Aerosol ultraviolet absorption experiment (2002 to 2004), part 1: ultraviolet multifilter rotating shadowband radiometer calibration and intercomparison with CIMEL sunphotometers

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Abstract. Radiative transfer calculations of UV irradiance from total ozone mapping spectrometer (TOMS) satellite data are frequently overestimated compared to ground-based measurements because of the presence of undetected absorbing aerosols in the planetary boundary layer. To reduce these uncertainties, an aerosol UV absorption closure experiment has been conducted at the National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC) site in Greenbelt, Maryland, using 17 months of data from a shadowband radiometer [UV-multifilter rotating shadowband radiometer (UV-MFRSR), U.S. Department of Agriculture (USDA) UV-B Monitoring and Research Network] colocated with a group of three sun-sky CIMEL radiometers [rotating reference instruments of the NASA Aerosol Robotic Network (AERONET)]. We describe an improved UV-MFRSR on-site calibration method augmented by AERONET-CIMEL measurements of aerosol extinction optical thickness (τ_a) interpolated or extrapolated to the UV-MFRSR wavelengths and measurement intervals. The estimated τ_a is used as input to a UV-MFRSR spectral-band model, along with independent column ozone and surface pressure measurements, to estimate zero air mass voltages V_0 in three longer wavelength UV-MFRSR channels (325, 332, 368 nm). Daily mean $\langle V_0 \rangle$, estimates and standard deviations are obtained for cloud-free conditions and compared with the on-site UV-MFRSR Langley plot calibration method. By repeating the calibrations on clear days, relatively good stability ($\pm 2\%$ in $\langle V_0 \rangle$) is found in summer, with larger relative changes in fall-winter seasons. The changes include systematic day-to-day $\langle V_0 \rangle$ decline for extended periods along with step jump changes after major precipitation periods (rain or snow) that affected the diffuser transmission. When daily $\langle V_0 \rangle$ values are used to calculate τ_a for individual 3-min UV-MFRSR measurements on the same days, the results compare well with interpolated AERONET τ_a measurements [at 368 nm most daily 1σ root mean square (rms) differences were within 0.01]. When intercalibrated against an AERONET sunphotometer, the UV-MFRSR is proven reliable to retrieve τ_a, and hence can be used to retrieve aerosol column absorption in the UV. The advantage of the shadowband technique is that the calibration obtained for direct-sun voltage can then be applied to diffuse-radiance voltage to obtain total and diffuse atmospheric transmittances. These transmittances, in combination with accurate τ_a data, provide the basis for estimating aerosol column absorption at many locations of the USDA UV-B Monitoring and Research network and for correction of satellite estimations of surface UV irradiance. © *2005 Society of Photo-Optical Instrumentation Engineers.* [DOI: 10.1117/1.1886818]

Subject terms: ultraviolet radiation; aerosol absorption; CIMEL sunphotometer; AERONET network; ultraviolet multifilter rotating shadowband radiometer; diffuse fraction measurements; Langley calibration.

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1 Introduction

Improved knowledge of aerosol absorption properties in the near UV is needed for modeling of tropospheric chemistry, because it affects the calculated rate of photolysis reactions,[1,2] smog production,[3] and penetration of biologically harmful UV radiation to the surface.[4–17] Radiative transfer (RT) calculations show that decreases in UV due to moderate increases in absorbing aerosol amounts are comparable to that caused by stratospheric ozone recovery,[17] with one important difference. Aerosols affect both the UV-B (280- to 320-nm) and UV-A (320- to 400-nm) spectral ranges, while ozone sensibly affects only the UV-B (at 310 nm, each 1% column ozone decrease produces approximately ~1% UV irradiance increase[4,6,17]). Therefore, local changes in aerosol amount or optical properties may enhance, reduce or even reverse UV radiation changes caused by expected stratospheric ozone recovery.[17] Although it is well known that iron oxides in desert dust[18–20] and soot produced by fossil fuel burning and urban transportation[21–23] strongly absorb UV radiation, properties of other potential UV absorbers, e.g., nitrated and aromatic aerosols,[5] are poorly known. Use of measurements from a shadowband radiometer[24–30] [the UV-multifilter rotating shadowband radiometer (UV-MFRSR), Yankee Environmental Systems, Turners Falls, Massachusetts] in both the

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Fig. 1 UV-MFRSR shadowband radiometer, part of USDA UVMRP (left), and CIMEL sun/sky photometer, part of NASA AERONET network (right) were continuously run side by side at NASA GSFC in Greenbelt, Maryland (lat=39.03 deg N, long=76.88 deg W), in 2002 to 2004. The elevated location (the height of elevated platform at the roof of the building is ~20 m above ground and ~90 m above sea level) enables unobscured view of horizon by both instruments.

