Validation of MFRSR Data Analysis: Comparison with the Langley Approach

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Introduction

In the present study, we validate the retrieval algorithm (Alexandrov et al. 1998a, 1998b, 1998c) for processing of Multifilter Rotating Shadowband Radiometer (MFRSR) data from clear and partially cloudy days, providing daily time series of aerosol optical depth, aerosol column mean particle size, ozone and NO_2 column amounts.

The inability to absolutely calibrate MFRSRs with sufficient accuracy demands the determination of instrument calibration from the data. The traditional way to do this is the Langley approach that assumes that the optical depth of the atmosphere does not vary significantly during the day. Such a behavior is not typical for most of the sites, so averaging of the calibration coefficients determined from the Langley analysis over 20 to 40 clear days within about 3 months is required for accurate calibration (Harrison and Michalsky 1994). The instrument filters degradation with time requires calibration to be checked for every period of operation. This may be problematic for many sites having long periods without a sufficient amount of "langleyable" days. In this situation, development of calibration/retrieval methods is important and would increase the reliability of instantaneous daily calibrations and allow the number of clear days necessary for accurate averaging to be reduced.

Below, we use the notion "calibration coefficient" referring to the parameter

$$c_i = -\ln C_i , \tag{1}$$

where C_i is the constant entering the relation

$$I_i = C_i I_i^0 \, exp\left(-\frac{\tau_i}{\mu} \right) \tag{2}$$

between the measured direct beam intensity in the i^{th} channel I_i, the corresponding nominal top of (the) atmosphere (TOA) intensity I_i^0 and the optical depth τ_i, μ is cosine of the solar zenith angle. (We number the channels in the order: 415, 500, 615, 670, 870, and 940 nm.) In these notations, the non-calibrated optical depth $\tilde{\tau}_i$ relates to the true τ_i, as

$$\tilde{\tau}_i = -ln\left(\frac{I_i}{I_i^0}\right)\bullet\mu = \tau_i + c_i\mu. \qquad (3)$$

The method considered in the present study consists of two basic steps. In the first step, consistency between direct normal and diffuse horizontal measurements in the fifth (870-nm) channel is used to determine aerosol optical depth and calibration constant in this channel. Technically this means that the difference between the non-calibrated optical depth obtained from the direct beam measurement and the optical depth inverted from the calibration-independent ratio of the direct and diffuse intensities is being explained as calibration effect. As it follows from Eq. (3), this difference is supposed to have the form $c_5\mu$, where c_5 is a calibration coefficient in the fifth channel, which is constant during the day.

In the second step, a special regression technique is used for retrieval of daily time series of column mean aerosol particle size, aerosol optical depth in all channels, NO_2, and ozone column amounts together with calibration of the first four channels. This technique is similar to the 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.

To validate the method at hand, we compare calibration coefficients and optical depths obtained by its means with these determined by the Langley approach. An exceptional clear-sky data set from Davis, California (January to July 1996), was selected for comparison. This site is operated by the U.S. Department of Agriculture (USDA) ultraviolet B radiometer (UVB) Radiation Program. Only completely cloudless days were selected (note that in summertime almost every day at Davis satisfies this condition).

At this point, we should address the now-popular issue of the clear-sky direct-to-diffuse discrepancy, i.e., an overestimation of diffuse irradiance by radiative transfer models that use as inputs the optical parameters obtained from the direct beam measurements (Halthore et al. 1998). Our modeling of the diffuse beam (under assumption of conservative scattering) shows that the optical depths inverted from direct-to-diffuse ratios cannot match the non-calibrated direct beam optical depths just by addition of a term proportional to μ. What is actually required is to add a quantity of the form $c_5\mu + \tau_x$, where τ_x is an additional optical depth that appears to be practically constant during the day. This optical depth missing from the diffuse measurements has an average value of 0.02 (that coincides with the results of Halthore et al. [1998]). The discrepancy can be resolved by assuming an unphysical aerosol single-scattering albedo of about 0.5.

We believe that this phenomenon is related more to instrumental problems of diffuse intensity measurements than to the presence of an unknown atmospheric absorber, and that the direct beam measurements still can be trusted. However, it is clear that a scientific solution to this problem requires additional studies (e.g., extensive comparison of data obtained by collocated instruments).

The purpose of the present work is not to find the origins of the direct-to-diffuse discrepancy, but use the observed stability of the missing optical depth to improve the direct-diffuse calibration procedure. This stability allows us to apply Langley-like regressions to the difference between direct beam and direct-diffuse ratio optical depths to obtain the instrument's calibration constant (instead of dividing this difference by μ, which would be suitable if $\tau_x = 0$).

Application of this calibration method to the Davis data set showed that such regressions are generally more consistent than the corresponding Langley regressions; for instance, their morning and afternoon slopes are usually much closer to each other than in the Langley case. For long-term calibration history (Figure 1, the bottom plot) this results in the fact that while agreeing on average (approximated by the dashed line) with the Langley approach results (dotted line), the coefficients obtained with the use of diffuse horizontal flux (solid line) are substantially more stable. Results of comparisons for the other channels are similar (Figure 1), except for the first channel where advantages of our method are less pronounced because the regressions based on stability of NO_2 column amount used for determination of c_1 are usually not much better than usual Langley plots.

