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ON THE POLARIZATION ANGLE OF SKYLIGHT REFLECTED BY NATURAL SURFACES: PROPERTIES AND APPLICATION FOR REMOTE SENSING OF PLANETARY ATMOSPHERES

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ABSTRACT. In this study, we focus on the polarization angle of light scattered by terrestrial atmosphere-surface systems. The polarization angle describes the orientation of the plane in which the linearly polarized portion of light propagates. We show for skylight how this angle varies with the solar zenith angle and that, for skylight reflected by natural surfaces, these variations remain the same for wide ranges of atmospheric conditions and surface properties. This provides a tool for extracting scattering properties of the atmosphere from remote sensing observations of the Earth without any knowledge of the underlying surface. We demonstrate this principle for simulated data, and apply it to observations obtained by an airborne polarimeter over open oceans.

1. Introduction

The advantages of polarimetry in remote sensing of planetary atmospheres are well known from theoretical studies. These advantages include the large sensitivity of polarized light scattered by aerosol particles to the size, shape, and composition of these particles; and the weak sensitivity of this polarization to multiple scattering of light [1]. The largest sensitivity of polarimetry to aerosol particle properties occurs in the vicinity of backscattering direction. Analyses of actual polarization observations obtained from aircraft [2, 3] and spacecraft [4] confirm these study results, but require in addition accounting for the contributions of reflection by the underlying surface. That is because, near the back-scattering direction, the polarized reflectance of diffuse skylight reflected by this surface becomes comparable to or even larger than the polarized reflectance of the atmosphere alone.

Accounting for the remote sensing contributions of surface reflection involves computing the reflection properties of this surface, and computing multiple reflections of light between the atmosphere and this surface. Both these computations are feasible, but the accuracy for reflectances is sensitive to uncertainties in the surface polarization properties. The computations can, at times, be also time-consuming. As an alternative we propose considering the polarization angle, as opposed to the polarized reflectance, when accounting for remote sensing contributions of surface reflection. Certain species of bees, flies, spiders, and ants have the ability to ‘see’ this angle for the skylight hemisphere, and it has been theorized that they use it as a compass to find the sun’s position when the sun itself is obscured. This suggests that, for a given view of the skylight, variations of this angle caused by changes in atmospheric conditions play a less important role. If reflection of this skylight by the underlying surface further diminishes variations of the polarization angle with atmospheric conditions, and if the variations in the properties of this surface have a negligible impact as well on the polarization angle of reflected light, then we have a tool to predict (rather than compute) this angle for remote sensing contributions of surface reflection.

2. Methodology

In this study, we first consider simulated variations with solar zenith angle of the polarization angle of skylight. We confirm that these variations are much larger than those caused by changes in the atmospheric conditions. We then investigate the polarization angle of simulated skylight that is reflected by a surface. Here, we demonstrate that this angle remains near the backscattering direction relatively constant for wide ranges of aerosol properties and of surface roughness and refractive indices. Finally we apply these results to simulated remote sensing observations near the backscattering direction, and show how certain scattering properties of the atmosphere can be obtained without prior knowledge of the underlying surface. An example is provided for actual remote sensing observations obtained by the Research Scanning Polarimetry (RSP) instrument [5], which is an airborne version of the Aerosol Polarimetry Sensor (APS) spacecraft instrument [6].

The radiative transfer model for our polarized light simulations is taken from [7]. That is, we use the doubling/adding method described by [8] and [9] to obtain the reflection and transmission properties of the atmosphere. For the aerosol in this atmosphere we consider several models and vary the optical thickness for each of them. The reflection properties of the underlying surface are computed by assuming a Gaussian distributed slope distribution of Fresnel facets. The refractive index for these facets is varied between 1.3 and 1.5.

3. Results

The results for simulated variations of polarization angle are shown in the format of polar plots. The polar viewing angle in these plots ranges from 0 degrees at the center point to 60 degrees at the circumference, whereas the polar azimuth angle increases clockwise from 0 degrees to 360 degrees. The results for simulated data of polarization angle are shown as a function of viewing angle for a given azimuth angle. The viewing angle in these figures ranging from 0 degrees to 60 degrees, whereas the azimuth angle is fixed at 0, 15, or 30 degrees.

4. Case study

The RSP data analyzed here were collected during phase B of the NASA- sponsored field experiment called the Intercontinental Chemical Transport Experiment (INTEX). The INTEX objectives were to study the transport and evolution of gasses and aerosols on trans- and inter-continental scales, and to assess their impact on air quality and climate. The INTEX-B field study was coordinated with other agencies as part of the Megacity Initiative: Local and Global Research Observations (MILAGRO) campaign, which focused on the flow of pollution out of Mexico City during the month of March 2006. Various flights were carried out over and downwind of Mexico City by the Sky Research Inc. Jetstream 31 (J31) aircraft to study aerosol, water vapor, cloud, and surface properties. We limit our analyses to RSP data obtained on 10 March 2006, when the J31 flew over a patch of open ocean waters.

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