A Comparison of Photodiode Based Sunphotometer-derived AOD with NASA AERONET

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Abstract

Five years of spectral aerosol optical depth (AOD) measured by inexpensive handheld sunphotometers constructed at Appalachian State University (APP) are compared with AOD measured at APP's NASA AERONET site. Initial results indicate good agreement for the 500nm and 870nm channels, but weaker for the 670nm channel. No instrument bias was present, and no calibration drift was observed, facilitating the usage of median calibration voltages. The initial comparison suggests that well-calibrated handheld sunphotometers could be used to expand geographic coverage of AOD and for evaluation of satellite-measured AOD. Future work will include cloud screening of data, time-interpolation of calibrations, sensor temperature dependence tests, and finalization of a microcontroller-based model to ease data collection and transfer.

Motivation

Regional and global studies of aerosol direct radiative forcing (DRF) and, more recently, surface-level particulate matter concentrations (PM2.5), rely on aerosol optical depth (AOD) measurements from satellite-based platforms such as NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard Terra and Aqua due to near-global coverage daily. However, recent comparisons of MODIS-measured AOD with "ground-truth" AOD measurements at NASA AERONET sites located in mountainous regions around the world demonstrated a weaker agreement[1], with a small negative AOD bias over the Southern Appalachian Mountain Region[2]. To aid in validation of MODIS-retrieved AOD over these regions, networks of inexpensive handheld sunphotometers may be deployed to increase the spatial density of measurements where research-level instrumentation is otherwise unavailable[3]. Currently, few (if any) assessments of sunphotometer sensitivities or uncertainties have been conducted; to this end, the primary research goals are to quantify these unknowns and begin deployment to establish a mountainous citizen science network.

Methods

- Measurements were taken using a four wavelength, photodiode-based handheld sunphotometer over a five year period from August 2011 to December 2016.
- Calibrations were performed periodically over the duration via the Langley plot method, and the median calibration constants were used in this comparison.
- AOD for each wavelength was calculated using the Beer-Lambert-Bougher equation (Holben et al., 1998), accounting for the optical depth due to Rayleigh Scattering and absorption by trace gases (O3, NO2).
- AOD comparisons were performed between the sunphotometer and hourly-averaged AERONET level 2.0 data (Holben et al., 1998) for the 500, 670, and 870nm channels (Figure 2).

