

Building Climatologies of Atmospheric Aerosols, Trace Gases, and Water Vapor on the Basis of MFRSR Remote Sensing Retrievals

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Introduction

Atmospheric (and especially tropospheric) aerosols with their direct and indirect radiative forcing remain the source of one of the most significant uncertainties in climate change modeling. Retrieval of aerosol spatial and temporal distribution on a global scale is a task for current and future satellite measurements [such as advanced very high-resolution radiometer (AVHRR), Total Ozone Mapping Experiment Spectrometer (TOMS), moderate resolution imaging spectroradiometer (MODIS), MISR, etc.]. The increased emphasis on satellite aerosol retrievals has produced a need for ground-based, ground-truth aerosol measurements. In addition, measurements from ground-based sunphotometer networks can be also used to produce a land-based aerosol climatology, which is complementary to satellite retrievals that currently are being performed mostly over ocean.

The multi-filter rotating shadowband radiometer (MFRSR) has become a popular instrument in recent years. Several existing networks [such as Solar Irradiance Research Network (SIRN) sponsored by National Aeronautics and Space Administration (NASA), U.S. Department of Agriculture (USDA) UVB Radiation Monitoring Program and Atmospheric Sciences Research Center (ASRC) network affiliated with the State University of New York] operate about a hundred instruments providing a good geographical coverage of the United States.

The MFRSR makes simultaneous measurements of the direct solar beam extinction, and horizontal diffuse flux, at six wavelengths (nominally 415, 500, 615, 670, 870, and 940 nm) at one-minute intervals throughout the day (see Harrison et al. 1994 for additional information). Besides water vapor at 940 nm, the other gaseous absorbers within the MFRSR channels are NO₂ (at 415, 500, and 615 nm) and ozone (at 500, 615, and 670 nm). Aerosols and Rayleigh scattering contribute atmospheric extinction in all MFRSR channels.

Provided that the instrument calibration is accurately known and the unique spectral signature of each atmospheric constituent is given, retrievals can be obtained from the direct beam measurements to provide the daily time series of aerosol, NO₂, ozone, and water vapor variability. Since in practice laboratory and field calibration procedures using standard lamps do not yield calibrations of sufficient

accuracy, techniques must be developed to derive the instrument calibration from the data. Traditionally, these instruments have been calibrated using the Langley method. In this approach, it is assumed that optical depth is constant over the day. Such behavior is not typical for most sites and more accurate calibrations are obtained by averaging the Langley-derived coefficients over 20 to 40 clear days (Harrison and Michalsky 1994). Nevertheless, some sites of interest for an aerosol climatology have long periods without days clear enough for Langley analysis and require some other calibration techniques.

To improve this situation, we developed a new calibration/retrieval method for processing of MFRSR data from clear and partially cloudy days (Alexandrov et al. 1999). This method increases the reliability of instantaneous daily calibrations and reduces the number of clear days needed to obtain accurate calibration coefficients.

Method

In this paper, we present further development of the technique of Alexandrov et al. (1999a, 1999b) and show more extensive retrieval results.

This method uses consistency between direct normal and diffuse horizontal measurements in the 870-nm channel to determine aerosol optical depth and the calibration constant for this channel. A special regression technique is then used to retrieve daily time series of column mean aerosol particle size, aerosol optical depth in all channels, NO₂ and ozone column amounts together with the calibration coefficients for the first four channels. This technique is similar to Langley method; however, instead of optical depth stability, it relies on the substantially better stabilities of the spectral shape of aerosol extinction and gases column amounts.

Determination of the aerosol size and optical depth allows us to separate the water vapor and aerosol contributions to the 940-nm channel total optical depth, and to use the modified Langley technique (Reagan et al. 1987; Michalsky et al. 1995) to retrieve the water vapor column amount.

This method shows better calibration stability compared to the Langley approach in our validation study (Alexandrov et al. 1999c) on an exceptionally clear data set from Davis, California (January to July 1996). We validate our ozone retrievals through comparison with TOMS satellite measurements. Our water vapor retrieval algorithm (i.e., a new component of our method) will be validated against standard water vapor measurements (e.g., microwave radiometer).

