Effect of polarization on UV sky radiance during twilight

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Abstract. It is recognized that neglecting polarization in the radiative transfer equation leads to errors in radiance field simulation. However errors of scalar calculations has not been estimated yet for twilight. We have compared vector and scalar radiative transfer simulations of scattered radiance observed from the ground during twilight. Simulation has been carried out for the solar deep angle up to 7 degree below the horizon for UV-A and UV-B wavelengths. Error of the scalar calculation may reaches 15% and significantly depends on wavelength and the direction of observation.

Introduction

Accurate description of radiation field in the atmosphere requires solution of the transfer equation in unknown vector of Stokes parameters, which characterize the radiance intensity and the radiance polarization [*Chandrasekhar 1950*]. A simplified treatment of light as a scalar value equal to the radiance intensity may have only limited area of applications. The point is that light comes from the Sun being originally unpolarized, then scattered from air molecules or aerosol becomes partially polarized. It produces different source functions of the components in two perpendicular polarization directions for second scattering what the scalar theory neglects. Several studies, beginning from [*Chandrasekhar 1950*] as well as more recent papers [*Lacis et al. 1998*] and [*Lenoble et al. 2003*], compared solutions of the vector and the scalar radiative transfer equations for various observational geometries. They showed that scalar calculations of the radiance intensity are in error by up to 5-10% for many cases, depending on geometry of observations, aerosol loading and surface albedo.

Though several observational conditions were exploited, effect of polarization in modeling of UV radiance has not been yet investigated for twilight conditions. To understand better importance of the complete vector treatment of radiance in this case, we estimated error of scalar calculation for scattered radiance observed from the ground relative to more accurate vector modeling for limited number of scenarios. Simulation has been carried out for the solar deep angle up to 7 degree below the horizon for UV-A and UV-B wavelengths.

Radiative transfer model and optical model of atmosphere

To simulate radiance field, the radiative transfer model MCC++ for a spherical atmosphere has been applied [*Postylyakov 2004a* and *2004b*]. The vector and scalar versions of the MCC++ model, which employed the Monte Carlo method of conjugate walk, were used. An optical model of the atmosphere took into account molecular and aerosol elastic scattering, gas and aerosol absorption, and Lambertian surface albedo. Refractive bending was ignored. The MCC++ model was previously compared with other models in particular for twilight conditions [*Postylyakov et al. 2001*].

Mid-latitude winter model air density and ozone concentration profiles were taken from *Zuev and Komarov* [*1986*]. A total ozone column was normalized to 345 DU. Ozone cross section taken from *Burrows et al.* [*1999*] and Rayleigh scattering cross section from *Bates* [*1984*] were used. Molecular depolarization factor was neglected. Aerosol phase matrixes were calculated by Mie theory. Aerosol particle size distribution and refraction index recommended by model *WMO* [*1986*] for the background stratospheric condition was used above 12 km. Aerosol properties corresponding to the continental type of aerosol [*WMO 1986*] were exploited below 12 km. The aerosol extinction profile showing the best correlation with polarization observation of paper *Ugolnikov et al.* [*2003*] was used. This aerosol extinction profile corresponds to very clear troposphere and the background aerosol concentration in stratosphere. The surface albedo was equal to 0. The alditude was 200 m.a.s.l.

Simulation results and discussion

Scattered in the zenith UV solar radiation is strongly polarized during twilight (see Fig. 1). The degree of linear polarization may reach 65% at 330-340 nm, and increases up to 85% at 305 nm. Increased polarization corresponds to wavelengths, which have larger part of single scattered radiance as a consequence of stronger ozone absorption. Setting the Sun leads to decrease of polarization due to reduction of the part of almost completely polarized single scattering radiance.

