Nighttime aerosol optical depth measurements using a ground-based lunar photometer

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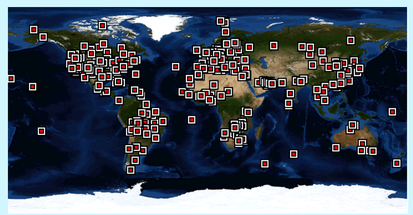
http://aeronet.gsfc.nasa.gov/ Holben et al., JGR, 2001

- Approximately 400 sites around the globe
- Direct sun flux measurements:
  .34, .38, .44, .5, .67, .87, .94, 1.02 um, 1.5 um
- Aerosol optical depth (AOD), Angstrom parameter
- Near real-time results, Publicly accessible data base
- Automated sensors and data processing, enabling long-term continuous monitoring
- Used extensively for wide range of climate & pollution studies, satellite calibration/validation, model validation

Automatic tracking sunphotometer (Commercial product by Cimel Eletronique)



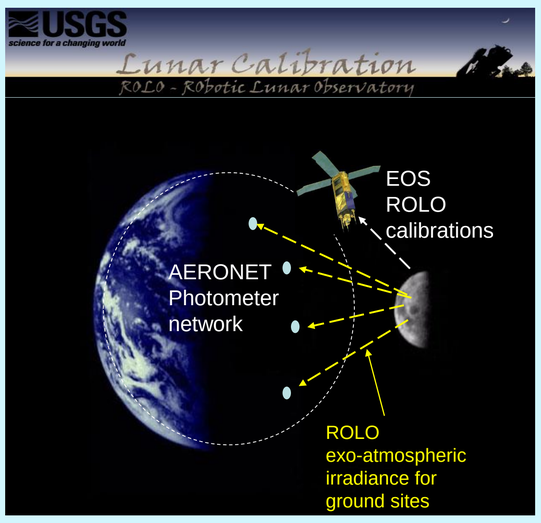
Map of AERONET sites

A new capability for AERONET has emerged to obtain nighttime AODs!

(image credit: http://en.wikipedia.org/wiki/Lunar_phase)

In recent years it was proposed (Berkoff et al., 2011) to combine AERONET network photometer capabilities with a high precision lunar model used for satellite calibrations (USGS ROLO, see Keiffer et al., 2005) to retrieve columnar nighttime AODs. The USGS lunar model can continuously provide pre-atmosphere high precision lunar irradiance determinations for multiple wavelengths at ground sensor locations. When combined with measured irradiances from a ground-based AERONET photometer, atmospheric column transmissions can determined yielding nighttime column aerosol AOD and Angstrom coefficients.

Additional demonstrations have utilized this approach (see Baretto et. al, 2013 & Stone et al., 2013) to further develop calibration methods and to obtain data in polar regions where extended periods of darkness occur. This new capability enables more complete studies of the diurnal behavior of aerosols, and feedback for models and satellite retrievals for the nighttime behavior of aerosols. It is anticipated that the nighttime capability of these sensors will be useful for comparisons with satellite lidars such as CALIOP(Winker et al., 2007) andCATS(McGill & Yorks, 2014) in additional to ground-based lidars in MPLNET(Welton et al., 2001) at night, when the signal-to-noise ratio is higher than daytime and more precise AOD comparisons can be made.

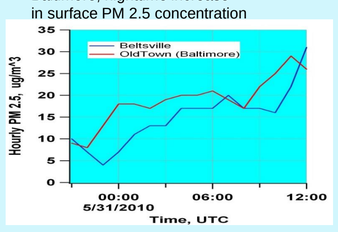


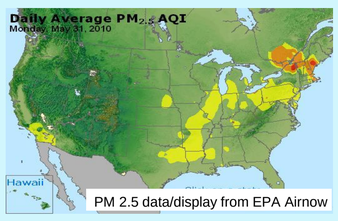
Prior Work: Initial nighttime demonstration with a "sun" photometer

Initial automated measurements started in late 2009, using a "sun" photometer that was never designed for lunar irradiance levels. Nevertheless, this early-stage measurement combined with ROLO information demonstrated the first nighttime AODs near full-moon, and later in 2010 captured a nighttime pollution event in the Washington-Baltimore region shown here.

Nighttime pollution event: 31 May, 2010

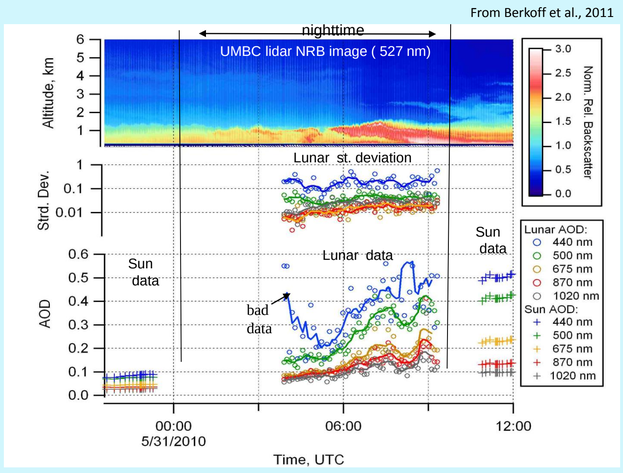
Baltimore; nighttime increase in surface PM 2.5 concentration