Figure 2a shows that overall difference between the instantaneous daily mean optical depths in the 870-nm channel obtained by the two methods is relatively small.

Figures 2b and c present the time series of daily means of aerosol effective particle radius, ozone and NO_2 column amounts retrieved using the method at hand for the same period of time. For all these plots, the value of 0.1 of the effective variance of aerosol size distribution was assumed. (While the effective variance is a parameter very difficult to determine, this value was most often encountered in our retrievals.)

References

Alexandrov, M., A. Lacis, B. Carlson, and B. Cairns, 1998a. Analysis of the MFRSR data from SGP and NYC sites. In *Proceedings of the Eighth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, DOE/ER-0738, pp. 13-17. U.S. Department of Energy, Washington, D.C.

Alexandrov, M., A. Lacis, B. Carlson, and B. Cairns, 1998b: Retrieval of aerosol optical depth, aerosol size distribution parameters, ozone and nitrogen dioxide column amounts from multifilter rotating shadowband radiometer data. In *Proceedings of the Seventh Atmospheric Radiation Measurement (ARM) Science Team Meeting*, CONF-970365, pp. 379-383. U.S. Department of Energy, Washington, D.C.

Alexandrov, M., A. Lacis, B. Carlson, and B. Cairns, 1998c: *J. Aerosol Sci*., **29**, Suppl. 1, S523-S524.

Halthore, R X, S. Nemesure, S. E. Schwartz, D. G. Imre, A. Berk, E. G. Dutton, and M. H. Bergin, 1998: *Geophys. Res. Lett*., **25**, 3591-3594.

Harrison, L., and J. Michalsky, 1994: *Appl. Opt*., **33**, 5126-5132.

