University of Maryland Baltimore County - UMBC
Phys650 - Special Topics in Experimental Atmospheric Physics (Spring 2009)
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http://userpages.umbc.edu/~martins/PHYS650/

Calibration of the Sunphotometer and other radiometers:

- *Calibrations in the Lab:*

At this point you have already performed a few procedures for characterization and calibration of your portable sunphotometer. You have measured:

- Spectral response in detection and emission modes
- Field of view (FOV) of the plain LED
- FOV of the LED + collimator
- Luminance and radiance calibration at the integrating sphere with the plain LED (in most cases if not all, there was not enough sensitivity to measure the signal from the integrating sphere with the LED + collimator).

For the luminance calibration you have compared the signal coming out of the integrating sphere with the voltage signal produce by your photometer and most of the students showed excellent linear relationships with intercepts crossing near zero. Do not forget to subtract the effective dark current of your system (signal when the LED detector is covered).

For the radiance calibration, your ultimate goal should be to quantitatively calibrate your photometer inside the box with the LED + collimator aligned. Since most photometer did not have enough sensitivity for this measurement, we suggest the following procedure to complete the photometer calibration in front of the integrating sphere:

1- use your measurements with the wider FOV (plain LED) and calibrate the system's radiance [W m^{-2} um^{-1} sr^{-1}] measurements in the right wavelength range
2- Determine the relationship between the voltage readings and the radiation flux arriving at your detector [in W m^{-2}] for the plain LED case
3- Determine the system's Radiance x Voltage calibration for the case of LED + collimator.
4- Determine the relationship between the voltage readings and the radiation flux arriving at your detector [in W m^{-2}] for the case of LED + collimator.

In your calculations you should use the relationship between the solid angle of the plain LED and the solid angle of the LED+collimator. You should also determine the number of photons arriving at the surface of your detector. This number is essential on the radiometric analysis of any quantitative optical instrument and should be understood thoroughly.

- ***Alignment of your photometer:***

The FOV measurement of the LED + collimator should be performed only after your photometer is fully assembled and the box is closed. At that point, you can mark the center of the FOV in the target glued on the side of your photometer. Though this alignment could have been done in the lab during your final FOV measurements, it can also be perfectly performed during your solar observations. In order to do so, make a mark on the front target (draw a cross, make a dot, or glue black tape with a hole at the center) which will be projected on the second target when the front of the instrument is aligned with the sun. Glue a piece of paper on the back target, and make an alignment mark on the projected shadow of the front target when the instrument is perfectly aligned with the sun. A perfect alignment with the sun corresponds to the maximum signal that you can obtain with your photometer while pointing it to the sun. You should mark the back target exactly at the geometry that provides you the maximum signal. You may have to repeat this operation a few times to make sure you have obtained the right alignment. The use of a pointing tripod or other type of support can also help. An exception to a maximum signal during the perfect pointing to the sun may occur in those cases when the LED presents a dark spot on the center of the FOV. In these cases you may want to find the local minimum at the center of the LED.

- ***Calibration of the Sunphotometer using Langley plots:***

Langley plot is a simple and accurate procedure to provide the calibration of sunphotometers. In fact, most (if not all) professional sunphotometer systems (like Aeronet) rely on Langley plots as their primary calibration procedure and not on laboratory calibrations, because Langley plots can be extremely accurate, simple and versatile. The idea of a Langley plot follows directly from Lambert-Beers law defining the transmittance of the atmosphere:

$$I = Io\ exp(-\tau/cos\theta) \qquad (1)$$

Where Io is the intensity of the solar radiation at the top of the atmosphere; I is the intensity of solar radiation arriving at Earth's surface, τ is the atmospheric optical thickness (including scattering and absorption by aerosol particles and gas molecules), θ is the solar zenith angle (can be measured or calculated for each latitude, longitude and particular date and time).

Since the Voltage measured by your photometer is proportional to the light intensity arriving at the detector, the same expression can be written as:

$$V = Vo\ exp(-\tau/cos\theta) \qquad (2)$$

where *Vo* is the voltage that your instrument would show by measuring solar radiation at the top of the atmosphere, V is the measured voltage on Earth's surface, and the other variables are the same as the above equation. For the objective of measuring the atmospheric optical thickness, the calibration of the sunphotometer corresponds to simply determining the extraterrestrial constant *Vo*. The optical depth can then be determined as:

$$\tau = -\cos\theta \cdot \ln(V/Vo) = \cos\theta \cdot [\ln(Vo)-\ln(V)] \qquad (3)$$

or, alternatively, one can write the linear expression of *ln(V)* as a function of the atmospheric air mass, defined as $1/\cos\theta$:

$$\ln(V) = \ln(Vo) - \tau/\cos\theta \qquad (4)$$

The methodology to obtain the Langley plot calibration consists in obtaining several measurements of *V* as a function of the solar zenith angle θ, until you get enough points to fit a straight line on the expression above (figure 1) and obtain the linear coefficient (or the natural logarithm of the extraterrestrial constant *Vo*). The extraterrestrial constant is a number that applies to each individual instrument. It accounts for all the particularities of that particular instrument including gain of the amplifier, efficiency of the LED, etc.

