ON THE CHOICE OF SPECTRAL INTERVALS IN THE PROBLEMS OF TWILIGHT SENSING OF THE ATMOSPHERE

V.E. Pavlov, L.A. Egorova

Astrophisical Institute Kaz.SSR Academy of Science, Alma-Ata.

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Based on the measured spectograms of the solar radiation in the visible and near IR dose to the horizon. We have identified spectral intervals with minimal absorption by gases. These intervals can be used for twilight sensing of atmospheric aerosols.

Recent advances in the development of methods for solving the radiative transfer equations for dispersed media with complicated geometry have provided the basis for qualitative analysis of observations of brightness and polarization of the twilight sky in studies of atmospheric aerosol properties at different altitudes. From this point of view, the Monte Carlo method[1–3] seems to be much promising. However, mathematical modeling of light scattering processing produce upward-and downward-propagating fields often requires that many optical parameters be chosen a priori, and these are very difficult to determine. Significant uncertainties appear due to uncertainty in the vertical profiles of the atmospheric gas transmission function in each specific situation. The point is that even weak absorption bands, which can scarcely be detected during the daytime by a convential Bouguer technique, can quite noticeably affect the brightness of the twilight sky as a function of solar zenith angle. Just this function is usually taken as a basis for solving the inverse problems. For this reason, one wishes to identify spectral regions where the contribution of molecular absorption to the total extinction vanishes, or is at least minimized.

In choosing spectral regions for twilight sounding of the atmosphere, one should bear in mind the following circumstances. In the first place one has to take into account that the twilight layer is narrower for shorter wavelengths[4] λ. But at the same time, localizing the emission with respect to height by reducing the observing wavelength could not be considered the only efficient way to do so, since the contribution of molecular and multiple scattering to the observed brightness of the sky then increases markedly, while the main objective of twilight sounding is to obtain information on atmospheric aerosols. It is therefore usually recognized that the use of observation wavelengths shortter than 0.45 μm is inadvisable for twilight sensing. In the second place, IR radiation with wavelengths $\lambda > 1.3$ μm is also useless for twilight sensing because of the weakness of light scattering at those wavelengths and the lack of high-sensitivity photodetectors. It is also a disadvantage of this region that the transmission windows of the atmosphere are overlapped by the far wings of absorption bands of atmospheric gases[5]. That is why in this paper we sought out spectral intervals for twilight sensing in the range from 0.45 μm to 1.3 μm, which would be unaffected by absorption bands of atmospheric gases.

Of all the beams, of light from the sun that are responsible for illuminating the twilight sky, the ray tangent to the Earth's surface is the one that undergoes the greatest attenuation. Taking advantage of this fact, we have carried out spectral measurements of the direct solar radiation intensity at different zenith angles z_0, including $z_0 = 90°$, which was made possible by the circumstances of the observation point used. Such an experimental study and analysis of the atlas of solar spectral lines[6] enabled us to detest quite weak selective absorption bands and identify the boundaries of the spectral intervals where the absorption of radiation by atmospheric gases vanishes.

The device used to measure atmospheric transmission included a double prism monochromator DMR-4 provided with repleceable PMT's for the visible and IR regions. The field of view of the device was set by the objective's focal length and the geometric dimensions of the horizontal entrance slit of the monochromator; this field of view was $32' \times 32''$. This solar intensity recorder was installed on a parallactic mount, making it possible to maintain a steady image of the solar disk on the entrance slit of the monochromator with only minor corrections. Since the dynamic range of the solar flux exceeds four orders of magnitude as the Sun travels from culmination to the horizon, provision was made to stop down the objective sis necessary. Spectral width of the entrance slit used for recording solar spectra was about 1.3×10^{-3} μm in the vicinity of $\lambda = 0.63$ μm.

Analysis of the spectrograms has shown that at moderate spectral resolution, overlapping Fraunhofer and telluric lines in the spectrograms form distinctive large-scale patterns that are well easily seen in the figures. When little or no absorption occurs, such patterns, being only 2 to 3×10^{-3} μm wide, retain their configuration at solar zenith angles down to $z_0 = 90°$. At the same, time molecular absorption, which strongly increases with increasing z_0, leads as a rule to strong distortions of these patterns. Either new structural patterns may appear, or strong deformation of those already existing at small z_0.