Results

We have used the algorithm to analyze MFRSR measurements from a number of instruments both from large networks and operated by individual users. So far we have processed only a fraction of the available MFRSR data with the primary goal of testing our retrieval algorithm under various geographical and climatological conditions. Currently, we can present long-term retrievals (at least a year of data and often several years) from nine sites in the continental United States and from islands (Mauna Loa, Hawaii, Bermuda, and Barbados). Having completed our testing, we are ready to begin data processing to substantially increase the temporal and geographic coverage of our retrievals.

The analysis of long-term MFRSR measurements provides a description of seasonal and inter-annual changes in aerosol optical depth and particle size, as well as column amounts of ozone, NO₂ and water vapor as a function of geographical location. This information can be used for comparison with both transport models and satellite measurements.

Our retrievals show that in most places aerosol properties exhibit pronounced seasonal changes with the magnitude dependent on geographical location. This reflects the local atmospheric processes leading to creation, transport, and deposition of aerosols. For example, the summer/winter variations in aerosol optical thickness (and its mean summer values) are larger in the eastern United States. Most of the sites we considered have larger aerosol optical thickness in summer while the particles are smaller (we should note that we can retrieve properties only of optically active fine mode aerosols). For some sites (especially in the eastern United States) this behavior can be explained by enhanced summer production of sulfate aerosol particles from a gaseous phase.

Ozone amount has maximum in spring, which is in agreement with the expected seasonal change for the locations considered. Maximum of NO₂ column amount usually occurs in summer, which can be explained as a photochemical effect. A correlation between NO₂ amounts and aerosol optical depth suggests that both may be originated from the same pollution source. The pollution origin of the detected NO₂ is also supported by the fact that geographically maximal amounts of NO₂ are detected in the north-eastern United States that have large emissions of nitrogen oxides.

Figure 1 shows a sample of aerosol seasonal behavior for nine sites representing various regions of the United States. Summer (June, July, August) and winter (December, January, February) means of the aerosol optical thickness (at 550-nm wavelength) and effective radius of the aerosol size distribution (effective variance of 0.2 is assumed) are presented by small histograms placed at the locations of the sites. The left and right bins represent correspondingly winter and summer means. The sites and periods depicted are (from West to East): Oregon (SIRN) 5/97-5/98; Davis, California (USDA) 1-12/96; Salt Lake City, Utah (SIRN) 2/97-1/99; Central Plains Experimental Range, Colorado (USDA) 1-6/96; Southern Great Plains, Oklahoma [Atmospheric Sciences Research Center (ASRC) and U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program] 9/95-8/96; Miami, Florida (University of Miami) 5/94-5/95; New York City (SIRN) 12/95-11/96; Albany, New York (ASRC) 1-12/95; and Howland, Maine (ASRC) 1-12/95. A number of other sites are also depicted by dots to show the potential geographical coverage.

Summary

A retrieval/calibration algorithm for MFRSR data analysis is described and validated. It provides time series of aerosol optical depth and column mean particle size, as well as ozone, nitrogen dioxide, and water vapor column amounts. It does not rely on laboratory calibration of the instrument and has less calibration variability and less sensitivity of retrievals to calibration accuracy than traditional approaches.

