SPECTRAL SUN PHOTOMETRY

It’s History, Purpose and Applications

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What is a Sun Photometer?

A sun photometer is a device which is used to measure the sun's radiance. Its design can have varying degrees of complexity, which allow for different kinds of data acquisition, but its general idea is essentially the same. By collecting direct sunlight through a narrow bandwidth, the device is able obtain information and produce results such as the amount and types of different gases and aerosol present in the atmosphere. It is also able to monitor the amount of existing pollution and haze. (Haze-SPAN)

There are many factors that influence the outcome of a sun photometer measurement. Time of day, atmospheric circumstances, and sunlight are a few of the conditions which effect the data obtained. Although direct sunlight is used in order to collect information, the reality is that the energy measured on the ground is not equivalent to the energy released by the sun. Since there are particles in the air due to gases and aerosols, light from the sun is absorbed and scattered when it passes through the atmosphere. Two processes of scattering, Rayleigh scattering and Mie scattering are prominent forms of light dissipation. Rayleigh scattering occurs when molecules of air, (such as oxygen and nitrogen), scatter light as they interact with each other. Mie scattering occurs because of aerosols in the air, (such as bacteria, salt, black carbon particles created by fires, sulfates, pollen, smoke, nitrates, miniscule droplets of water, dust etc…) The scattering and absorption of light and energy means that the final measured result is a combination of both the energy released by the sun and the effect of the atmosphere on that sunlight. To understand this relationship we turn to Beer's Law. In the 1800's a German physicist by the name of August Beer derived a principle that describes how the strength or intensity of a beam of light becomes smaller or is decreased as it travels through various thicknesses within a medium. In other words, the natural logarithm of the sun photometer's Extraterrestrial Constant minus the natural logarithm of the intensity of sunlight determined by the sun photometer, all divided by the air mass, equals the optical thickness of the atmosphere when measured using a sun photometer. (Haze-SPAN, Sun Photometer, Rayleigh scattering, Hanson)

Langley Plot and History

Today it is possible to determine the amount of light that is present without any interference from the atmosphere using a process called the Langley Method. Developed by Samuel Pierpont Langley between 1878 and 1880, his approach the measures the extraterrestrial constant, (the total amount of sunlight reaching the top of the atmosphere), without ever leaving the ground.

Born on August 22nd, 1834 in Roxbury Massachusetts, Langley's contributions would become some of the most important work the world of science has ever seen. His education as a child was well-rounded, attending private schools in Boston until graduating high school in 1851. After learning the ins and outs of Civil Engineering and Architecture he left Boston in 1857 to pursue his career. For seven years he lived and worked in Chicago and St. Louis. In 1864 Langley traveled to Europe with his brother. For one year he visited beautiful art galleries and astronomical observatories, developing an interest in both as well as in the work produced by various scientific institutions. Armed with a newly acquired passion, he worked toward becoming a significant member in this field, and upon his return to Boston in 1865 he became an assistant at the Harvard College Observatory. From there his achievements only increased; appointed assistant professor of mathematics in the United States Naval Academy at Annapolis in 1866, and leaving a year later for the Western University of Pennsylvania to be the director of the Allegheny Observatory and professor of astronomy and physics. He would remain at this post for 20 years. During his time Langley accomplished a number of substantial scientific advancements. He was responsible for introducing a system of standard time distribution to different railroads and cities, and from the revenue he earned by implementing this system he was able to fund much of his highly esteemed and appreciated work regarding the sun.

Samuel Langley's considerable body of work as a well respected and experienced astronomer has provided applications that are still in practice today. In addition to the Langley method, he invented the bolometer, and was heavily involved in the examination of radiation, including: the distribution of radiation over the sun's surface and in sun spots; the lunar energy spectrum and the temperature of the moon; the solar energy spectrum and its extension toward the infra red; the spectra of terrestrial sources and determination of hitherto unmeasured wavelengths; and finally, as previously mentioned, the absorption by the earths atmosphere of the radiation of the sun, and the determination of the solar constant of radiation. (Walcott 254) He was certain of the implications and practical uses this research would have on climate and life on the planet in the future.

Langley's contributions far exceed the endeavors mentioned here. Throughout his life he would continue to excel, publishing papers, books, and by becoming the secretary of the Smithsonian Institution. He is even recognized, and to some, most notably viewed as a founder and inventor in the world of aviation. In 1896, after the end of his experiments in the field of man-made flight, he is quoted as saying these truly foretelling words:

> I have brought to a close the portion of the work which seemed to be specially mine—the demonstration of the practicability of mechanical flight—and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others. The world, indeed, will be supine if it do not realize that a new possibility has come to it, and that the great universal highway overhead is now soon to be opened.