PM 2.5 data/display from EPA Airnow

From Berkoff et al., 2011

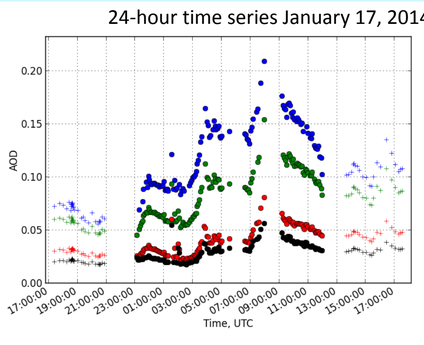


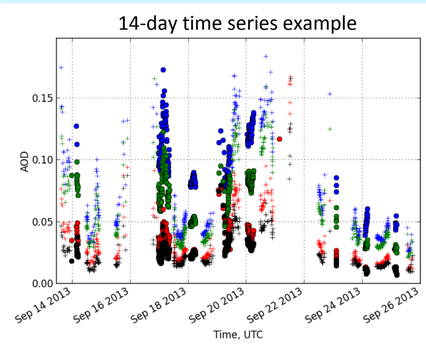
The 31 May data captured the arrival of a pollution event in the Baltimore area. Nighttime, lunar-derived AODs agree with Lidar backscatter and solar data obtained before and after the event. **NOTE**; initial 440 nm data was bad due to large air mass attenuation.

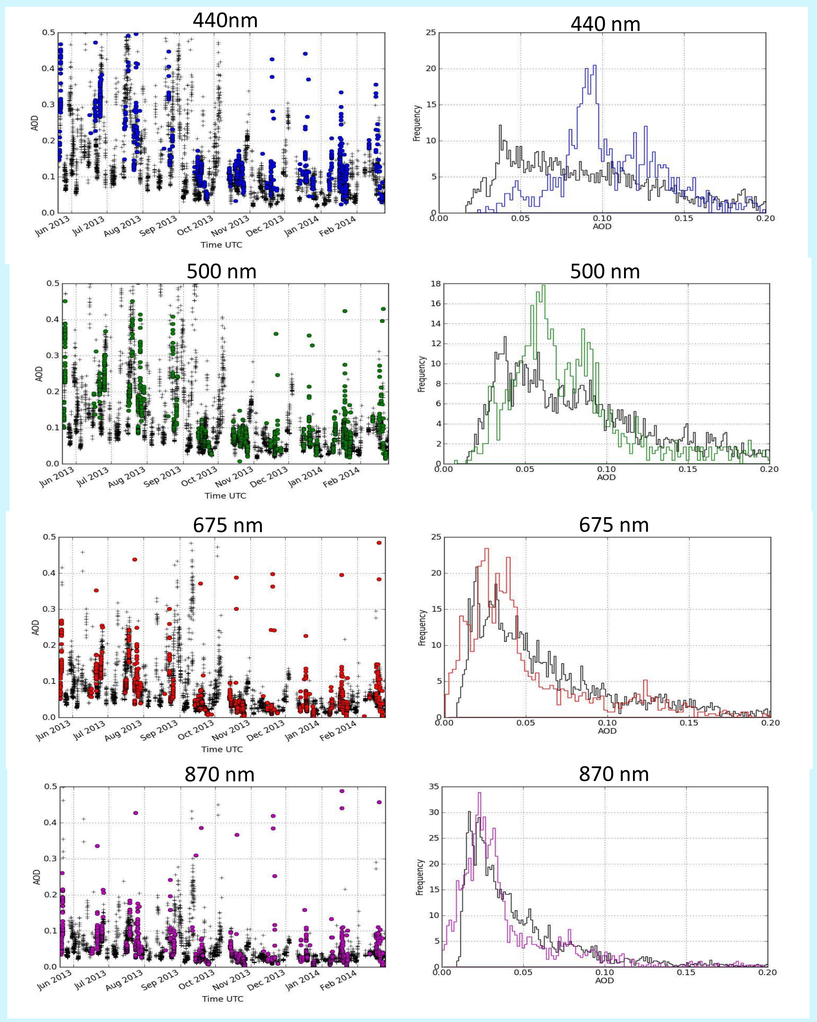
Data collection with enhanced photometer in 2013 & 2014

