8.3 MODELING AND GROUND-BASED OBSERVATIONS OF LIGHT ABSORBING AEROSOLS AND THEIR EFFECT ON THE DEGREE OF LINEAR POLARIZATION

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1. INTRODUCTION

The impact of tropospheric aerosols on climate can vary greatly based upon small variations in aerosol properties, especially light absorption. Polarimetric measurements have been advocated in recent vears as an additional tool to better understand and retrieve the complex set of aerosol properties which are needed for improved predictions of aerosol radiative forcing on climate. The goal of this study is to investigate to what extent polarimetric measurements can be useful in studies of absorbing aerosols such as black carbon and its mixtures with other aerosol species. Employing a newly developed radiative transfer code with polarization POR-TAL (POlarimetric Radiative Transfer with Aerosol Loadings), we conduct modeling experiments to determine how the degree of linear polarization (LP) is affected by varying size distribution, refractive index, and vertical distribution of atmospheric aerosols representative of different urban environments. A special focus is on the effect of the mixing state of black carbon, the resulting change in single scattering albedo (ω_o), and the effect upon LP. We also use our forward modeling results to interpret measurements conducted in urban environments. In particular, we utilize a set of aerosol measurements conducted in Atlanta, which include a CIMEL sun-sky photometer with a polarized channel at 870 nm. We find that measurements are consistent with our modeling studies, and hold at least some potential in better characterizing aerosols in urban environments.

2. MODELING APPROACH

We address aerosol effects upon LP by employing our newly developed forward model PORTAL. POR-TAL utilizes a polarized radiative transfer code of Evans and Stephens (1991), which requires a detailed description of the atmosphere through a series of layers. PORTAL is highly flexible in that it can provide these properties considering three aerosol mixing treatments (external mixing, core/shell treatment, and volume weighting), along with a treatment to account for molecular scattering.

Each layer in the model atmosphere is calculated considering an external mixture of aerosol, and molecular components. The optical properties used to describe the model atmosphere are scattering coefficient, extinction coefficient, and the scattering matrix. Each aerosol component's optical properties are calculated through a choice of Mie theory depending upon the mixing state option, and combing these properties with molecular scattering. Molecular scattering is treated following Hansen and Travis (1974) using a depolarization factor of 0.035.

For the case when internal mixing is considered, there are two options, one that uses a core/shell Mie theory, and another that uses homogenous sphere Mie theory with a volume weighted refractive index. With either option, the layer properties are calculated through combining the internal mixing optical properties with molecular scattering through an external mixing procedure. For the core/shell mixing option, the mixture is described by the core fraction, or the ratio between the core radius, and the shell radius. The volume weighting option uses the total volume of each aerosol species to calculate an effective refractive index before using a homogenous sphere Mie theory.

In each of our modeling experiments, we consider an aerosol mixed with molecules. The aerosol profile is described either by a decaying exponential with a scale height of H, or through a uniform 1 km thick layer which is adjusted. Molecular scattering is calculated using a US-standard atmosphere profile. Another non-trivial consideration is surface parameterization. For each case we consider the surface to be Lambertian with a surface albedo of 0.13. While surface albedo is known to have an effect on LP (Coulson 1988), we will observe changes in LP based upon changes in aerosol properties while

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holding surface albedo constant, thus representing a site with known surface albedo. We consider a wide range of solar zenith angle, and present data for LP in the solar principal plane.

Through the use of PORTAL, we analyze what signals are present for changes in the following aerosol properties: changes in BC refractive index, changes in mixing state (internal vs. external), different optical treatments for internal mixing, and changes in vertical distribution. Using our modeling analysis of LP, we identify what signals are embedded in LP, and which of these signals can be uniquely identified.

3. MODELING RESULTS

In an upcoming paper (Karpowicz and Sokolik 2006), we present an extensive set of results which show how properties of carbonaceous aerosols and their mixtures with non-absorbing aerosol species can affect LP. Here we will focus on how changes in optical depth (τ), and single scattering albedo (ω_o) affect LP. Figure 1 shows values of LP calculated using PORTAL over a range of 0-90° solar zenith angle. The aerosol loading conditions for Figure 1 are for an external mixture of black carbon and nonabsorbing species, with two values for the imaginary part of black carbon refractive index. The two values considered 0.44, and 1.0, are associated with ω_o values of 0.786, and 0.661, respectively, for a considered size distribution. In viewing Figure 1, it is clear that both τ and ω_{α} have a significant effect upon LP. It is also clear to see two tendencies: an increase in τ results in a decrease in LP, and a decrease in ω_{o} (greater absorption) leads to an increase in LP. This effect is more clearly observed by considering values of ΔLP shown in Figure 1 which is calculated as:

$$\Delta LP = LP_{Im[m_{BC}]=0.44} - LP_{Im[m_{BC}]=1.0}$$
(1)

where ΔLP , $LP_{Im[m_{BC}]=0.44}$, and $LP_{Im[m_{BC}]=1.0}$ are the change in LP, and the values for LP calculated using PORTAL with a value of 0.44, and 1.0 for the imaginary part of the BC refractive index, respectively.

While the methodology to represent mixing state and changes in ω_o are certainly important, and are explored in depth by Karpowicz and Sokolik (2006), we use these tendencies observed in Figure 1 to interpret measurements conducted in Atlanta.



Figure 1. Degree of Linear Polarization in the principal plane for a range of zenith angle from $0-90^{\circ}$ at $\lambda=870$ nm, calculated using an external mixture with two different values of the refractive index of black carbon.

4. ATLANTA MEASUREMENTS

During the month of May 2005, we conducted measurements using a suite of aerosol instrumentation in Atlanta, GA, a region well known for its poor air quality. The suite of instruments included: a CIMEL sun-sky photometer with a polarized channel at 870 nm, a Magee Scientific Aethalometer, two Radiance Research Particle Soot Absorption Photometers (PSAPs), a Radiance Research Nephelometer, and a Sunset Labs EC/OC instrument. The CIMEL sun-sky photometer allowed for measurements of LP and τ , while the Aethalometer, PSAP. and EC/OC instrument allowed for a measure of absorption. The nephelometer combined with the PSAP measurement was used to compute a value of ω_o at a wavelength \sim 550 nm. In Figures 2 and 3 data collected are presented for May 24 and May 26, respectively. In viewing both Figures 2 and 3, it is clear that there is a low value for optical depth at 870 nm, however, there is a larger value for optical depth in the afternoon for May 26. Along with this increase in optical depth, the measured value for LP at 870 nm decreases. In viewing changes in ω_o calculated using the combination of the PSAP, and nephelometer this decrease in LP between the afternoon of May 24 and May 26 may also be associated with an increase in ω_{o} . Both tendencies are consistent with our modeling studies.

5. CONCLUSIONS

Through our modeling studies presented here and in Karpowicz and Sokolik (2006), we have shown that LP is affected by changes in τ and ω_o . Our results show that there is some potential for retrieval of aerosol properties, specifically τ and ω_o using combined measurements, and modeling of LP. Additional results presented in Karpowicz and Sokolik (2006) show that LP is also affected by changes in black carbon refractive index, mixing state, and size distribution. Other changes LP due to changes in aerosol properties including vertical distribution and non-sphericity will be the focus of our future research using PORTAL and ground-based observations.

References

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Figure 2. Data collected in Atlanta, GA on May 24, 2006.



Figure 3. Data collected in Atlanta, GA on May 26, 2006.