ON THE INFLUENCE OF OPTICAL THICKNESS DUE TO SCATTERING AND ABSORPTION OF LIGHT BY CLOUD PARTICLES ON THE CONTOUR OF THE TELLURIC LINE OF OXYGEN

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The contours of the oxygen telluric line in the cloudy sky spectrum are calculated. The intensity of radiation has been calculated by a modified method of spherical harmonics. The influence of light absorption by cloud particles on the line depth has been studied assuming different optical thickness of clouds due to light scattering.

Use of CCD matrices to detect weak light fluxes enables one to essentially improve the spectral resolution of instrumentation that is being used in spectroscopy of day-time skies. This, in turn, provides for a possibility of determining contours of telluric lines in a reasonably long time intervals needed for signal accumulation. As a consequence, some ambiguities, existing so far, in the interpretation of observations of the sky brightness in unresolved bands may also be overcome. This, in particular, refers to non-saturated oxygen lines in the spectrum of cloudy skies. The study of these lines is important when solving some problems in climatology and atmospheric optics. Let us remind, for instance, that measurements of the out going radiation within the oxygen absorption bands has been used in space-based studies[1] to retrieve the height of the upper boundary of cloudiness.

It is natural that interpretation of the experimental data must be based on numerical solutions of the radiative transfer equations assuming different models of the atmosphere. In this paper, we discuss calculated results on the contour of oxygen line in the vicinity of 0.57 μm wavelength, in the day-time sky spectrum of scattered light, under the overcast conditions. The primary goal of this study was to consider how the optical thickness due to scattering, τ_0, and weak continuous absorption, τ_{abs}, of radiation by cloud particles influence the telluric line contour. We have solved the radiative transfer equation by a modified method of spherical harmonics.[2]

The atmosphere has been presented in this study as a set of plane layers characterized by certain optical parameters. Height profiles of aerosol extinction coefficients, $\sigma_{aer}(h)$, and of the scattering phase functions, $\mu_{aer}(h,\varphi)$, for a cloudless atmosphere have been set in accordance with the model from Ref. 3. The cloud was assumed to be at a height of 1 to 2 km and characterized by the so-called «narrow» droplet-size distribution.[4] The asymmetry coefficient of the scattering phase function of such particles, for the case of pure scattering, in the spectral region about 0.57 μm wavelength was taken to be 16.1. The albedo of the underlying surface $q = 0.12$ has been chosen as corresponding to reflection from a grass cover in summer.

The spectral behavior of the optical thickness caused by the absorption, τ, at some points of the contour of non-saturated line of oxygen has been set in the following way. The telluric line at $\lambda = 0.5694$ μm has been chosen as a sample (or an example) from the Minnaert atlas[5] that presents the results of recording the photoelectric current, when measuring the fluxes of direct solar radiation. Light absorption in the wings of this line is assumed to be negligibly small at the distances above 1 nm from the line center. In other words, we assume that $F = F_0$ (F_0 is the solar radiation flux in the regions out of the absorption line). Then, the optical thickness τ due to absorption can be defined as $\tau = \ln(F_0/F)$ at any point of the line contour. This value appeared to be equal to 0.318 at the line center. When calculating the intensity of scattered radiation, few a little bit smaller values of τ have also been used what made it possible to get an idea on how is the contour of the telluric line in the sky spectrum being formed. The height profiles of the absorption coefficients of oxygen have been calculated, at the preset τ values, in accordance with the standard model of the atmosphere.[6]

Let $I(\tau)$ denote the intensity of scattered light at the absorption line and $I(0)$ be the intensity of light out of the absorption line. Then its contour in the sky spectrum is defined by the ratio $I(\tau)/I(0)$ as a function of wavelength λ. The values of $I(\tau)$ and $I(0)$ have been sought by solving the radiative transfer equation in an inhomogeneous atmosphere. The calculated results were believed as reliable if the

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intensity values did not vary within the limits of 1% with increasing number of harmonics used, when solving the radiative transfer equation. This number exceeded 56, as a rule.

Figure 1*a* presents contours $I(\tau)/I(0)$ calculated, using the model of purely scattering cloud, for the zenith direction of observations. The zenith angle of the Sun is 53°. It is clearly seen that the depth of oxygen line increases with the increasing optical thickness of the cloud from 0 (clear skies) and up to 150. The cause of this effect is known quite well. The matter is that cloud droplets act as multipass optical cells. From the first sight, it could seem that such a deformation of the line contour can be used for determining the optical thickness of a cloud due to scattering. However, there are two factors that significantly complicate the problem. Those are the absorption of light by cloud droplets and the Raman effect.

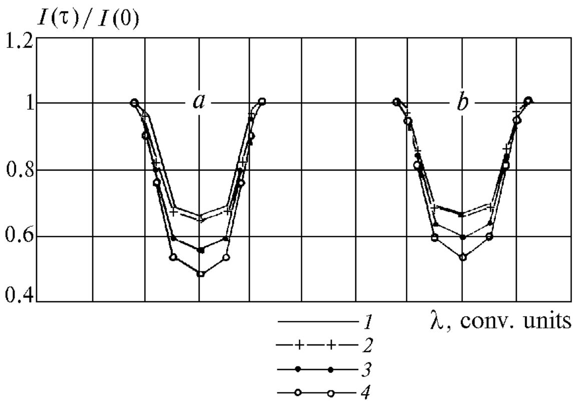

FIG. 1. Contours of the oxygen line in the cloudy sky spectrum without the absorption (a) and with the absorption (b) for optical thickness of cloud scattering: 0 *(1),* 20 *(2),* 80 *(3), and* 150 *(4).*

Let us fix all the optical parameters used in calculations of the line contour in an absorption-free cloud and add the optical thickness due to absorption of light by cloud droplets, $\tau_{abs} = 0.1$, that does not depend on wavelength within the line contour. The introduction of this optical parameter is equivalent to assignment of the probability of a photon survival $\omega = 0.995$ in a cloud with $\tau_0 = 20$ and $\omega = 0.9993$ for $\tau_0 = 150$. From the physical point of view, it is equivalent to a change of the real-valued refractive index by a complex one with a very small imaginary part what in fact has no effect upon the shape of the scattering phase function. The calculated results on the line contour in a cloud with absorption are presented in the Figure 1*b*.

As seen from the Figure, radiation absorption by cloud droplets is of certain importance in formation of the absorption line contour in the spectrum of a cloudy sky. It may be seen, for example, that the depth of the line decreases. Similar result is also obtained for the line contour in the flux of down welling diffuse radiation from the whole sky.

The second cause leading to considerable deformations of the line contour in the diffuse light from the sky is a dump of continual radiation into the line due to Raman scattering.[7,8] The latter effect has been so far studied only poorly, both in theory and experiment. Thus, it is very difficult to determine the optical depth of light scattering by clouds from observations of the telluric lines' contours.

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