(Walcott)

LED Sun Photometry: Forrest Mims

Sun photometry has come a long way in the last few years. Scientists have discovered that LED's are not only great light emitters, but also make excellent light detectors at specific wavelengths. The use of LED's in sun photometers are becoming increasingly popular. In fact, an amateur scientist and author named Forrest Mims III has developed a home made sun photometer; easily constructed and utilized by almost anyone. His haze-SPAN website: http://haze.concord.org/ gives thorough instructions and well worded explanations about the photometer. Educated at Texas A&M University where he graduated with a degree in government with minors in English and History, he is currently the Chairman of the Environmental Science Section of the Texas Academy of Science as well as the editor for *The Citizen Scientist,* a journal from the Society for Amateur Scientists. Mims websites, articles, and books (most notably his Engineer's Mini-Notebook series) are a helpful resource for understanding science concepts that would otherwise perplex most individuals. Although he has no formal schooling in the field of academic science, Mims has successfully made learning physics and engineering easy, fun, and very user friendly. (Forrest Mims, Haze-SPAN)

Objective:

The intent of this study was to detect and measure the various properties of the sun and atmosphere.

Although seemingly broad, sun photometry is actually made up of several distinct and useful components. There are a myriad of factors which comprise and effect the atmosphere and sun photometry makes it possible to observe and understand its inner workings. Various gases such as oxygen, nitrogen, carbon dioxide and water vapor are just a few of the components that are often studied. In truth, just one of those elements can be scrutinized, providing a wealth of information about our ecosystem. An example of this is water vapor concentration, which is observable at a wavelength of 940 nanometers. Its recordable matter is dependant on several variables including the position of the sun (which depends on the time of day), and the season; all of which may be detected using sun photometry. From this information many more determinations are able to be made. Water vapor concentration is related to humidity, including but not limited to the amount of humidity existing in our area. That, in turn, can be applied to other fields of study. For instance, when humidity is decreased, a greater number of fires occur; fire emits more aerosols in to the air, and aerosol, which is able to be detected and studied using a sun photometer, can provide a broader knowledge about the intensity and frequency of fires in the area.

This leads to our primary subject of interest when studying the atmosphere: Aerosol. In terms of sun photometry, aerosol is not a substance sprayed in to the air as most would suspect. It is instead a suspension of small particles within a gas, and, as illustrated earlier, aerosol has a significant impact on the earth's atmosphere.

Aerosol Direct Effect:

The Direct Aerosol Effect is an explanation of how aerosol particles interact with the atmosphere. Since the reflection of radiation by the aerosols in the atmosphere depend on the size of the particles, two types of scattering, Rayleigh scattering and Mie scattering are detected. As stated before, Rayleigh scattering involves the dispersion of radiation by all molecules in the air, while Mie scattering usually scatters and reflects radiation using particles of a specific size (about 0.1 to 2 micrometer.) It occurs when the size of the particle and the size of the wavelength are roughly equal. When this happens some of the radiation, or light, is reflected back toward space; a process called back scattering. If a particle is a great deal smaller than the incoming wavelength of light, the particle will have little to no influence on its path; any particle, very large or small, that is comprised of soot, carbon or any other light absorbing substances will cause the wavelength to be absorbed (this results in the production of heat); non-absorbing particles that are much larger than the wavelength will have little to no effect. Back scattering transpires when the particle is past a critical angle, to which the wavelength is not diffracted, but is instead reflected. This occurrence is especially apparent when the aerosol particle contains liquid, which is often the case. (Slania)

Data:

The apparatus utilized for this procedure consisted of a target point and radiance detector (essentially a metal tube), used to collect sunlight; a fiber optic sensor which was connected to a spectrometer; a Spectrometer made by Ocean Optics, including both master and slave; and Ocean Optics software (connected to the spectrometer and sensor through a USB port.) This was used to record the data on to the computer.

The trial was performed on a visually clear morning and measurements were taking at periodic intervals throughout the day. The equipment was set up on the roof of the Leifson Physics Building where all of the measurements were acquired. Data was obtained by using a small hole to focus the direct incoming light of the sun on to a small target point. Alignment with the target point helped to make sure that sunlight was entering the radiance detector in order to be measured by the sensor head. Once the sensor began to produce data on the computer, both the master readout and the slave readout were saved and the corresponding times of each acquisition were recorded. Using this data several graphs were constructed detailing the information gathered.