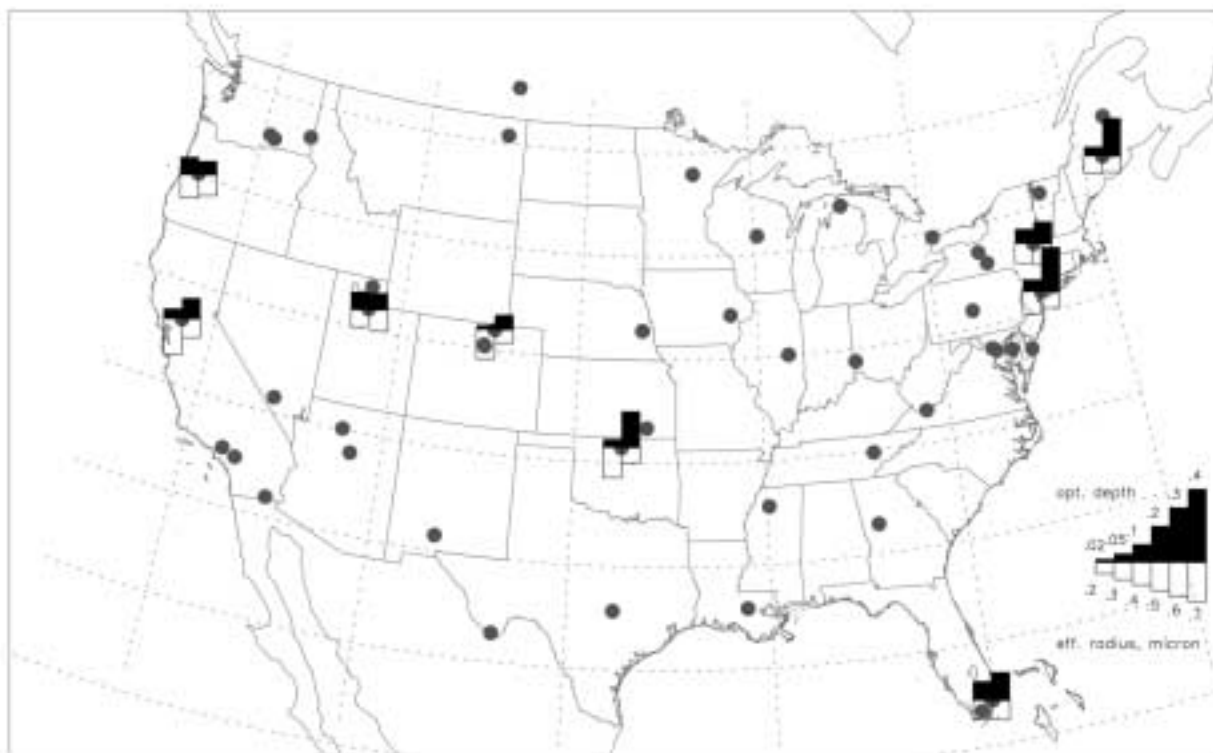


Figure 1. Sample of seasonal behavior of aerosol optical depth at 550 nm (upper bins) and effective radius of the aerosol size distribution (lower bins) for nine sites in the continental United States. Winter (December, January, February) and summer (June, July, August) means are represented correspondingly by left and right bins. To show the geographic coverage of MFRSR measurements, the locations of instruments belonging to the ASRC, SIRD, SURFNET, and USDA UVB networks are depicted by dark dots.

The method proposed has been successfully tested by processing long-term data from a number of sites spread over the U.S. and representing a variety of climatological conditions. During these studies we determined both time and geographic variability of aerosol properties and gaseous column amounts, which show seasonal behavior specific to each geographic location. This method makes the relatively inexpensive and automatic MFRSR an important tool in climatological research. The growing number of these instruments and increasing density of their locations open possibility to build large-scale climatologies basing on the MFRSR network data.

References

Alexandrov, M., A. Lacis, B. Carlson, and B. Cairns, 1999a: Remote sensing of atmospheric aerosols, nitrogen dioxide and ozone by means of multi-filter rotating shadow-band radiometer. In *Remote Sensing of Clouds and Atmosphere*, J. Russell and C. Serio, Eds, Proc. SPIE 3867, 156-170.

Alexandrov, M., A. Lacis, B. Carlson, and B. Cairns, 1999b: Atmospheric aerosol remote sensing by means of multi-filter rotating shadow-band radiometer. In *Proceedings of the European Aerosol Conference 1999*, Suppl. to *J. Aerosol Sci.*, **30**, S615-S616.

Alexandrov, M., A. Lacis, B. Carlson, and B. Cairns, 1999c: Validation of MFRSR data analysis: Comparison with the Langley approach. In *Proceedings of the Ninth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9903/alexandrov-99.pdf

Harrison, L., J. Michalsky, and J. Brendt, 1994: Automated multifilter shadow-band radiometer: Instrument for optical depth and radiation measurement. *Appl. Opt.*, **33**, 5118-5125.

Harrison, L., and J. Michalsky, 1994: Objective algorithms for the retrieval of optical depths from ground-based measurements. *Appl. Opt.*, **33**, 5126-5132.

Michalsky, J., J. Liljegren, and L. Harrison, 1995: A comparison of sunphotometer derivations of total column water vapor and ozone to standard measures of same at the Southern Great Plains atmospheric radiation measurement site. *J. Geophys. Res.*, **100**, 25,955-26,003.

Reagan, J., K. Thome, B. Herman, and R. Gall, 1987: Water vapor measurements in the 0.94 micron absorption band: Calibration, measurements, and data applications. In *Proc. Int. Geoscience and Remote Sensing '87 Symposium*, Ann Arbor, Michigan, IEEE, 63-67.