Integrated Study of MFRSR-Derived Parameters of Atmospheric Aerosols and Trace Gases Over the ARM CART Site Extended Facilities - Comparison with Satellite and Other Ground-Based Measurements

M. D. Alexandrov and B. Cairns
Columbia University
National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, New York

A. A. Lacis and B. E. Carlson
National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, New York

Comparison of SGP MFRSR Network Aerosol Retrievals with MODIS Aerosol Product

The network of Multi-filter Rotating Shadowband Radiometers (MFRSRs) at the Atmospheric Radiation Measurement (ARM) Program Cloud and Radiation Testbed (CART) site consists of 21 instrument sites located at Central (CF) and Extended Facilities (EF) and covering an area of approximately 3 by 4 degrees. Application of the previously developed MFRSR data analysis algorithm (Alexandrov et al. 2002a) yields daily time series of aerosol optical depth and particle size as well as NO_2 and ozone column amounts. The individual instrument retrievals are then combined (with the use of local wind measurements) into series of satellite-image-like two-dimensional (2D) maps displaying the evolution of spatial distribution of the retrieved atmospheric parameters (Alexandrov et al. 2002b) throughout the day.

MFRSR-derived 2D images of aerosol optical depth retrievals from Southern Great Plains (SGP) EFs were compared with Moderate-resolution Imaging Spectroradiometer (MODIS) Level 2 Aerosol Product. MFRSR data were taken at the time of Terra satellite overpass (12:00 Local Standard Time [LST]). Here, we illustrate the comparison procedure using the data obtained on May 9, 2001. Only 24 points, where available MFRSR measurements and MODIS retrievals (10 by 10 km pixels) are located within 0.1 degree (approximately 10 km) from each other, were suitable for direct comparison (Figure 1). To extend the MFRSR spatial coverage we used ground wind measurements and inverse distance interpolation-averaging with 0.3 degree smooth cutoff. This increased the number of co-location points but did not significantly change the statistical differences between MFRSR and MODIS aerosol optical depth (AOD). Increasing the averaging radius to 0.5 degree and applying