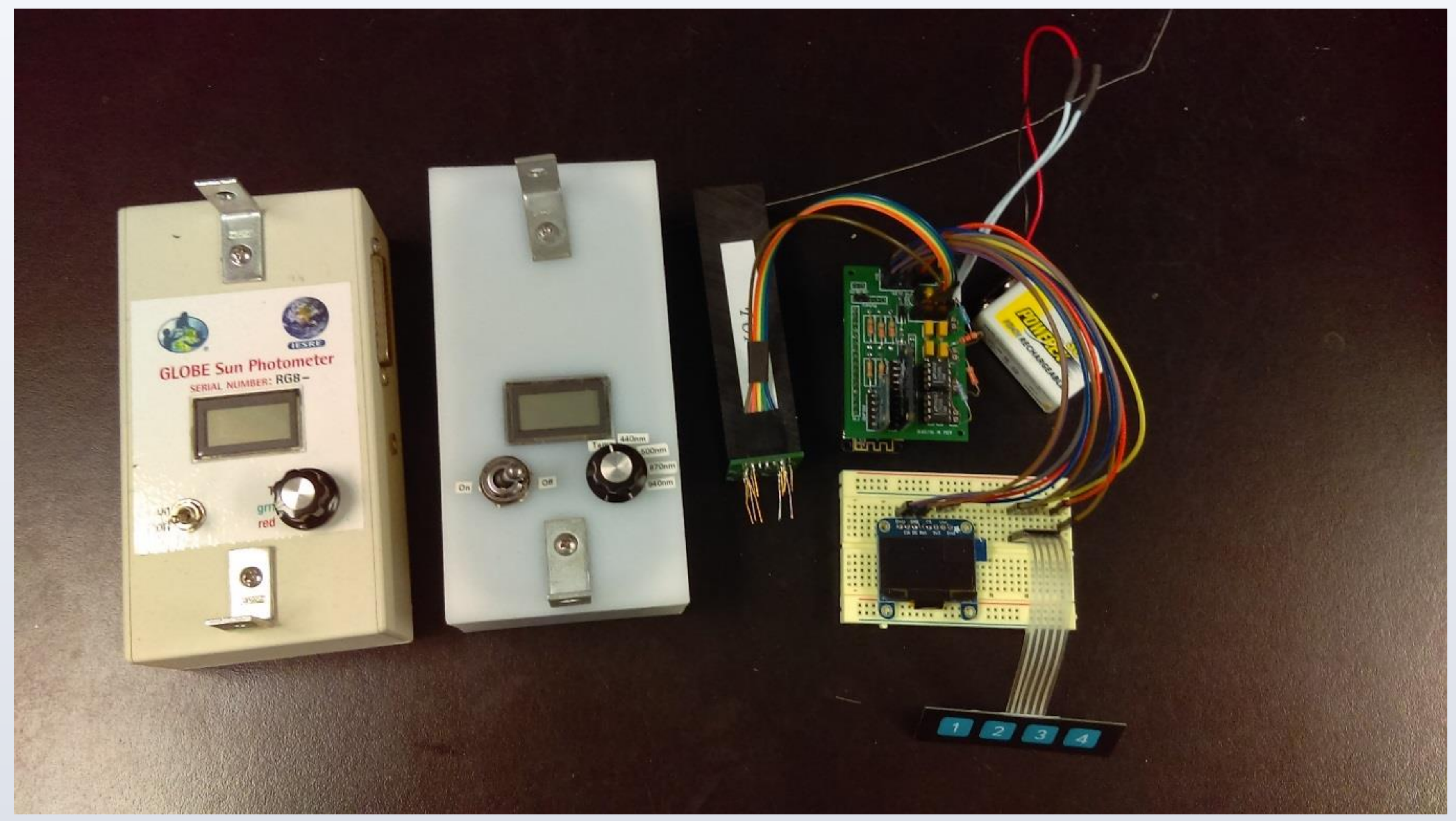

Figure 1. Three "generations" of sunphotometers have been used/developed at Appalachian State University. The first (left) is the GLOBE sunphotometer featuring LED detectors, followed by the filtered photodiode model (middle). The first microcontroller-based model in the final stages of development (right, without case).

Results and Discussion

In general, the handheld sunphotometer AOD agrees well with AERONET. There is negligible instrument bias, since the y-intercept is 0.01-0.02, and the slopes of the correlation plots are all within about 5% of 1.0. However, while the correlation coefficients are reasonably strong for the 500 and 870nm, the 670nm channel was much weaker, with a coefficient of 0.55.