Step By Step Process of the Day (February 12th, 2008):

- I gathered the equipment and headed upstairs to the roof
- I set up the equipment, the computer on one chair and the spectrometer on another chair with the radiance detector and sensor facing the sun.
- At different intervals I would take a measurement, making sure the sun was shining directly on to the target to the best of my ability.
- At that time I would record the data on to the computer, using the Ocean Optics program, saving the readouts of both master and slave.
- I also kept an account of the exact time I recorded each measurement.
- I took two measurements at different times of dark spectra, as a control.
- When the sun was setting I completed my data acquisition and made sure it was saved.
- I packed up the equipment and put it back in the lab.

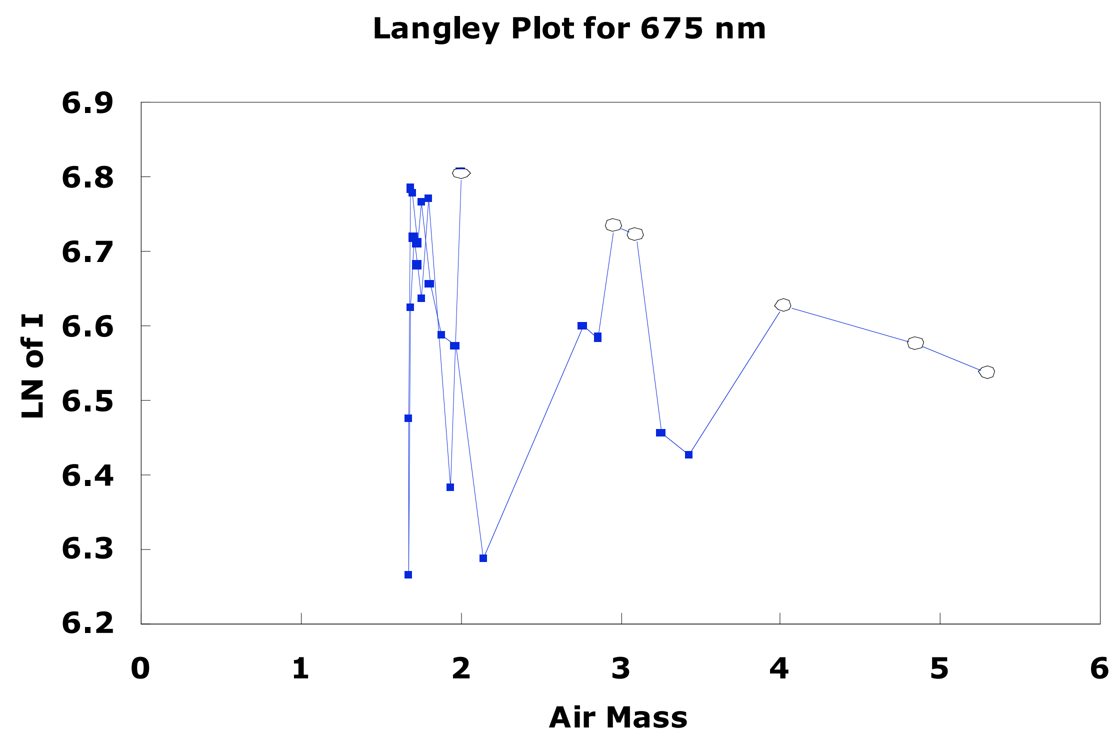

Figure 1: Graph of 'Master' Langley Plot for 675 nm

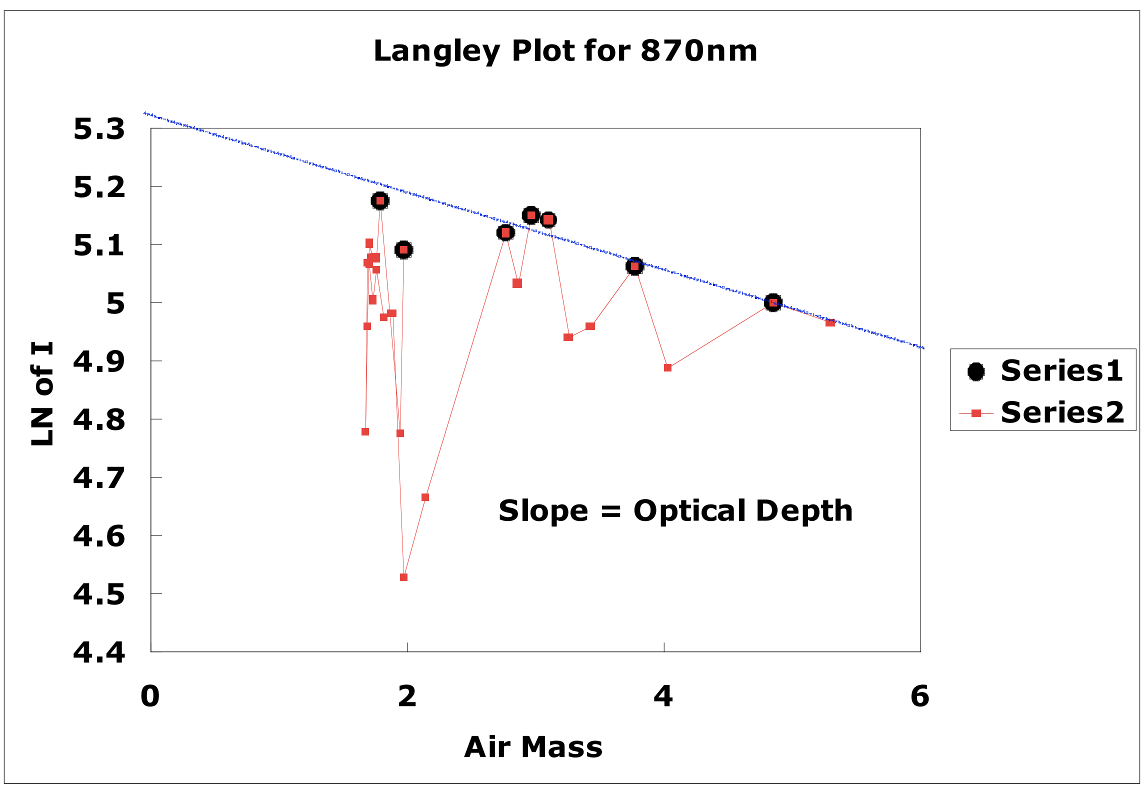

Figure 2: Graph of 'Slave' Langley Plot for 870 nm

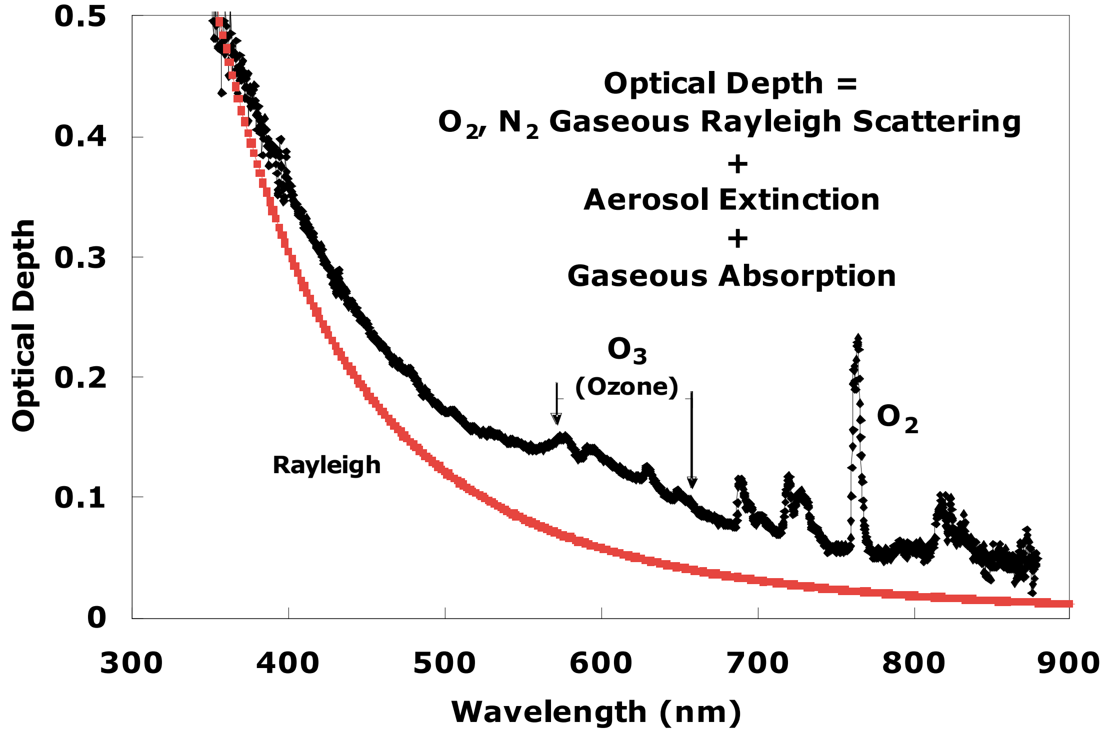

Figure 3: Graph of ‘Master’ Optical Depth Plot

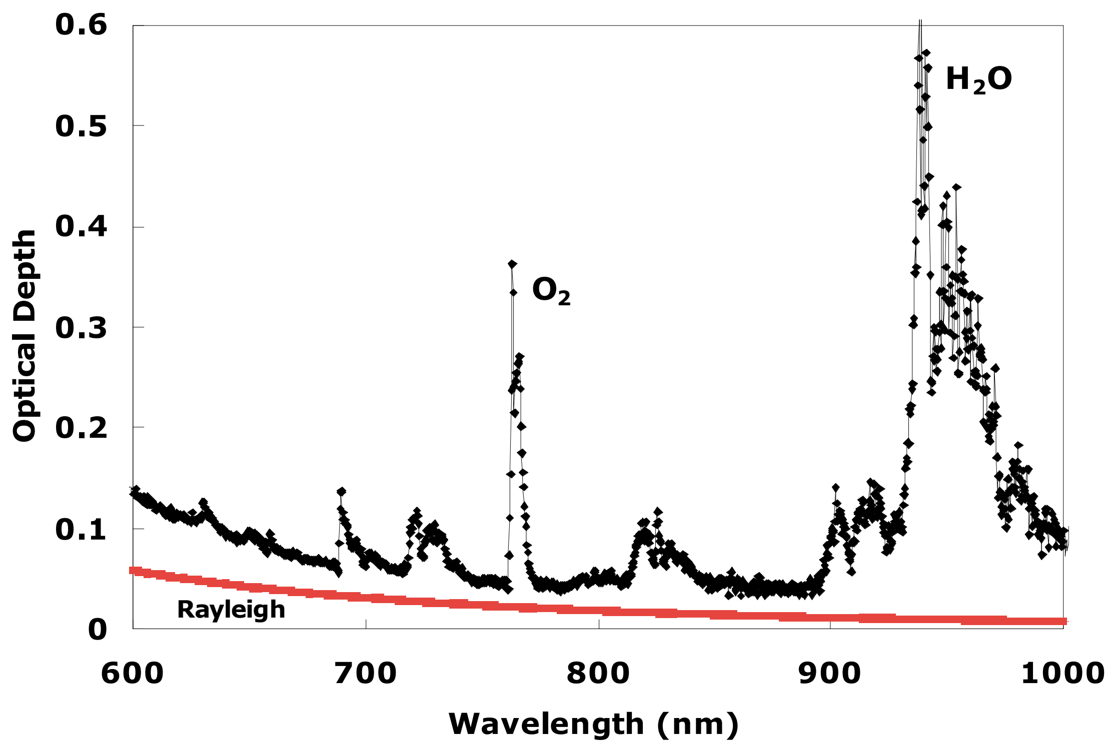

Figure 4: Graph of ‘Slave’ Optical Depth

Trials:

There were a few obstacles during the process of this study. After the first section of research was completed, it was determined that the slave sensor did not yield results comparable in strength to that of the master. This could be attributed to a defect in the equipment itself, for example, poor alignment between the sensor and the detector, or possibly human error.

Another potential obstacle was ensuring that there was accurate alignment within the radiance detector which streamed the sunlight to the sensor. This issue was difficult to resolve because it was nearly impossible to control what was going on within the metal tube. It was uncertain whether stray light was entering (as opposed to direct sunlight), or whether all of the intended light was coming through and reaching the sensor in its entirety. Light entering the apparatus may not have had a direct path to the sensor, bouncing instead within the cylinder before reaching the sensor. This setback was ultimately rectified following this study. The apparatus was modified with a new radiance detector which was much longer and contained an aperture in the middle to reduce stray light. The new detector was found to have performed quite a bit better than its ancestor. Additionally, the software was tweaked and during the gathering process the background noise was zeroed out after every measurement, instead of only periodically as before.

Conclusion:

The study performed yielded a number of very practical applications because the data gathered generated a useful amount of information. When looking at the optical depth associated with the data, it is possible to characterize the total optical depth of the atmosphere, including aerosol and gases for that day. One may also use the sun photometer as a calibration device if desired.

In addition, through experimentation it was realized that the design of our sun photometer could be much improved. It is necessary for the sensor head to be positioned and calculated to best capture only direct sunlight. A new design featuring a longer radiance tube containing an aperture was created to maximize the sunlight arriving at the sensor. Alignment is critical, and this was an extremely useful insight to have gained.

Finally, sun photometry is becoming a popular subject in science today. With the ever changing climate, and the growing emphasis on "going green" the earth and the things that influence its changes are becoming a forefront topic.

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