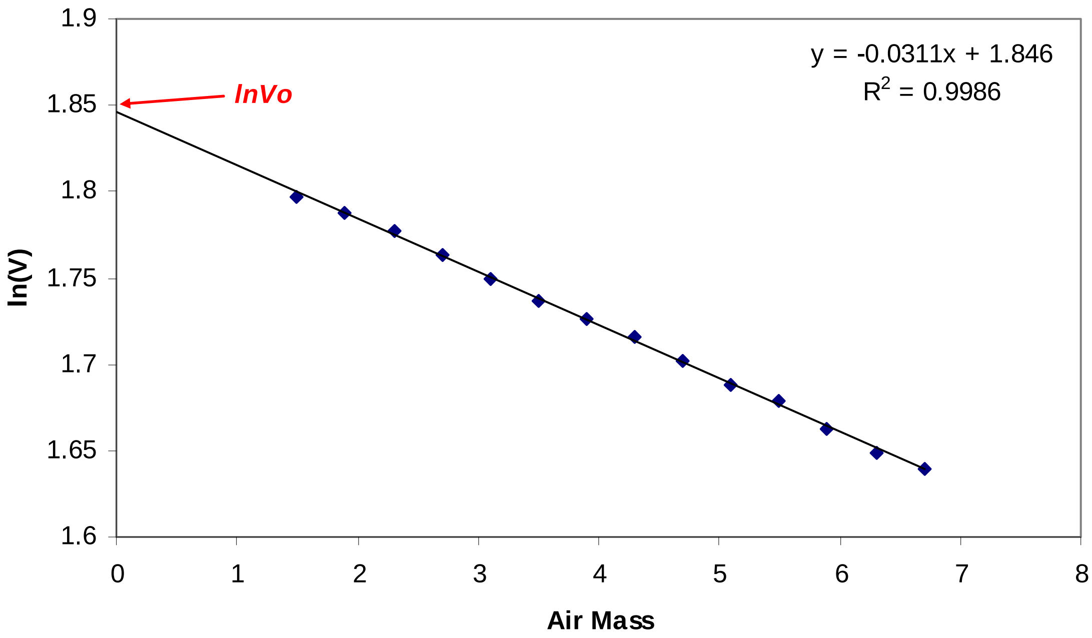

Figure 1 – Example of Langley plot and linear fit.

A good Langley plot depends on having enough variation in the atmospheric air mass while the optical thickness (which is the slope of equation 4) remains constant. The largest variation of air mass as a function of time happens in the morning or at the end of the day, giving you more chances of obtaining a constant atmosphere during the period of your measurements. Due to atmospheric refraction, surface albedo, and other issues, the air mass should be limited to angles smaller than 65 or 70 degrees. You should be able to see these non-linear effects in your own calibration. A good Langley plot also requires a cloud free sky and is usually more accurate in clean days when the atmospheric optical thickness is lower, though the main requirement is for the optical thickness to be constant during the period of your measurements. More accurate Langley plots can be obtained at the top of high mountains in locations with low atmospheric optical thickness. Aeronet calibrations for instance are performed on the top of Mauna Loa in Hawaii.

The solar zenith angle or the air mass can be directly measured during the time of each photometric measurement, or it can be calculated as a function of the day, time, latitude and longitude of the measurement. For calculations, you must be sure that your clock is very accurate during the measurements. Even slight inaccuracies in time, latitude and longitude can introduce significant errors in your measurements. A link to the spreadsheet (solar-angle-calculations.xls) to calculate the solar geometry (solar zenith and azimuth angles) can be found in item 11 of the link: http://userpages.umbc.edu/~martins/PHYS650/External_Links_and_Resources.htm.

Each student must perform Langley plots for the calibration of his/her own sunphotometer.

- ***What to do after you are done with your calibrations:***

After your Langley plot calibration, you want to compare your results with the previous calibration that you performed at the integrating sphere. Using the solar spectrum produced by SBDART at the top of the atmosphere (see SBDART links at: http://userpages.umbc.edu/~martins/PHYS650/External_Links_and_Resources.htm), add the extraterrestrial constant to your previous calibration of spectral radiance versus radiance performed at the integrating sphere. Compare and discuss your results.

At this point, you are ready to start using your sunphotometer to perform measurements of the optical depth of the atmosphere. Your direct measurements will be composed by the sum of the optical depths of the gas and aerosol scattering and absorption components:

$$\tau_{\mathrm{atm}} = \tau_{\mathrm{gases}} + \tau_{\mathrm{aerosols}}$$

Our ultimate goal is to measure only the aerosol optical depth ($\tau/\cos\theta$). The optical depth of the gas component can be estimated using SBDART runs without aerosols.

Next, start using your photometer as much as you can. You should design experiments where you are going to use it to measure the aerosol optical depth of the atmosphere and compare it with other available measurements. You should make plans to intercompare your measurements with Aeronet, with Lidar, with MODIS retrievals, with the filter station measurements, etc. You should also intercompare with your colleagues in order to check the accuracy of your measurements, as well as to increase the amount of information by using multiple wavelengths.

Take notes, save, and organize all your data and intercomparisons for your final project report.