The Vertical Distribution of Aerosols: Lidar Measurements versus Model Simulations

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Abstract

The vertical distributions of aerosols simulated by global aerosol models are evaluated using aerosol profiles measured by two lidars. Aerosol extinction profiles and aerosol optical thickness (AOT) simulated by aerosol models participating in the Aerosol module inter-Comparison in global models (AEROCOM) project are compared with Department of Energy Atmospheric Radiation Measurement (ARM) Climate Research Facility (CRF) Raman lidar (CARL) measurements acquired during 2000 and 2001. Average aerosol extinction profiles from the AEROCOM models typically show good agreement with the Raman lidar profiles above about 2 km; below 2 km the average model profiles are significantly (30-50%) lower than the Raman lidar profiles. The vertical variability in the average model aerosol extinction profiles is less than the variability in the corresponding Raman lidar profiles.

Introduction

Global models have been increasingly used to assess climate change scenarios. Since some of the largest uncertainties in model simulations of climate change are associated with aerosols, evaluating how these models portray aerosol characteristics is vital for determining uncertainties in climate change simulations. Such evaluations are being conducted as part of the Aerosol module inter-Comparison in global models (AEROCOM) project (Kinne et al. 2005), which seeks to diagnose aerosol modules of global models and subsequently identify and eliminate weak components in aerosol modules used for global modeling. (A list of the AEROCOM models is provided at http://nansen.ipsl.jussieu.fr/AEROCOM/data.html.) AEROCOM intercomparisons have shown large differences in how models represent the vertical distribution of aerosols (Textor et al. 2005). Consequently, lidar profiles of aerosol extinction provide an important means of evaluating and hopefully improving aerosol models.

Raman Lidar

Through its design as a turnkey, automated system for unattended, around-the-clock profiling of water vapor and aerosols, the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) Raman lidar has provided a climatological database of aerosol and water vapor profiles (Turner et al. 2001). CARL autonomously measures profiles of aerosols, clouds, and water vapor in the low to mid troposphere throughout the diurnal cycle over the ARM Climate Research Facility (ACRF) Southern Great Plains (SGP) site (36.62 N, 97.5 W, 317 m) (Goldsmith et al. 1998). Profiles of water vapor mixing ratio, relative humidity, aerosol backscattering, and aerosol extinction (355 nm) are derived using a set of automated algorithms (Turner et al. 2002). Water vapor mixing ratio profiles are computed using the ratio of the Raman water vapor signal to the Raman nitrogen signal. Relative humidity profiles are computed using these profiles and the temperature profiles from a collocated atmospheric emitted radiance interferometer. Profiles of aerosol scattering ratio are derived using the Raman nitrogen signal and the signal detected at the laser wavelength. Aerosol volume backscattering cross section profiles are then computed using the aerosol scattering ratio and molecular scattering cross section profiles derived from atmospheric density data. Aerosol extinction profiles are computed from the derivative of the logarithm of the Raman nitrogen signal with respect to range. Aerosol optical thickness (AOT) is derived by integration of the aerosol extinction profile with altitude.

Raman Lidar/AEROCOM Comparisons

Figure 1 shows the average annual AOT (355 nm) over the ACRF SGP site from the various AEROCOM models, as well as annual averages derived from CARL and the AERONET Cimel sun photometer located at the SGP site. Averages were computed from the monthly averages and error bars represent standard deviations. Note how the average annual AOT from the various models and the CARL and sun photometer measurements

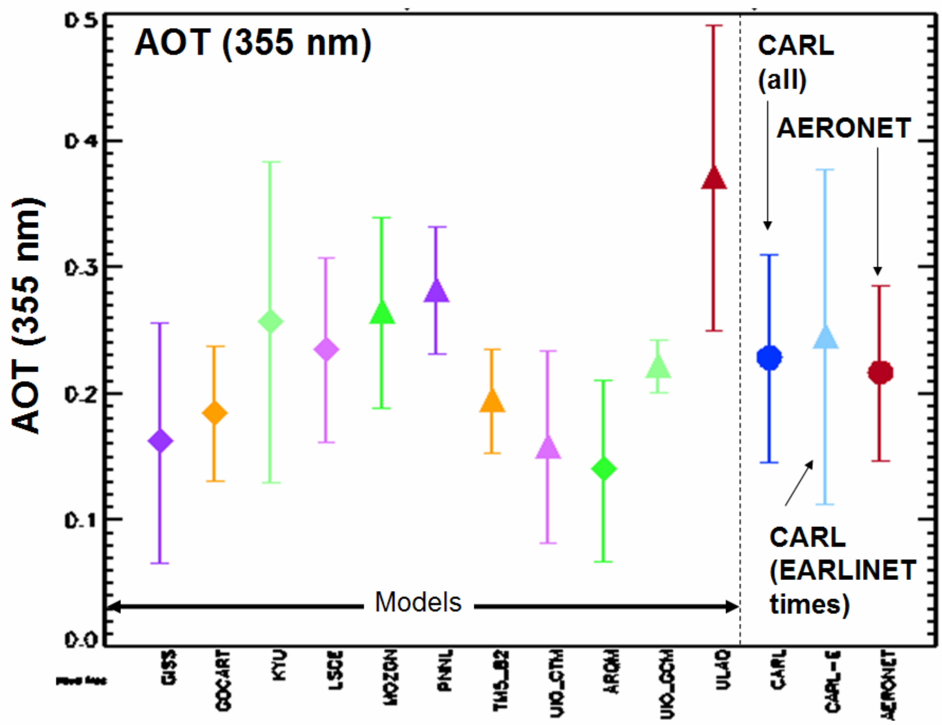

Figure 1. Average annual AOT over the ACRF SGP site during 2000.