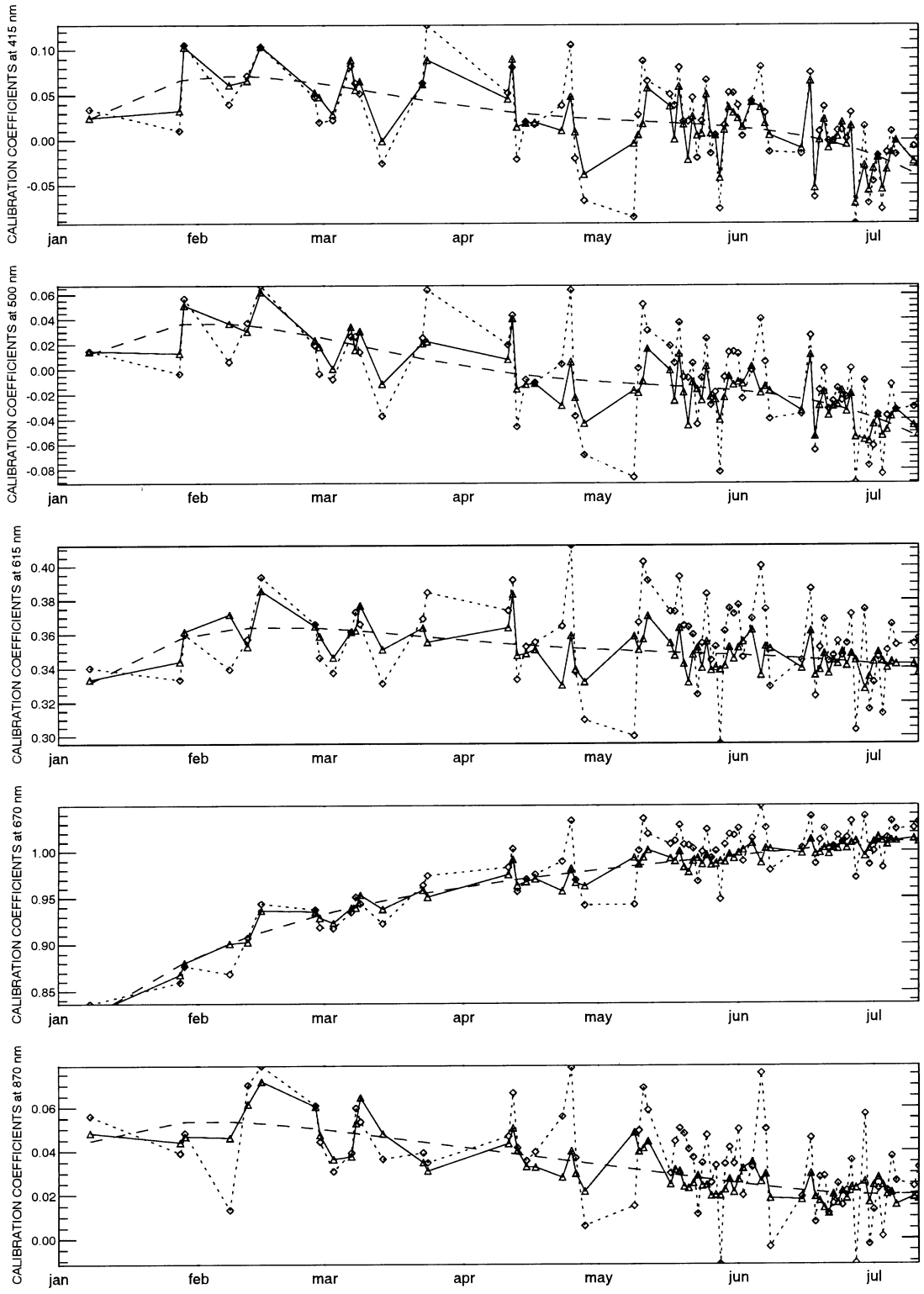

Figure 1. Comparison between calibration coefficients obtained by the proposed method (solid lines) and the Langley method (dotted lines), dashed lines represent polynomial fits.

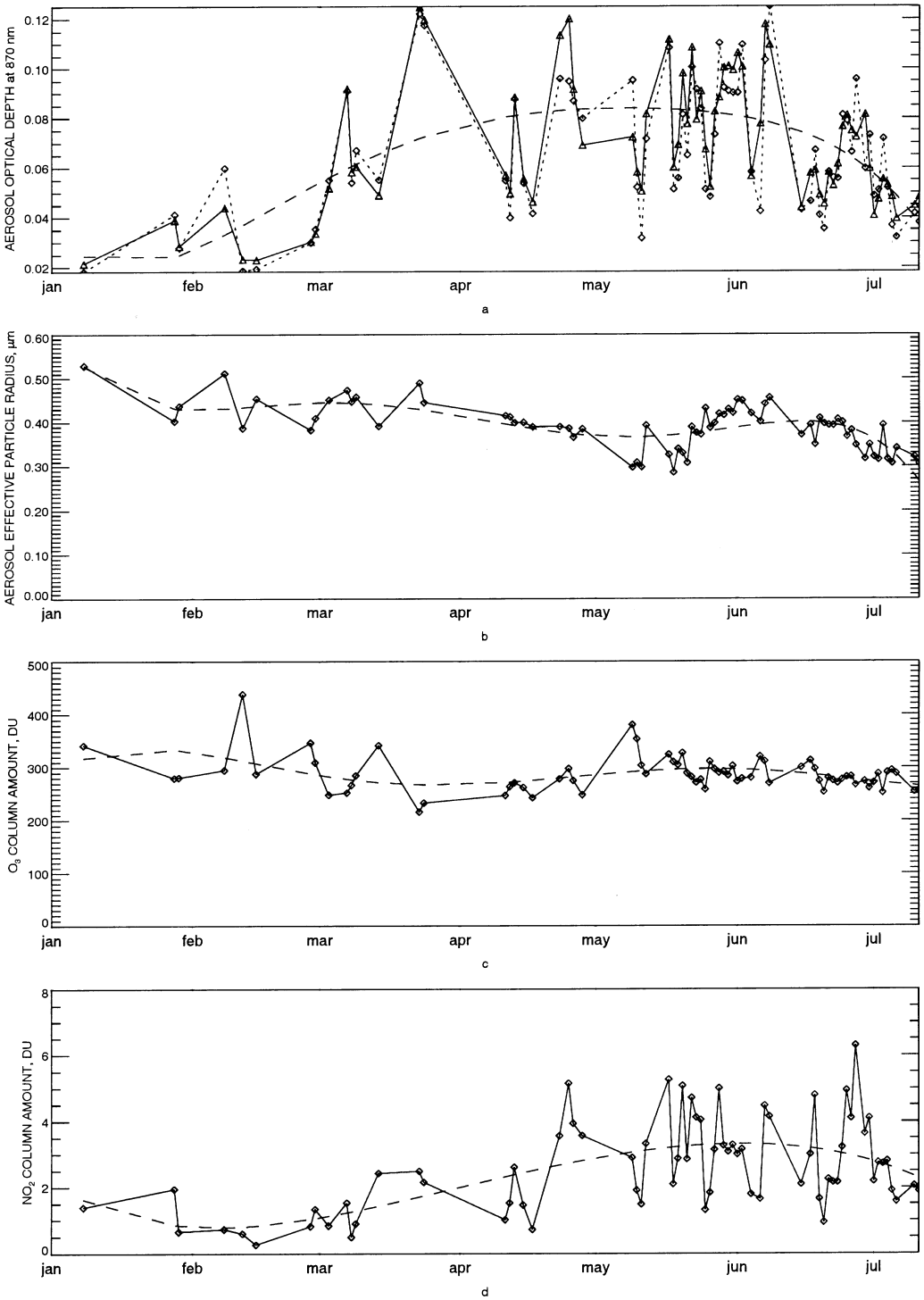

Figure 2. Comparison between optical depths at 870 nm obtained by the proposed method (solid line) and the Langley method (dotted line) (a); time series of daily means of aerosol effective particle radius (b); ozone (c); and column amounts retrieved using the method at hand for the same period of time. Dashed lines represent polynomial fits.