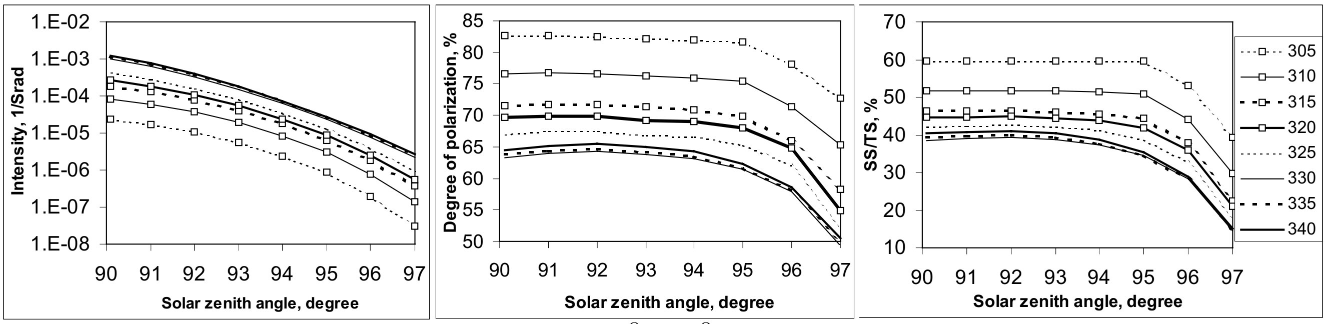

Figure 1. The zenith radiance for solar zenith angles from 90 ^{O} to 97^{O} and wavelengths from 305 to 340 nm: the intensity (for unit incoming radiance), the degree of linear polarization, and the part of single scattering radiance.

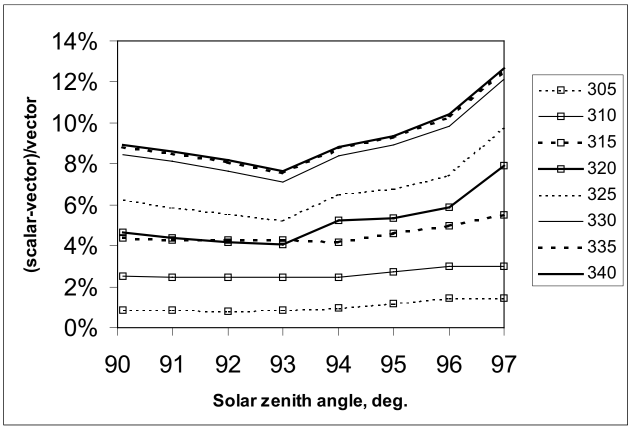

Figure 2. Error of scalar calculation of intensity of zenith radiance for solar zenith angles from 90^{O} to 97^{O} and wavelengths from 305 to 340 nm.

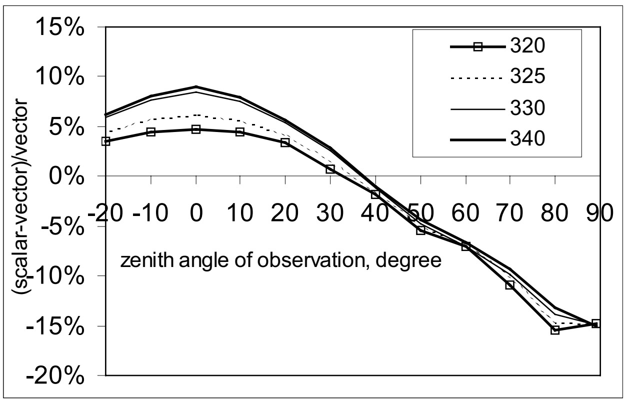

Figure 3. Error of scalar calculation of intensity for different direction of observation in principal solar plane for wavelengths from 320 to 340 nm. Solar zenith angle is equal to 90.1^{O}.

Errors of scalar calculation of intensity (see Fig. 2) significantly depends on wavelength and solar zenith angle (SZA). Single-scattering radiance fields given by both vector and scalar radiative transfer theories are equivalent. Therefore, the calculations for longer wavelength and large solar zenith angle, which have smaller part of single scattering radiance, differ more. The error of scalar calculation for the zenith observation reaches 13% at 305 nm for SZA=97^{O}.

Fig. 3 shows that the scalar description of radiative transfer gives strongly distorted diffuse UV radiance field at twilight for SZA=90.1^{O}. The error of the scalar description varies from negative in direction to the sun along the horisont (up to approximately -15%) to positive for observation in the zenith (up to +13%).

First results of the investigation showed that radiative field in twilight atmosphere may be handled correctly only using the vector theory, what should be taken into account in problems of radiative budget estimation and of remote sensing of the atmosphere exploited twilight period.

Investigation of the scalar description of the UV sky radiance for different solar deep angles and the detailed study of influence of ozone distribution, aerosol loading and microphysics, surface reflectance are a subject of interest and of the future work, as well as comparisons with field UV measurements.

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