Evaluating a Homemade GLOBE Sun Photometer for Aerosol Optical Depth Measurements

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Abstract

Atmospheric aerosols scatter and absorb incoming solar radiation, influencing air quality, climate, and human health. Aerosol Optical Depth (AOD) is commonly used to quantify aerosol concentrations throughout the atmosphere. This study evaluated whether a low-cost, student-built GLOBE Sun Photometer could reliably measure AOD by comparison with a commercial Calitooo Sun Photometer. Measurements were collected in Dearborn Heights, Michigan, from July 14–19, 2026, at 15-minute intervals around solar noon following NASA GLOBE protocols. Across all sampling days, the homemade photometer consistently captured the same temporal changes in AOD as the commercial instrument, although it generally reported slightly higher values. A Canadian wildfire smoke event during the study produced elevated AOD and demonstrated the instrument's ability to detect changing aerosol conditions. Overall, the results suggest that the homemade GLOBE Sun Photometer is a practical, low-cost tool for monitoring temporal changes in atmospheric aerosols and supporting STEM education and citizen science.

Research Question

- Can a homemade GLOBE sun photometer provide reliable measurements of atmospheric aerosols under different sky conditions?
- How closely do AOD measurements from a homemade GLOBE sun photometer agree with those from a Calitooo sun photometer?

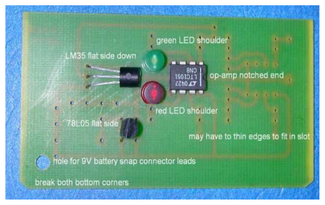
Introduction

Aerosols are tiny particles suspended in the atmosphere that play an important role in climate, weather, visibility, and human health. These particles originate from both natural sources, including dust, wildfire smoke, and volcanic eruptions, and human activities such as transportation, industrial emissions, and fossil fuel combustion. As sunlight passes through the atmosphere, aerosols scatter and absorb portions of the incoming radiation. This interaction can be quantified using aerosol optical depth (AOD), which measures the amount of light removed from the direct solar beam by atmospheric particles. AOD is widely used by scientists to monitor aerosol concentrations, assess air quality, and study atmospheric processes. In this project, AOD values calculated from a homemade GLOBE sun photometer are compared with measurements from a Calitooo sun photometer to determine how well a low-cost instrument can estimate atmospheric aerosol concentrations.

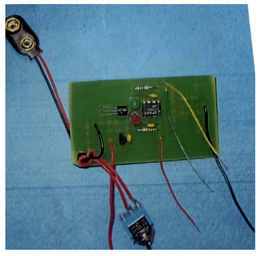
Methods

A two-channel GLOBE sun photometer was assembled by mounting the electronic components onto a circuit board and connecting them to a 9-V battery, selector switch, display, and red and green sensing channels. Each channel contains a filtered photodiode that detects a specific wavelength of incoming sunlight. When light reaches the photodiode, it produces a small electrical current. Resistors and operational amplifiers convert and strengthen this signal into a measurable voltage, which is shown on the instrument display. The completed circuit was secured inside a protective housing with alignment openings that allow the photometer to be aimed directly at the Sun.

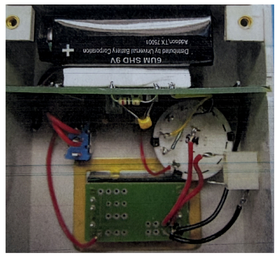
During data collection, the green and red GLOBE voltages, dark voltage, Calitoo AOT values, barometric pressure, time, and sky conditions were recorded every 15 minutes from one hour before to one hour after solar noon in Dearborn Heights, Michigan. Dark voltage was measured by blocking light from the sensors. GLOBE voltages were converted into AOT using the GLOBE equation, and Calitoo AOT values were adjusted to the GLOBE wavelengths before comparison. Additional measurements will be collected over 5–7 more days to increase the sample size and evaluate performance under different sky conditions.



Printed circuit board for the two-channel GLOBE sun photometer, including the red and green LED photodetectors, op-amp, voltage regulator, and supporting circuitry.



