Characterization of Atmospheric Mineral Dust from Radiometric and Polarimetric Remote Sensing

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LONG-TERM GOALS

The overall goal is to improve an understanding of the properties of mineral aerosols and their interactions with visible and IR atmospheric radiation, and to develop the dust optical models needed for new satellite radiometric and polarimetric sensors proposed for the NPOESS and other satellite missions.

OBJECTIVES

The main objectives of this research program are as follows:

1) develop advanced optical models of mineral dust required for the new generation of multi-channel, multi-angle remote sensors operating in the visible to IR spectral ranges;

2) develop robust techniques for discriminating dust from clouds and evaluate the contamination of aerosol signal by cloud scattering;

3) investigate the capability of polarimetric remote sensing to quantify dust microphysical and optical properties.

APPROACH

Our approach combines an extensive forward modeling, analysis of laboratory and in-situ data of dust microphysical, optical, and radiative properties, analysis of remotely sensed data from currently operating satellite sensors (such as MODIS, MISR and AIRS) as well as ground-based polarization measurements in the urban and dust-laden conditions.

WORK COMPLETED

1) We used four years of MODIS Terra data to investigate the spatial variability of visible radiances in the presence of dust and clouds over oceans. Two different measures of spatial variability such as the standard deviation (STD) and local inhomogeneity parameter (LIP) were introduced and analyzed. Based on this analysis, we tested two statistical methods for the discrimination between mineral dust and clouds. Performance of both methods was compared against the cloud-aerosol mask based on the fixed STD threshold, which is commonly used in passive remote sensing (e.g., MODIS). We

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demonstrated that for discrimination of dust from clouds introducing the probability distribution function of STD offers a number of advantages over the fixed STD technique as well as the technique based on the local inhomogeneity parameter. The results of this study were presented at several scientific meetings (Darmenov and Sokolik, 2006, Sokolik, 2006) and are about to be submitted for publication in *Geophysical Research Letters*.

2) We continued our work on the development and testing of a one-dimensional radiative transfer model with polarization (called PORTAL) capable of computing the Stokes parameters taking into account multiple scattering and absorption of aerosol particles in multi-layered aerosol conditions. A series of modeling experiments has been conducted to investigate how the mixing of absorbing and non-absorbing aerosols affects the degree of linear polarization (LP) observed from the ground-based and space-born polarimetric sensors. Several distinct features in the behavior of LP were identified as a function of aerosol mixing state. In addition, we tested the role of vertical resolution in PORTAL in clear sky and aerosol-laden conditions. The results were presented at the American Meteorological Society meeting (Karpowicz et al., 2006) and the Radiation Conference (Karpowicz and Sokolik, 2006).

3) We have computed new IR high spectral resolution optical constants in the spectral range from 860 to 3750 cm^{-1} for multi-component aqueous mixtures composed of ammonium sulfate, ammonium nitrate, sulfuric acid and nitric acid over a range of compositions and temperatures representative of tropospheric conditions. The optical constants were determined from attenuated total reflectance (ATR) measurement data (provided by Prof. Martin, Harvard University) using a Kramers-Kronig transformation. Analysis of the spectral absorbing features of these multi-component aerosols has been performed, focusing on the IR high-spectral resolution remote sensing needs. These new data also enable us to examine the performance of several mixing rules that are commonly used to model optical constants (such as the Lorentz-Lorenz, Maxwell-Garnett, Bruggeman, the volume-average refractive index, the volume-average dielectric constant, and the weighted-average refractive index). We demonstrated that the optical constants of the studied mixtures are not accurately modeled using pure solute optical constants, e.g. ammonium sulfate optical constants, and the optical constants of pure water due to the complex ion-ion and ion-water interactions. Interestingly, the mixing rules based only on mass fraction or volume fraction weighting of the "component" optical constants performed as well or better than the more complicated rules. The results have been submitted for publication in *Journal of Quantitative Spectroscopy and Radiative Transfer* (Boer et al., 2006, Part1 and Part 2).

4) We continued working on a new measurement methodology to provide information on physicochemical characteristics of regional dust aerosols needed for modeling their optical properties. Our work in FY06 was focused on investigating the role of free iron and iron oxide speciation (hematite vs. goethite) as well as constraining the selection of minerals required for the IR. Analysis was performed for atmospheric dust samples as well as samples generated in a wind-tunnel from soils. These samples are representative of several important dust sources in East Asia and Northern Africa. The results of this work are reported in a series of paper by Lafon et al. and were presented at several scientific meetings (Sokolik and Lafon, 20006, Sokolik 2006).

RESULTS

1) Our analysis of four years of MODIS data revealed that introducing the probability distribution function of the standard deviation (STD) of visible radiances has a high potential for the improved

discrimination of dust from clouds over oceans. This provides a conceptual basis for the development of a new probabilistic approach for passive remote sensing. The probabilistic approach is not only superior to the common fixed STD method in discriminating dust from clouds, but also offers a number of advantages such as detection of dust-cloud mixed scenes in addition to “pure” dust and “pure” cloud pixels. Furthermore, the probabilistic dust-cloud mask gives information on detection skill that is of great importance to many applications, including validation of and data assimilation by chemical transport models.

2) We have computed new IR optical constants of multi-component aerosols consisting of ammonium sulfate, ammonium nitrate, sulfuric acid and nitric acid (Boer et al., 2006). These new optical constants are of great relevance to IR high spectral resolution remote sensing as well as radiative transfer modeling in climate studies. With the increasing availability of high spectral resolution IR data from satellites, aircraft and ground-based sensors, there is an increasing need for high spectral resolution aerosol models. The aerosol models require high spectral resolution optical constants and the ability to mix them to produce accurate multi-component optical constants. The new IR optical constants of our analysis can support the development of such models.

3) We have developed a measurement methodology which was specifically designed to determine iron oxides in mineral dust aerosols as well as their composition in terms of key minerals that are needed for improved optical modeling from the visible to IR.

IMPACT/APPLICATIONS

New techniques, dust optical models, and IR optical constants that were developed under this grant will be of interest to the large scientific community working on the various remote sensing problems, including the passive and active remote sensing from the UV to IR.

TRANSITIONS

Our main results were published in peer-reviewed journals and presented at numerous scientific meetings.

RELATED PROJECTS

We have been working on developing the non-spherical dust models for the space lidar CALIPSO. Our work on both projects has the high potential to provide a framework for the development of the new generation of aerosol models required for both passive and active remote sensing from the UV to the IR.

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