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Claudia Emde, Bernhard Mayer

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Errors induced by the neglect of polarization in radiance calculations for three-dimensional cloudy atmospheres

Claudia Emde, Bernhard Mayer

Meteorological Institute, Ludwig-Maximilians-University (LMU), Theresienstr. 37, Munich, Germany

Abstract

Remote sensing instruments observe radiation being scattered and absorbed by molecules, aerosol particles, cloud droplets and ice crystals. In order to interpret and accurately model such observations, the vector radiative transfer equation needs to be solved, because scattering polarizes the initially unpolarized incoming solar radiation. A widely used approximation in radiative transfer theory is the neglect of polarization which allows to greatly simplify the radiative transfer equation.

It is well known that the error caused by multiple Rayleigh scattering can be larger than 10%, depending on wavelength and sun-observer geometry [1]. For homogeneous plane-parallel layers of liquid cloud droplets the error is comparatively small (below 1%) [2]. Therefore, in radiative transfer modelling for cloud remote sensing polarization is mostly neglected. However, in reality clouds are not plane-parallel layers of water droplets but complex three-dimensional (3D) structures and observations of clouds usually include pixels consisting of clear and cloudy parts. In this study we revisit the question of the magnitude of error due to the neglect of polarization in radiative transfer theory for a realistic 3D cloudy atmosphere.

We apply the Monte Carlo radiative transfer model MYSTIC with and without neglecting polarization and compare the results. At a phase angle of 90° and 400 nm wavelength we find the maximum overestimation error of about 8% for complete clear-sky conditions. The error is reduced to about 6% in clear-sky regions surrounded by clouds due to scattering from clouds into the clear regions. Within the clouds the error is up to 4% with the highest values in cloud shadows. In backscattering direction the radiance is underestimated by about 5% in clear regions between clouds. For other sun-observer geometries, the error ranges between the two extremes. The error decreases with wavelength and in the absorption bands.

Keywords: 3D radiative transfer, polarization, scalar approximation, cloud scattering, Rayleigh scattering

1. Introduction

The vector radiative transfer equation is an integro-differential equation for the so-called Stokes vector [3], which can be solved numerically using a variety of approaches (e.g. , the doubling-and-adding method [4, 5], the spherical harmonics discrete ordinate method [6] or the Monte Carlo method [7, 8, 9]). A commonly used approximation to the rigorous vector radiative transfer equation is the scalar radiative transfer equation, which simplifies the numerical solution and allows much faster calculations of radiances. Widely used radiative transfer codes as for example DISORT (discrete ordinate method [10, 11]) use the scalar approximation.

Email address: `claudia.emde@lmu.de` (Claudia Emde)

In his pioneering book, Chandrasekhar [3] already pointed out that accurate radiative transfer calculations for Rayleigh scattering need to consider that radiation is polarized. Several studies followed and consistently found errors above 10% for light reflected by pure Rayleigh scattering layers (e.g. Adams and Kattawar [12], Mishchenko et al. [1] and references therein, Kotchenova et al. [13]).

The most detailed and comprehensive work by Mishchenko et al. [1] has shown, that for clear-sky molecular atmospheres the error due to the neglect of polarization is larger than 10% when the Rayleigh scattering optical thickness is about 1 for phase angles close to 90° and in backscattering directions. The phase angle is the defined as the angle between incident solar radiation and viewing direction. Mishchenko et al. [1]