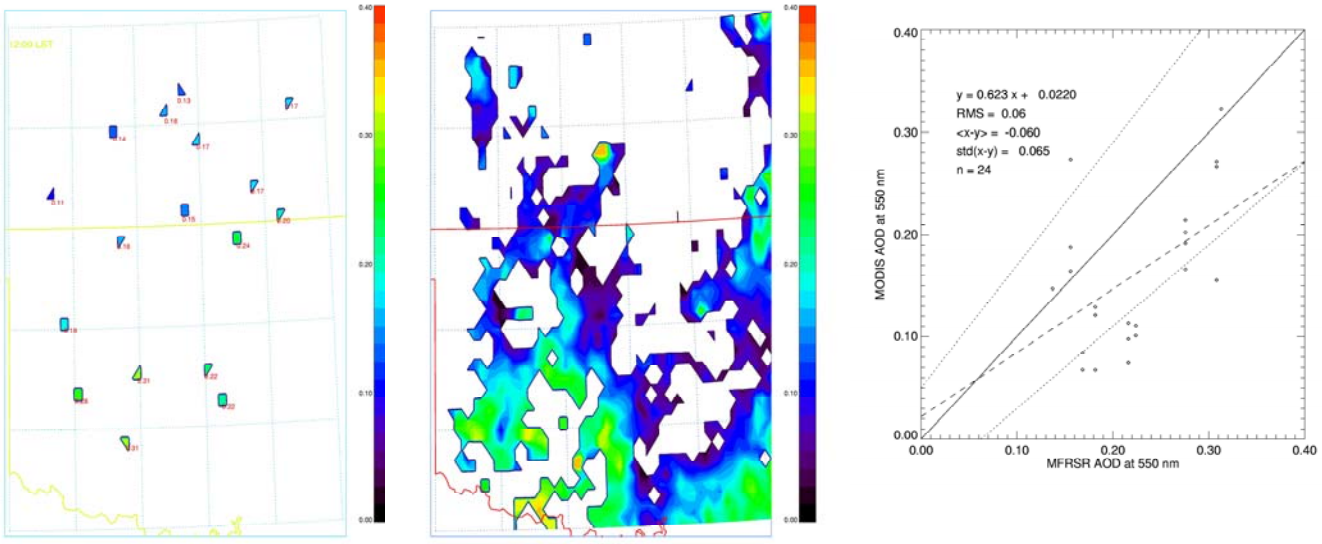

Figure 1. Left: Available MFRSR measurements of AOD at 550 nm for 12:00 LST on May 9, 2001; Center: MODIS pixels with Level 2 AOD values for the same time; Right: Scatter plot comparing MFRSR and MODIS AOD retrievals (dotted lines show MODIS accuracy: $\Delta\tau = 0.05+0.2\tau_a$).

the interpolation-averaging procedure to both MFRSR transported data and MODIS AOD (Figure 2) showed even better statistical relation between the two datasets (which mostly agree within the MODIS error bars). Both MODIS and MFRSR plots show an increase in AOD to the southwest of the area. The largest differences occur over the city of Wichita in central Kansas as a result of MODIS AOD overestimation over urban areas, and in eastern Oklahoma where both the MFRSR network and

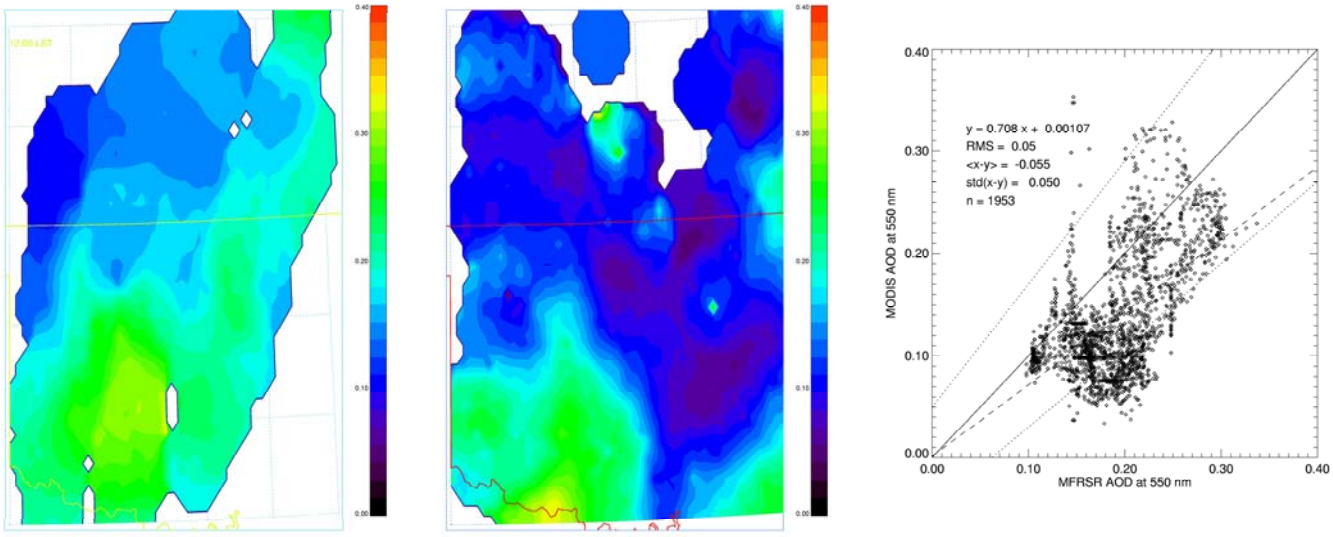

Figure 2. The same as in Figure 1, but with MFRSR AOD field extended using local wind measurements and both MFRSR and MODIS fields interpolated-averaged with 0.5° smooth cutoff.

MODIS datasets did not have sufficient coverage. A similar comparison made for April 23, 2001, data shows that even when the MODIS retrieval dataset and MFRSR network have almost no co-located measurements the interpolated values agree within MODIS accuracy.

