Effect of polarization on UV sky radiance during twilight

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Representation of polarised radiance

Stokes vector $\mathbf{I} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$ characterizes the polarized light in an atmosphere.

$I$ describes the intensity measured by a polarization non-sensitive instrument. And the others define the plane and ellipticity of polarization. $I$, $V$, and $\sqrt{Q^2 + U^2}$ are invariant under a rotation of axes, while $Q$ and $U$ are defined with respect to a certain reference plane.

The degree of linear polarization: $P_{lin} = \frac{\sqrt{Q^2 + U^2}}{I}$. 
Main goals

- To investigate UV radiance during twilight which is under strong influence of ozone, aerosol and surface albedo, and is interesting for estimation of radiative budget and for climatic research

- To evaluate accuracy of scalar calculation relative to more accurate vector modeling of scattered radiance

- To simulate the polarized radiance measured from the ground during twilight which may be exploited for remote sensing
Factors affecting on polarization at twilight

Strong polarization due to:
- Rayleigh single scattering at 90 degree

Decrease of polarization because of:
- Multiple scattering
- Aerosol scattering
- Scattering angle differ from 90 degree
Radiative transfer model MCC++

was designed for use in algorithms for retrieval of the aerosol and gas distributions in the Earth atmosphere basing on measurements of the visual and UV scattered solar radiation:

- polarization
- spherical atmosphere (spherically symmetrical)
- surface reflectance
- simultaneous calculation of derivatives with respect to absorption, and intensities
- multiple scattering for both

See also posters E27, G35, and oral E8
Radiative transfer model MCC++

Methods used for calculations:

- Monte Carlo method of conjugate walk (backward method) for multiple scattering
- Monte Carlo method of modified double local estimation for multiple scattering at twilight
- Direct integration of source function for single scattering

See also posters E27
Validation of the MCC++ model

See also posters E27

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Polarization at the zenith during twilight

Comparison of the calculated (bold solid lines) and measured (solid lines with markers) degree of linear polarization, $p$, at the zenith for different wavelengths: 356 nm (the evening, July 31$^{\text{th}}$, 1997), 440 nm (the morning, July 28$^{\text{th}}$, 2000), 550 nm, 650 nm and 700 nm (the evening, August 4$^{\text{th}}$, 2000), 800 nm (the evening, December 17$^{\text{th}}$, 1999). Calculation for the urban type of aerosol.
Polarization at the zenith during twilight

- Shorter wavelength
- Stronger ozone absorption
- More Rayleigh single scattered photons
- Larger polarization
Error of the scalar calculation of the zenith intensity

- unpolarized light from the Sun
- Rayleigh or aerosol first scattering
- partially polarized light
- different source functions of the components in two perpendicular polarization directions for second scattering
- resulting intensity field differ from the scalar calculation

Scalar calculation of intensity may overestimate zenith radiance up to 15%
Polarization of the sky during twilight

-50° < Observation ZA < 50°

- SS/TS changes slightly
- polarization depends on the phase matrix of aerosol/molecules mixture
  - angle dependence of polarization may be used for remote sensing of the phase matrix
Use of second derivatives of polarization

The polarization ratio second mixed derivative $d^2K/dzdzs$ obtained from 1997, 2000 and 2002 observations (dots) compared with radiative transfer simulation for pure Rayleigh scattering and different types of aerosol (solid lines). Solar zenith angle is equal to 90°.

See also posters G35

Urban, Maritime, Continental aerosol taken from:

Error of the scalar calculation of the zenith intensity

- Scalar calculations of the skylight intensity have error at SZA=90.1°
- Error depends on the direction of observation
- Scalar RT model
  - overestimate intensity in the zenith direction up to 9±1%
  - underestimate intensity in the horizontal direction up to 16±1%
  - underestimate integral intensity in principal plane up to 3±1%
Radiance changes due to TOC increase

TOC increase from 345 to 520 DU

Scalar RT model errors decrease due to increase of single scattering part of light
Conclusion

- Scalar RT model calculates UV intensity during twilight with significant error. The error strongly varies with wavelength, direction of observation, and solar position.

- Uncovered distortion of radiance field by scalar model reaches maximum of 16±1% at 340 nm. It may be underestimation or overestimation of radiance intensity depending on the solar ZA and the observation ZA.

- Shorter wavelengths has smaller error - about 5% at 305 nm due to larger part of single scattered light.

- A scalar RT model underestimate integral intensity in principal plane up to 3±1% at SZA=90.1° for wavelengths from 320 to 340 nm.

- Multiangle observations of polarization have information about aerosol phase function
Thanks!