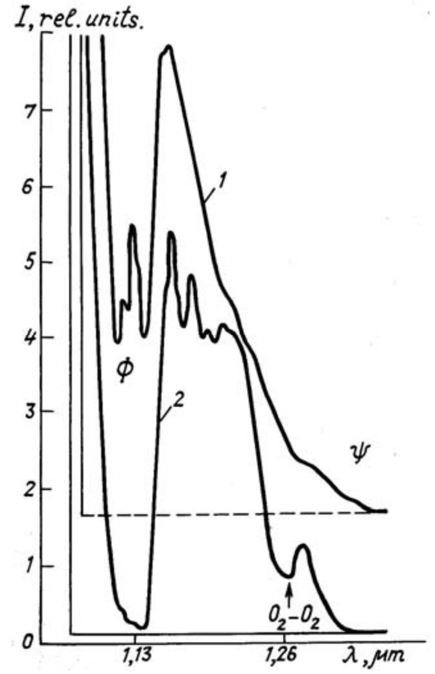

Fig. 1. Spectrograms of the solar radiation in the range 1.1 to 1.3 μm *at* z_0 *= 72.5° (curve 1) and 88° (curve 2). Dashed curve shows the zero level of signal for curve 1.*

As seen from the figure, the very smooth spectrum at $z_0 = 72.5°$ becomes strongly structured at $z_0 = 88°$ due to light absorption by the far wings of the absorption bands. Moreover, an absorption band appears in the vicinity of 1.26 μm which is usually ascribeded to the short-lived complex O_2—O_2. Figure 2 presents spectograms of the solar radiation in the range 0.46 to 0.49 μm at $z_0 = 70°$ and 89.9°.

A noticeable fall of in intensity at short wavelengths ($z_0 = 89.9°$) is due to Rayleigh scattering. The spectrograms have been superimposed using the long-wavelength wing of the Fraunhofer *A* line which, like the profile of the Fraunhofer *B* line, does not depend on z_0. One can clearly see from the figure the blurring of the large scale structures between the *A* and *B* lines caused by the absorption band of the O_2—O_2 complex^7. The band edges can be reliably identified and are shown by vertical lines.

Spectograms of the solar radiation in the near IR at $z_0 = 71°$ and 90° are presented in Fig. 3. As can be seen from this figure, the 'transmission window between the water vapor absorption bands ρστ and Φ undergoes strong deformation with increasing z_0 due to molecular absorption. It is also seen from this figure that in the vicinity of λ = 1.06 μm there appears an absorption band due to the O_2—O_2 complex^7. The ρστ and β water vapor absorption bands, as well as the *A* band of molecular oxygen, become deeper and wider. An analysis of the spectrograms in Fig. 1 and Fig. 3 shows that only in two narrow intervals at λ = 0.856 ± 0.003 and 0.776±0.004 μm, over the whole range from 0.75 to 1.3 μm, Is the contribution of molecular absorption to the total extinction negligible. These intervals are cross-hatched in the figures.

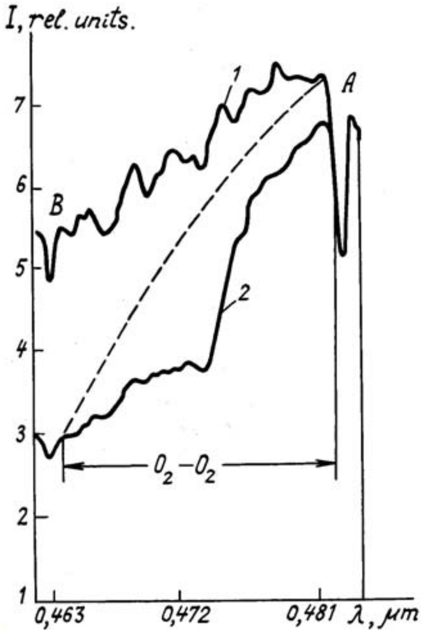

Fig. 2. Blue spectra of the Sun at z_0 *= 70° (curve 1) and 90° (curve 2). Dashed line shows the zone of absorption by* O_2*—*O_2 *complexes.*