Battery connector, electronic components, and wiring before installation in the housing.



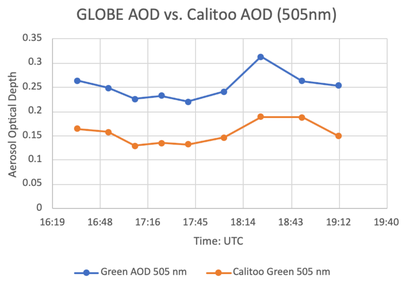
Interior of the photometer: 9-V battery, circuit board, switches, sensors, and completed electrical connections.

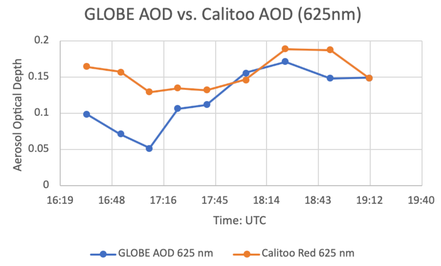


Completed two-channel GLOBE sun photometer with digital voltage display and red/green channel selector.

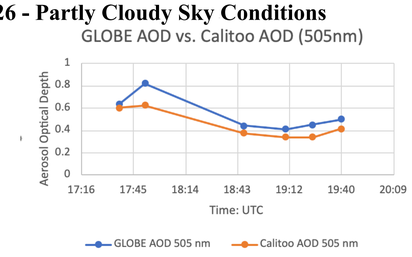
Results

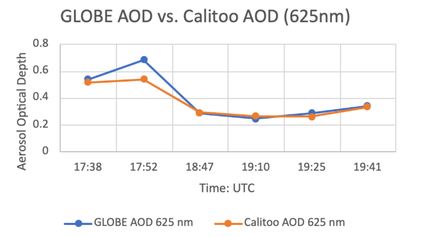
July 14, 2026 - Clear Sky Conditions



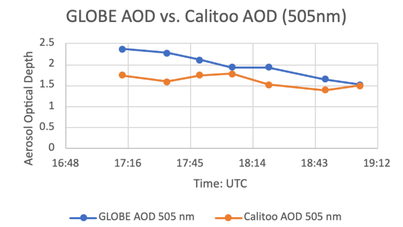


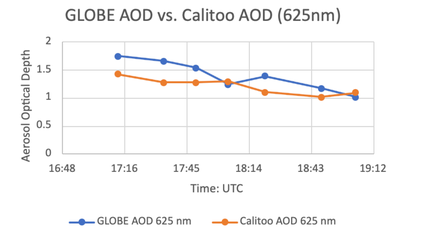
July 15, 2026 - Partly Cloudy Sky Conditions