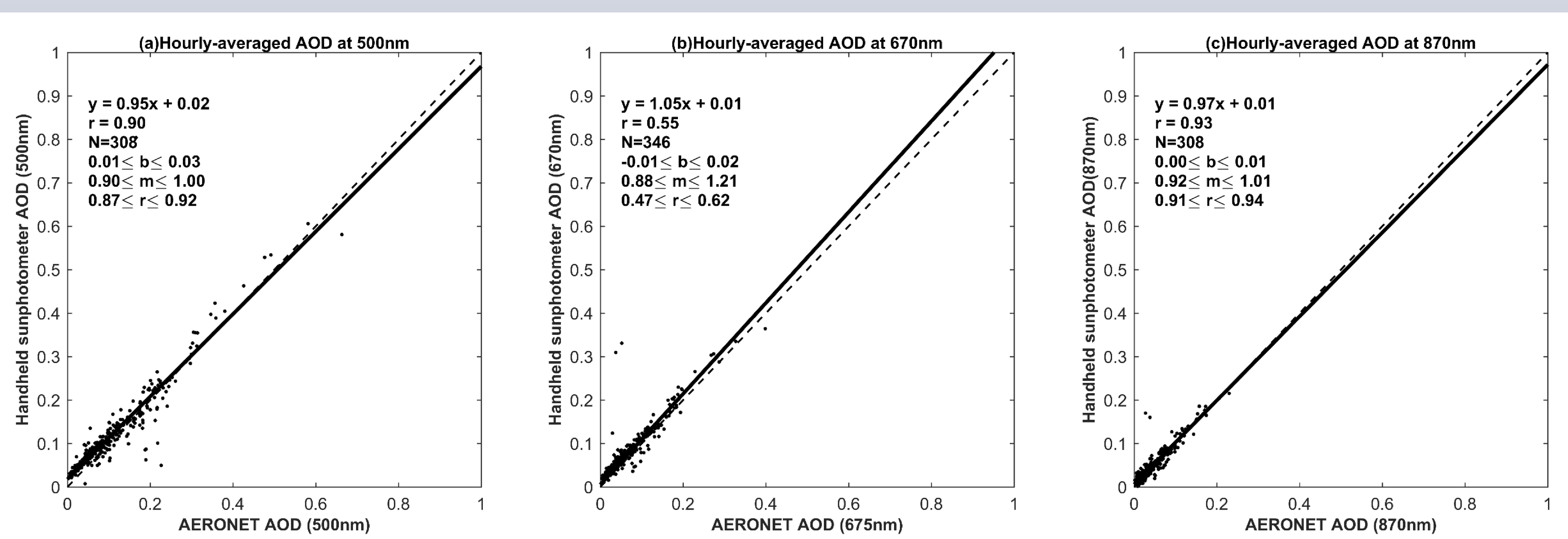

Figure 2. Linear regressions of handheld sunphotometer-measured AOD versus AERONET AOD at (a) 500 nm; (b) 670nm for handheld and 675nm for AERONET; and (c) 870nm. The thick black trace represents the linear equation and the dotted trace is the 1-to-1 line. Values for the 95% confidence intervals for the slope (m), y-intercept (b), and correlation coefficient (r) are shown on each plot .

Conclusions and Future Work

Agreement between handheld and AERONET-measured AOD over the 5-year period is strong, with a slope near 1 and a bias of ~0.01-0.02, roughly equal to the uncertainty in AERONET AOD (Eck et al., 1999). The lack of drift in the photodiodes over time may make them superior to the LED models used by the GLOBE network (Brooks and Mims, 2001), for which we have observed a strong temperature-dependence,. Overall, this initial comparison indicates that the filtered photodiode model is well-suited for deployment to collaborative Citizen Science network sites, beginning at Addis Ababa University in Ethiopia (as part of NSF grant). . Future microcontroller-based models will further improve the ease of data collection.

A. Temperature Dependence of LEDs and Photodiodes

Initial testing to examine the temperature dependence of both the photodiodes and LEDs suggests there is little to no effect when using photodiodes and 500nm LEDs. However, there appears to be a linear relationship between temperature and sensor output for the 670nm LED (about 10 mV/°C) and a stronger dependence for 870nm and 940nm. More in-depth testing will be performed to verify these results.

B. Advanced Data Processing Techniques

While none was implemented for the handheld sunphotometer in this initial study, cloud screening should further improve results. Additionally, only the median values for the calibration constants were used for the handheld sunphotometer; there appears to be very little, if any, drift in the photodiode-based model over time. However, a time-interpolated calibration constant may be a more robust method and improve future agreement.

C. Design of a Microcontroller-Based Sunphotometer

An early prototype and proof-of-concept sunphotometer using filtered photodiodes and a microcontroller was constructed by the ASU Optics class of fall 2016, with the goal of allowing the user to easily collect measurements and transfer them to a computer. The prototype has undergone several revisions as the design requirements have changed, however it will likely be completed fall 2017.

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