Scaling Properties of Aerosol Optical Depth Over SGP EF

To address the issue of parameterization of aerosol temporal and spatial variability, we follow the approach currently used in cloud remote sensing and construct variance spectra of AOD time series. These may be converted to spatial structure spectra using a factor depending on the mean wind speed. These spectra reflect the structure of atmospheric turbulence and usually have a piece-wise power law form (scale invariance with scale breaks). The traditional model of atmospheric turbulence predicts two main regimes with different power law spectra: large scale 2D turbulence (with the power exponent -3) and small-scale 3D turbulence (with the power exponent -5/3, approximately -1.67). In the intermediate range of frequencies, the "wall" turbulence power exponent –1 can be expected. In real situations, the actual values of power exponents may deviate from the theoretically predicted ones. Our analysis of the SGP data shows similar power exponents to those obtained for clouds: high frequency exponents range from -1.97 to -1.12 while the low frequency exponents (when pronounced) range from -3.71 to -2.74.

The plots in Figure 3 show correlation between AOD power spectra and the power spectra of local ground wind component, while both vary with season, location, and mean wind speed. Disagreements between AOD and wind statistics may be a consequence of long-range transport, when a large fraction of aerosol load is above the turbulent boundary layer.

Pollution Transport from Sooner Power Plant to SGP CF

The Sooner power plant is located at 36.45°N, 97.05°W, which is approximately 45 km to the southeast of SGP CF. It is a significant source of NO_x and SO_2 emissions: 14735.06 and 25138.8 tons respectively in 1999 according to the U.S. Environmental Protection Agency (EPA) Office of Air and Radiation NET Database. The correlation analysis of MFRSR-derived AOD and NO_2 column amounts for SGP CF (January-December 1997) is shown in Figure 4: the left and central plots present AOD and NO_2 as functions of local ground wind direction. The circles depict annual means, the green curves show the moving mean + standard deviation values. The plots demonstrate statistical maxima in both AOD and NO_2 corresponding to southeast winds (direction to the Sooner Power Plant is shown by the green line). This statistical dependence of AOD and NO_2 amounts on wind direction is suggestive of pollution transport from this facility and may explain high (similar to urban) NO_2 column amounts detected at SGP CF. Our MFRSR-derived NO_2 record shows clear seasonal behavior with the maximum in summer. This may be related both to NO_2 photochemistry and to a summer increase in power plant emissions (air-conditioning season). Our differential absorption retrievals of NO_2 from high-spectral resolution RSS data (Figure 4, right plot) showed 1 DU column amount on December 4, 1997 at SGP CF that is much larger than stratospheric and ambient tropospheric values. Our findings strongly suggest that NO_2 absorption should be taken into account in photometric aerosol retrievals.