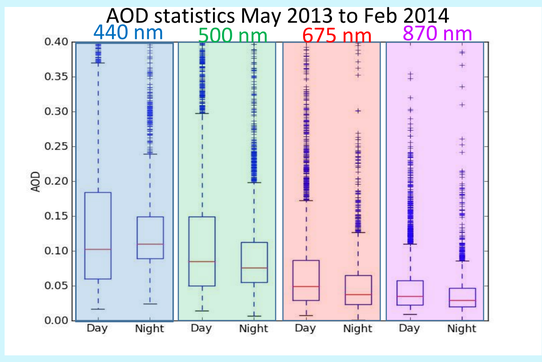
In this work, we present a new 9 month data record (May 2013 to Feb 2014) of nighttime AODs obtained with a prototype lunar photometer modified specifically for lunar irradiance levels. This photometer is the same size and shape as the sun-photometers used in AERONET. Approximately 1,700 lunar irradiance measurements were obtained from May 2013 to Feb 2014 at NASA-GSFC, providing an extended set of nighttime aerosol AOD data. The plots below show a couple of short time-frame examples (Left: 24-hour, Right: 14-day) with lunar data as circles, colored by wavelength. A separate co-located sun-photometer recorded daytime data (AERONET level 1.5) and is shown with "+" markers in between the night observations.

Time series examples
440 nm(blue), 500 nm(green), 675 nm(red), 870 nm(black)









May 2013- Feb 2014 Data Set

On the left side, all time series data from May2013 to Feb 2014 are shown, colored circles are nighttime AODs, while black "+" markers are co-located daytime AODs (AERONET level 1.5).

In general, magnitude and variability of AODs are larger during summer months for both day and night data. Both day and night data sets have some residual cloud contamination effects, resulting in outliers that will be further reduced once additional data quality steps are applied.

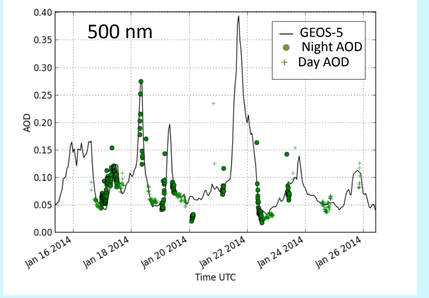
On the right side, day & night AOD distributions are shown, colored lines are nighttime AODs while black lines are the co-located daytime AODs.

The box-and-whiskers plot to the lower left summarizes the day and night AOD statistics for each wavelength with median (red line), lower & upper quartile (box) 1.5*inner quartile range (whiskers), and outliers ("+" markers).

Nighttime data display lower variability than daytime for all wavelengths. Median AODs are slightly lower at night, with the exception of the 440 nm wavelength. These results are preliminary, and additional review will be needed to bound instrument bias differences between the day and night photometers as well as other factors. However, these initial results generally seem consistent with the expected diurnal behavior of aerosols.

Nighttime Comparisons to GEOS-5 model

In addition to future CALIOP comparisons, the availability of nighttime AOD measurements are expected to contribute to aerosol models. The plot to the right is an example of night (circles) and day ("+" markers) photometer AODs compared with AOD (black line) calculated from the GEOS-5 produced "MERRAero" aerosol reanalysis. In MERRAero, the GEOS-5 global modeling system with the online GOCART aerosol module was run at 0.5 x 0.625 latitude-by-longitude horizontal resolution, driven by the MERRA atmospheric reanalyses and assimilating AOD based on MODIS Terra and Aqua measurements.(Da Silva et al, 2012). A more detailed correlation study is anticipated to further compare the entire set (May 2013 to Feb 2014) of nighttime AODs to GEOS-5.

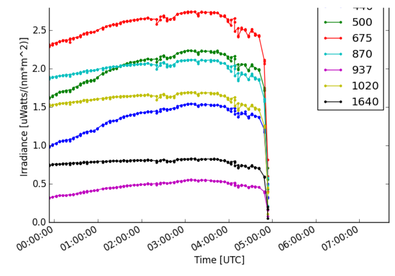


*GEOS-5 data provided by Peter Colarco & Arlindo da Silva

Summary & Future Plans

Lunar photometer set-up at the NASA LaRC CAPABLE trailer

Example Irradiance measurements from the NASA LaRC CAPABLE trailer



- The lunar photometer offers a unique opportunity to validate the aerosol optical depth retrievals of CALIOP and other spaceborne lidars at night when the signal to noise ratios are highest. An experimental lunar photometer at NASA Langley could be used to take collocated measurements at CALIPSO nighttime overflights (Williamsburg VA, Duck NC).
- Further analysis of this existing nighttime data will help to assess day v. night aerosol characteristics and correlation relationships with models (ie. GEOS-5).
- Day/night capable photometers are now commercially available (Cimel Electronique) and AERONET is currently incorporating day/night capabilities at multiple sites around the globe.
- A new lunar ROLO interface has been developed by USGS for use by AERONET to enable fully automated multi-site network operations.
- The nighttime photometer that was used to collect this data-set has been re-located to NASA Langley's CAPABLE trailer (Hampton, Virginia) and is continuing to collect nighttime AOD data. This system can potentially be transported to nighttime CALIOP overpass locations in the future.
- Although the lunar cycle is expected to limit the frequency of observations to 30%–40% compared to solar measurements, nevertheless this is an attractive extension of AERONET capabilities.

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