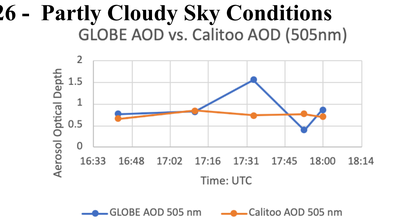


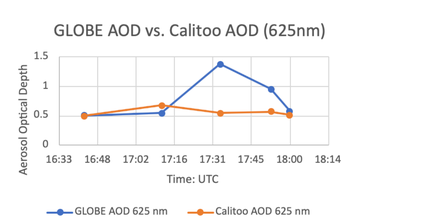
July 17, 2026 - Cloudy Sky Conditions



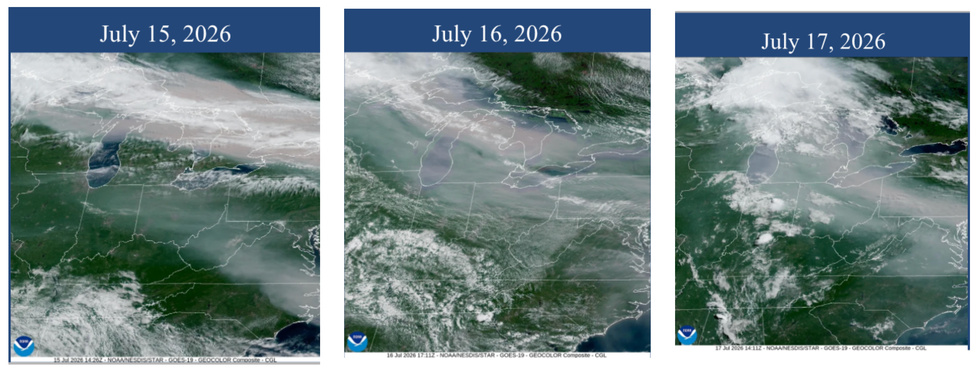


July 19, 2026 - Partly Cloudy Sky Conditions





Canadian Wildfire Smoke Event



GOES-East true-color satellite imagery showing the transport of Canadian wildfire smoke into southeast Michigan from July 14–17, 2026.

The wildfire smoke event provided a real-world opportunity to evaluate the GLOBE Sun Photometer under elevated aerosol conditions.Dense smoke on July 16 blocked the direct solar beam, preventing valid Sun photometer measurements. Measurements resumed on July 17, when smoke remained over the region Both photometers recorded the highest AOD values of the study, demonstrating their response to elevated aerosol loading.

Calculating AOD

$$\mathrm{AOT} = \frac{\ln\left(\frac{V_0}{R^2}\right) - \ln(V - V_{\mathrm{dark}}) - a_R\left(\frac{p}{p_0}\right)m}{m}$$

$$R = \frac{1-\varepsilon^2}{1+\varepsilon\cos\left(\frac{360^\circ d}{365}\right)}$$

$$\tau_\lambda = \tau_{\lambda_0}\left(\frac{\lambda}{\lambda_0}\right)^{-\alpha}$$

V = measured sunlight voltage
Vdark = dark voltage
V0 = calibration constant
R= Earth–Sun distance (AU)
ε= Earth's orbital eccentricity (0.0167)
d= day of the year
aR = Rayleigh scattering constant
p = measured barometric pressure
p0 = standard pressure (1013.25 mb)
m = relative air mass

Discussion

The homemade GLOBE Sun Photometer consistently captured the same temporal changes in aerosol optical depth as the commercial Calitooo Sun Photometer throughout the study. Although the GLOBE instrument generally measured slightly higher AOD values, both instruments responded similarly to changes in atmospheric aerosol loading. These differences were likely caused by wavelength differences, manual Sun alignment, and normal field measurement uncertainty. The Canadian wildfire smoke event provided an opportunity to evaluate the instrument under elevated aerosol conditions. Both photometers detected the increase in AOD associated with the smoke plume, demonstrating that the homemade instrument remained responsive across a range of atmospheric conditions. While the study was limited by its short duration and dependence on clear skies, the overall agreement between instruments supports the reliability of the GLOBE Sun Photometer. These findings suggest that the instrument is capable of producing meaningful measurements of temporal aerosol variability.

Conclusion

This study evaluated the performance of a homemade GLOBE Sun Photometer for measuring aerosol optical depth. Comparison with a commercial Calitooo Sun Photometer showed that the homemade instrument consistently tracked temporal changes in atmospheric aerosols. Although small differences in absolute AOD values were observed, the overall agreement between instruments was strong. The results demonstrate that a low-cost, student-built photometer can produce meaningful aerosol observations using standardized measurement procedures. Continued testing over longer time periods and under a wider range of atmospheric conditions would provide additional validation. Future comparisons with AERONET and satellite observations could further improve confidence in the instrument's accuracy. Overall, the GLOBE Sun Photometer shows strong potential as an accessible tool for atmospheric monitoring, STEM education, and citizen science.

Bibliography

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https://www.researchgate.net/publication/260046776_Development_of_an_inexpensive_handheld_LED-based_Sun_photometer_for_the_GLOBE_program https://www.star.nesdis.noaa.gov/goes/sector.php?sat=G19&or=cgl https://www.globe.gov/documents/10157/380993/Tool%2BKit?utm_source