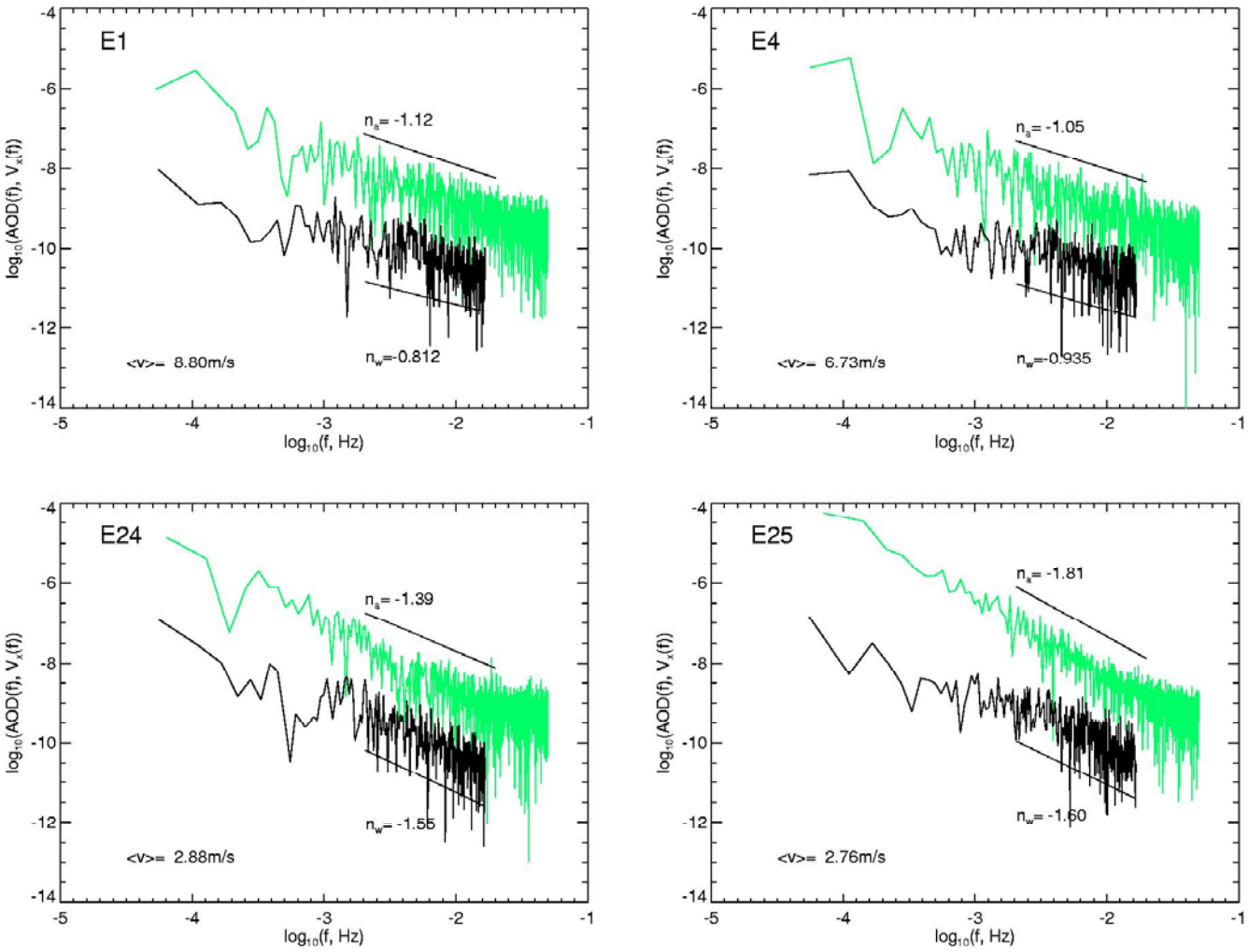

Figure 3. Power spectra of AOD time series at 870 nm (green) and of ground wind component (black) obtained at SGP EF on September 14, 2000. Slopes of the curves appear to be dependent on the mean wind speed: stronger winds induce more high frequency turbulent oscillations in both measured parameters.

MFRSR – Cimel Optical Depth Intercomparison

Our MFRSR calibrations and optical depth retrievals were compared with the optical depths derived from measurements by the AERONET CIMEL sun/sky radiometer co-located with MFRSR at the ARM CART site CF (Alexandrov et al. 2002a). Level 2.0 AERONET data are used. These measurements have been cloud screened and quality controlled. We sampled the MFRSR data to match the measurement times of the CIMEL measurements (they are less frequent in time) and selected for this comparison data collected during the period from January to June 1999. During this time period, there were 58 clear or partially clear days with data available from both instruments (total 1342 data points). This period contains a variety of atmospheric conditions, with aerosol optical depths ranging from 0.03 to 0.4 (at 500-nm wavelength). The MFRSR calibrations and retrievals are performed according to the algorithm described in this paper, including smoothing of the calibration coefficients.

