}$, whose intensity is equal to the integrated band intensity[6]

$$\kappa_{\text{cont}} = (Sd)\, F(\Delta\nu)\, \Phi(\Delta\nu)\, f(\nu,\nu_i)\ ,$$

$$f(\nu,\nu_i) = \frac{\nu(1-\exp(-\hbar\nu/\kappa T))}{\nu_i(1-\exp(-\hbar\nu_i/\kappa T))}\left((\nu-\nu_i)^{-1.6} + \frac{\exp(-\hbar\nu_i/\kappa T)}{(\nu+\nu_i)^{1.6}}\right).$$

The function $F(R)$ is determined by the intermolecular interaction potential of water molecules. Figure 1 shows its form at different temperatures. The function Φ is introduced to take into account the spatial dispersion present at those small intermolecular separations where highly nonresonant light absorption occurs. The form of F and Φ was discussed at length in Ref. 6.

The results of calculations of the continuum absorption coefficient at different temperatures according to the foregoing scheme are depicted in Fig. 2. Note that the pattern of the temperature dependence is consistent with that observed experimentally. The average selective absorption coefficients are also shown in this Figure. It can be seen that at low temperatures the absorption coefficient is entirely determined by the line wing absorption and at high temperatures by the selective absorption. It is evident that at intermediate temperatures a great variety of situations would be expected.

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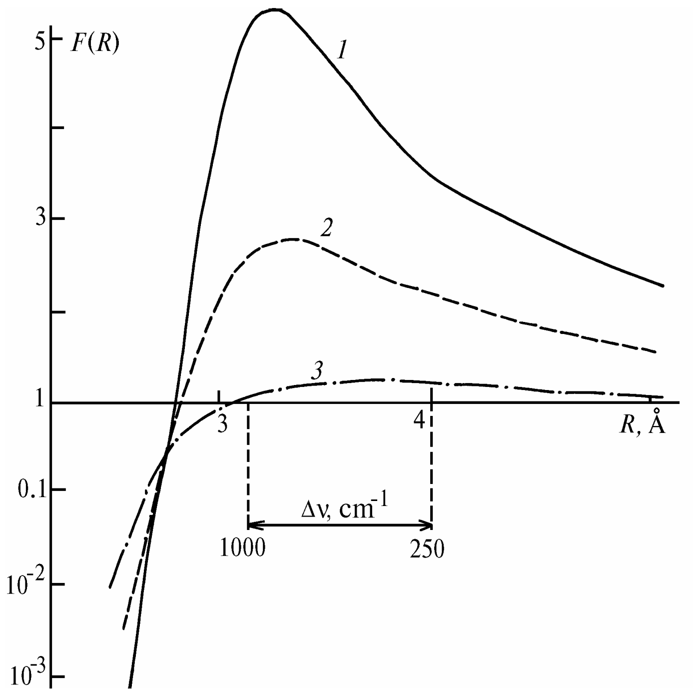

FIG. 1. Function $F(R)$ at different temperatures: 200 *(1),* 285 *(2), and* 633 K *(3). Arrows mark separations between interacting molecules corresponding to frequency detuning from* 250 *to* 100 cm^{-1}.

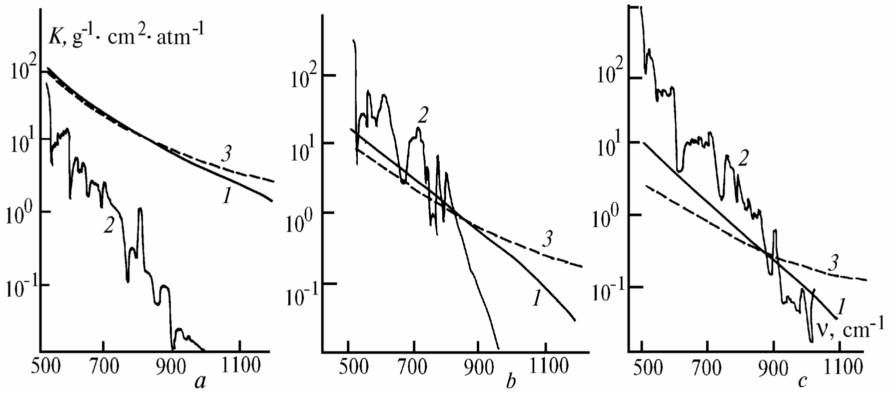

FIG. 2. Water vapor absorption coefficient at different temperatures: 300 *(a),* 500 *(b), and* 700 K *(c). Curve 1 corresponds to the model calculations of the continuum absorption, 2 – to the average selective absorption coefficients, and 3 – to calculations by the empirical formula suggested in Ref. 1.*

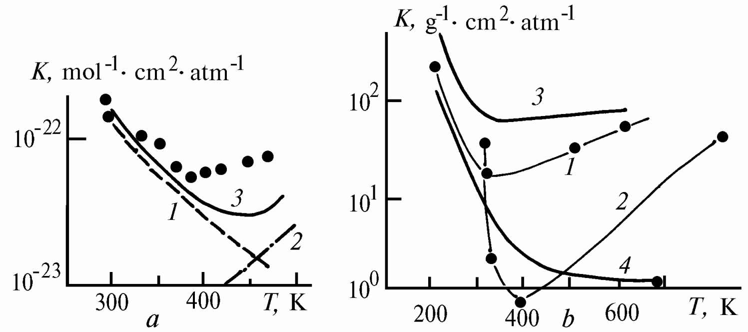

FIG. 3. Comparison of the measured temperature dependence of the water vapor absorption coefficient and the results of the model calculations at different frequencies: a) $\nu = 1203$ cm^{-1}*, 1 – calculations according to the line wing theory,*[6] *2 – the selective absorption component, and 3 – the total absorption coefficient; points mark experimental data.*[2] *b) experimental data:*[3] *1 –* $\nu = 815$ *and 2 –* $\nu = 954$ cm^{-1}*; results of model calculations: 3 –* $\nu = 655$ *and 4 –* $\nu = 925$ cm^{-1}.

The measured temperature dependence of the absorption coefficient and the present estimates for several frequencies are compared in Fig. 3. This comparison supports the main conclusion of the paper that the change in the temperature dependence of the absorption coefficient in the 8–12 μm atmospheric window is brought about by the change in the relative role of the selective and continuum absorption. Note that a similar situation is observed in the case of the CO_2 absorption coefficient (see Ref. 7).

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