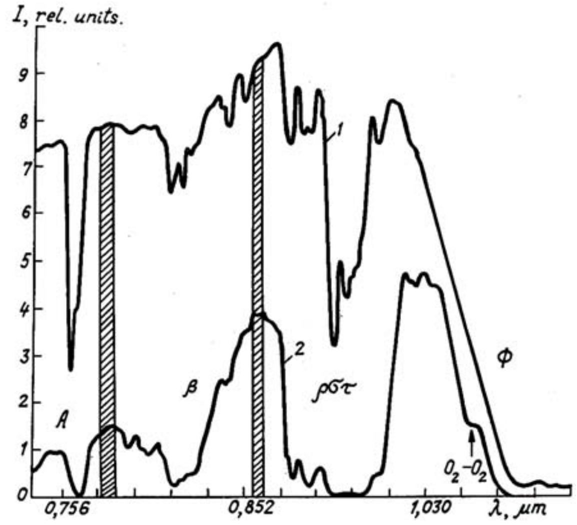

Fig. 3. Spectrograms of solar radiation in the near IR region at z_0 *= 71° (curve 1) and 90° (curve 2).*

Analogous solar spectrograms in the red are presented in Fig. 4. It is clearly seen from this figure how the absorption of radiation by water vapor distorts the H_α line and absorption by oxygen distorts the Fraunhofer spectrum in the region of 0.628 μm. Cross-hatched zones in the figure at 0.751±0.007 μm, 0.681±0.005 μm, 0.642±0.003 μm, and 0.611±0.011 μm are intervals where molecular absorption is negligible.

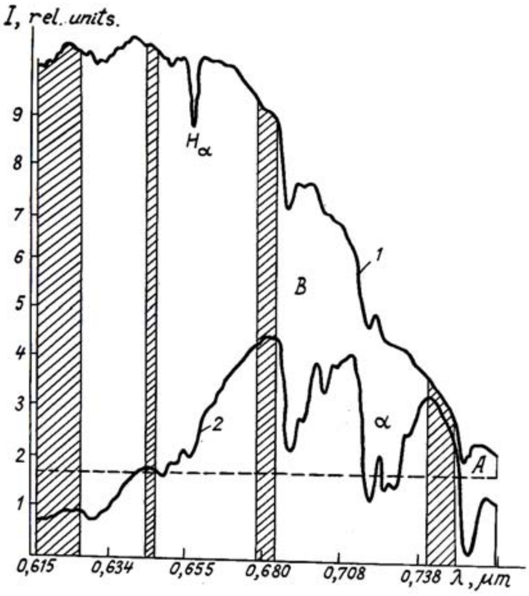

Fig. 4. The data analogous to that in Fig.3 but for red region at z_0 = 65° (curve 1) and 90° (curve 2). Zero level of signal for curve 1 is shown by dashed curve.

Similar deformations of large-scale spectral features at large z_0 due to molecular absorption are also observed in the range 0.57 to 0.60 μm. In particular, the profile of the sodium doublet in the solar spectrum is strongly deformed. In the range between 0.45 and 0.57 μm, except for the band shown in Fig. 2, we found no zones of noticeable molecular absorption. However, this does not mean at all that in this portion of spectrum, including all the cross-hatched zones in Figures 3 and 4, the probability of photon survival can be assumed to be 1 in calculations of the twilight sky brightness. This is due, first of all, to the fact that the whole visible spectrum is overlaid by weak diffuse ozone absorption band whose maximum is at 0.6 μm. In addition, radiation is .absorbed in all cases by aerosols.

Since the brightness of the twilight sky is very low, many investigators use fairly broad band transmission interference filters to separate out spectral ranges of interest. As a rule, the choice of filters is unrelated to any analysis of molecular absorption. As one example, the measurements by K.L. Coulson[8] at 0.7, 0.8 and 0.9 μm coincide with absorption bands of oxygen and water vapor (Figs. 3 and 4). This particular circumstance provided the impetus for the work discussed in this paper.

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