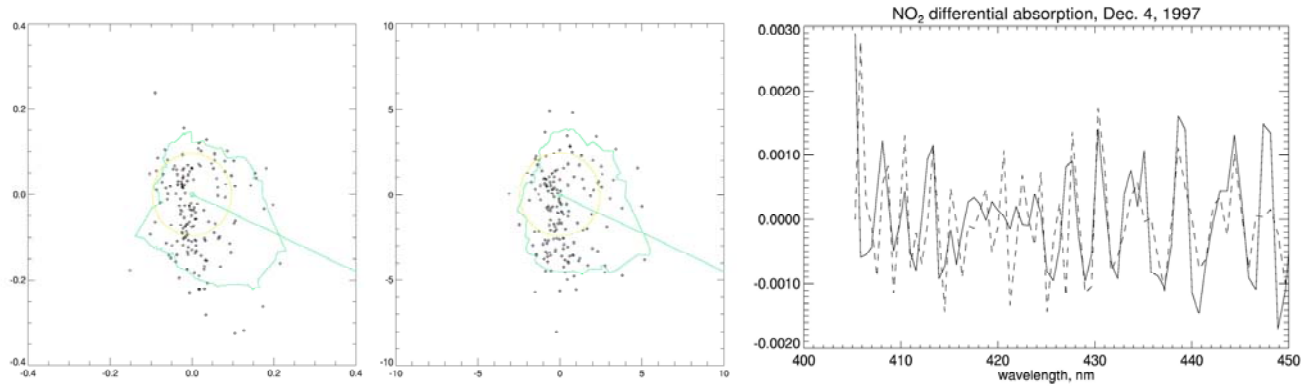

Figure 4. Dependence of MFRSR-derived 550 nm AOD (left) and NO_2 column amount (in DU, center) on daily mean ground wind direction at SGP CF for January – December 1997. Yellow circle represents the yearly mean value; the green curve is "maximum envelope" (sum of the moving mean and standard deviation). Straight line depicts direction to the Sooner power plant. Right: NO_2 differential absorption spectrum seen in RSS data on December 4, 1997, at SGP CF (dashed curve) and theoretical spectrum for 1 DU NO_2 column (solid curve).

The 500-, 670-, and 870-nm channels are common to both the CIMEL and MFRSR. For comparison with the 440-nm CIMEL channel, we interpolated between our retrieved optical depths at 415 and 500 nm to obtain an MFRSR-derived estimate of the optical depths at 440 nm. We compared the total optical depths measured by the two instruments with ozone contribution subtracted. Aerosol extinction and NO_2 absorption within MFRSR spectral range have similar spectral dependence. Separation between their contributions needs further improvement and was not performed for the intercomparison at visible wavelengths. However, when used for extrapolation of the MFRSR-derived AOD spectral dependence to the CIMEL's 380-nm channel, the extrapolated optical depth values appeared to be systematically lower than AERONET retrievals. This suggests that measurements at 380-nm wavelength are sensitive to the separation between aerosol extinction and NO_2 absorption and may be useful for resolving current uncertainties in this separation. Differences between the climatological ozone column amounts (used by AERONET) and the values retrieved using our algorithm appears to have a negligible effect on this comparison. Mean differences between our MFRSR retrievals and those of AERONET do not exceed 0.005 for 440-, 500-, and 870-nm channels, with standard deviation of 0.01 or less for all channels. We find small systematic bias of 0.01 for the 670-nm channel that may be an artifact of CIMEL recalibration procedure.

References

Alexandrov, M., A. A. Lacis, B. E. Carlson, and B. Cairns, 2002a: Remote sensing of atmospheric aerosols and trace gases by means of multi-filter rotating shadowband radiometer. Part I: Retrieval algorithm. *J. Atm. Sci*., **59**, 524-543.

Alexandrov, M., A. A. Lacis, B. E. Carlson, and B. Cairns, 2002b: Derivation of 2D fields of aerosol and trace gases parameters by integrated analysis of multi-instrument MFRSR dataset from DOE ARM Program CART site, in *Remote Sensing of Clouds and the Atmosphere VI*, K. Schafer, O. Lado-Bordowsky, A. Comeron, M. R. Carleer, J. S. Fender, Editors, Proc. SPIE Vol. 4539, 277-288.