UV-A and UV-B spectral regions enable separation of ozone absorption[31,32] and aerosol extinction and absorption effects[8,11–13] on surface UV irradiance. Since previous estimates of aerosol optical properties in the UV were sparse and not yet validated,[6–13] it was difficult to explain the observed discrepancy in modeled and measured UV irradiances[14–17] and photolysis rates.[1–5] The RT model discrepancy is a serious problem in satellite estimation of UV irradiance, even in cloud-free conditions.[14–17]

To reduce uncertainties in RT calculations of UV irradiance and actinic flux in cloud-free conditions, an aerosol UV absorption closure experiment has been conducted at the National Aeronautics and Space Administration, Goddard Space Flight Center (NASA/GSFC) site in Greenbelt, Maryland, using 17 months of data (2002 to 2004) from a shadowband radiometer [UV-MFRSR, U.S. Department of Agriculture (USDA) UV-B Monitoring and Research Network] colocated with a rotating group of three sun-sky CIMEL radiometers [reference instruments of NASA Aerosol Robotic Network (AERONET) network[33,34]]. This paper describes the UV-MFRSR on-site calibration and intercomparisons with AERONET measurements of aerosol extinction optical thickness[34] (τ_a). First, instrumentation and data sets used in this study are briefly described in Sec. 2. This is followed by a detailed description of the UV-MFRSR operating procedures, raw voltage corrections, and measurement uncertainties. The new on-site UV-MFRSR calibration technique was derived from comparisons with extrapolations and interpolations of AERONET τ_a, obtained by the CIMEL direct-sun technique and its Mauna Loa Langley calibration.[33,34] The technique and a spectral band model used to calibrate UV-MFRSR direct voltage measurements are discussed in Sec. 3, followed by analysis of the calibration results and comparisons with the Langley plot technique in Sec. 4. Long-term changes in the UV-MFRSR V_0 calibration observed at our site are discussed in Sec. 5. Finally, conclusions are given in Sec. 6, showing that the UV-MFRSR, when intercalibrated against an AERONET sunphotometer, was proven reliable to retrieve UV-A aerosol extinction optical thickness τ_a with accuracy better than 0.02 and hence can be used to infer the weak to moderate UV aerosol column absorption expected at relatively clean suburban Greenbelt site.[35] The inversion method and results of our aerosol absorption measurements are presented in a follow-up paper[36] (Part 2).

6 Conclusions

A new method of on-site UV-MFRSR calibration was developed using colocated direct sun AERONET/CIMEL τ_a measurements. The AERONET τ_a was interpolated or extrapolated to UV-MFRSR wavelengths and measurement intervals and used as input to the UV-MFRSR spectral band model along with column ozone and surface pressure measurements to estimate zero air mass voltages V_0. The method does not require stability of τ_a and enables independent V_0 estimations for every 3-min measurement in each spectral channel. Daily average $\langle V_0 \rangle$ estimates were obtained for cloud-free conditions and compared with the on-site Langley technique. On the clearest stable days, both calibration techniques were consistent.

Daily mean $\langle V_0 \rangle$ values were used to calculate τ_a for individual 3-min UV-MFRSR measurements (~5% outlier data rejection). These results compared well with interpolated AERONET τ_a measurements [at 368-nm daily rms differences in τ_a were within 0.01 (1σ) for $\tau_{\mathrm{ext}}<0.4$ and within $0.015(1\sigma)$ for $\tau_{\mathrm{ext}}<1.2$]. Therefore, the UV-MFRSR, when intercalibrated against an AERONET sunphotometer on the same day was proven reliable to retrieve τ_a. However, the calibrations should be repeated daily due to systematic day-to-day changes in UV-MFRSR throughput. The changes included periods of systematic day to day $\langle V_0 \rangle$ decline for time periods of over a month [we identified four such periods with ~0.15%/day decline in $V_0(368\,\mathrm{nm})$] alternated with step jumps changes after major precipitation periods (rain or snow). The $\langle V_0 \rangle$ day-to-day changes were highly correlated in three longer wavelength UV-MFRSR channels (325, 332, 368 nm), and possibly result from diffuser contamination and cleanings. Such V_0 changes necessitate Teflon diffuser cleanings of stand-alone UV-MFRSR field instruments at least two times weekly or adding a quartz dome, which is less likely to absorb dirt particles.

The essential advantage of the shadowband technique is that $\langle V_0 \rangle$ calibration obtained for direct-sun voltage can be applied to diffuse and total voltages to obtain total and diffuse atmospheric transmittances. These transmittances in combination with accurate τ_a data provide an essential foundation for the aerosol column absorption retrievals described in the second part of this paper.[36]