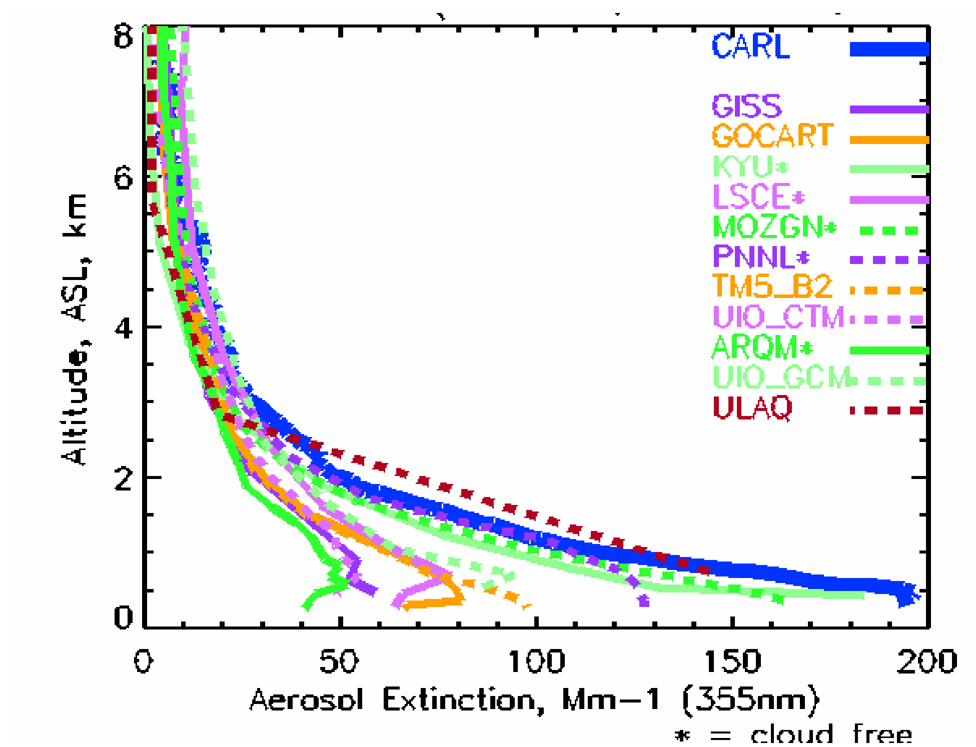

Figure 2. Average aerosol extinction profiles over the ACRF SGP site during 2000.

agree within the standard deviations of the averages. Figure 2 shows the average vertical distribution of aerosol extinction (355 nm) for 2000 simulated by several AEROCOM models and measured by CARL. These distributions were comprised of monthly averages. Note the wide range in how the models represent the aerosol extinction profiles over the ACRF SGP site. Deviations between mean aerosol extinction profiles are generally small (~20-30%) for altitudes above 2 km, and grow considerably larger below 2 km. The generally low bias of the model aerosol extinction profiles with respect to the lidar measurements within the lowest 2 km is similar to an earlier study that compared Raman lidar measurements from European Aerosol Research Lidar Network (EARLINET) Raman lidar measurements (Bosenberg et al. 2002) and simulations from the Interaction with Chemistry and Aerosols model (Guibert et al. 2005). The larger differences near the surface may be due to too little vertical mixing or not enough humidification of the aerosol simulated by the models. CARL measurements often show high aerosol extinction and relative humidity values located within thin layers near the surface. Average annual relative humidity profiles were also examined. Relative humidity Differences between CARL measurements and model simulations were generally small (<10%) except near the surface, where CARL profiles, especially at night, show significantly higher amounts than the models.

Comparisons for 2001 are very similar to those shown in Figures 1 and 2 for 2000. A subset of models also participated in comparison experiment that used identical prescribed emissions and meteorological fields. The model annual average profiles from this experiment also exhibited large model-to-model differences and were also systematically lower than the average CARL profile within the lowest 2 km.

In contrast to the periodic EARLINET Raman lidar measurements, which were derived from lidar data collected only near sunset on two days per week, the results presented here use CARL profiles collected essentially continuously, 24 hours per day and 7 days per week. The impact of periodic (i.e., EARLINET) vs. continuous (i.e., ARM) sampling on the lidar/model comparisons was also examined using a subset of CARL data collected during the EARLINET sampling times. As an example, Figure 1 shows two average AOT values for CARL; the first corresponds to all CARL data, and the second corresponds to the subset of data acquired only during the EARLINET sampling times. The difference between these two AOT average values is small. In contrast, bias and root mean square differences between the model and CARL aerosol extinction profiles were significantly larger, and correlations were smaller, when using the periodic sampling times than when using the continuous sampling times. Additional studies using CARL data also showed significant diurnal variations in the vertical distributions of aerosols and water vapor.

Summary

On average, aerosol extinction profiles simulated by global aerosol models generally agree with corresponding profiles measured by the ground-based Department of Energy ARM Raman lidar and the National Aeronautics and Space Agency Langley airborne differential absorption lidar for altitudes above 2 km. Below 2 km, the model profiles are systematically lower than the lidar profiles. Comparisons of AOT over the ACRF SGP site show good agreement among the AEROCOM models and between the models and measurements; in contrast, there are large differences in the vertical profiles of aerosol extinction among the models and between the models and lidar measurements. The large variability among the AEROCOM profiles remained even when the models used similar input emissions and meteorological fields.

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