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Independent Research Report: Attenuation of Light by Aerosols

Introduction.

Due to their impact on both health and environmental issues, aerosols are the focus many studies. In this project, a diode laser system was developed to observe the attenuation of light by aerosols. Aerosols are essentially matter suspended in the atmosphere. When light travels through this suspension, the aerosols cause the light to scatter. Since the light is scattered, the amount of light which travels forward is reduced. By measuring the amount of this reduction, or attenuation, a relative density-size can be inferred.

The total scattering occurs by two processes: Rayleigh scattering and aerosol scattering. Rayleigh scattering is not a consequence of aerosols. Very small molecules, like N_2, are responsible for this process. In order to measure the scattering, light is passed through a distance, L, of air. The intensity of the light is measured at the emitter, I_0, and at a distant detector, I_f. The transmittance, T, can be found by examining the ratio initial to final intensities. Attenuation is when transmittance decreases.

$$T = I_f / I_0 = exp[-(\tau_R(\lambda)+\tau_S(\lambda))]$$

Here, τ_R is Rayleigh optical depth, the contribution to the attenuation by Rayleigh scattering, and τ_S is aerosol optical depth, the contribution from aerosol scattering. As usual, λ is the wavelength of the light. Optical depth is unit-less and, in general, path dependent. In general, this attenuation should in include absorption, but it is my understanding that the absorption contribution is comparatively very small.

Both τ's are found via integration of their extinction coefficients over the distance traveled.

$$\tau = \int_0^L \alpha(\lambda,x)dx$$

In this project, the characteristics of the incident air are assumed to be constant throughout the path, so $\alpha(x)$ is a constant, α. It follows that

$$T = I_f / I_0 = exp[-(L*(\alpha_R(\lambda)+\alpha_S(\lambda))]$$

The Rayleigh extinction coefficient can be determined in several ways[1,2]. In order to isolate $\alpha_S(\lambda)$, the Rayleigh contribution is assumed to follow the table included by Bucholtz.

In the aerosol scattering contribution, it is assumed the majority of scattering occurs when the wavelength of light is close to the size of the scattering body. Therefore, examining α_S as a function of wavelength can give us information about the size and number density of aerosols.

The apparatus includes two diode lasers of wavelengths 532nm and 655nm. Originally, the scheme included a 407nm laser as well, but bad wiring caused the diode to burn out during test runs and before any data was taken. The lasers are made collinear via dichroic mirrors and the beam is passed through a 8.3 magnification beam expander. The beam expansion allows the light to interact with a larger cross section of the air, averaging out small scale variations and increasing attenuation.

Figure 1.The original scheme for the apparatus is shown. The final version did not include the blue diode or associated dichroic mirror.

Data.

In order to measure the intensities, a photometer was used. A single, central reading was taken at the beam expander, and several measurements were made at the incident image (100m away), for both wavelengths. Flux taken was measured as a function of radial distance to the center of the image, and integration performed assuming circular symmetry. The validity of the circular symmetry is questionable, as can be seen in figure 2.

Two sets of data were retrieved. In the first set, taken April 11th, 2009, a few points in a horizontal line were taken through the center of the image. Linear and Gaussian fits were applied to each color. In the second set of data, in order to better account for asymmetries, measurements were taken both along a horizontal and a vertical line from the center at regular intervals, then average flux calculated for each radius and used for linear and Gaussian fits.

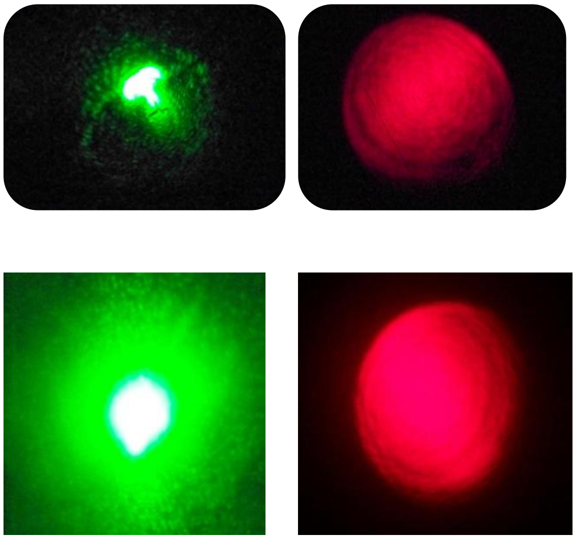
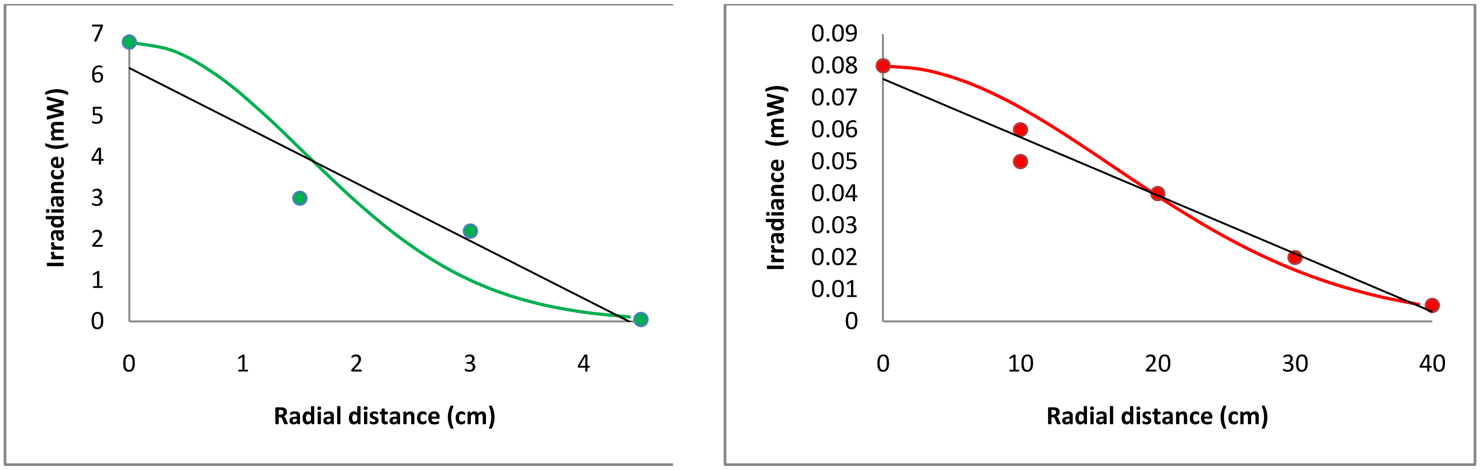


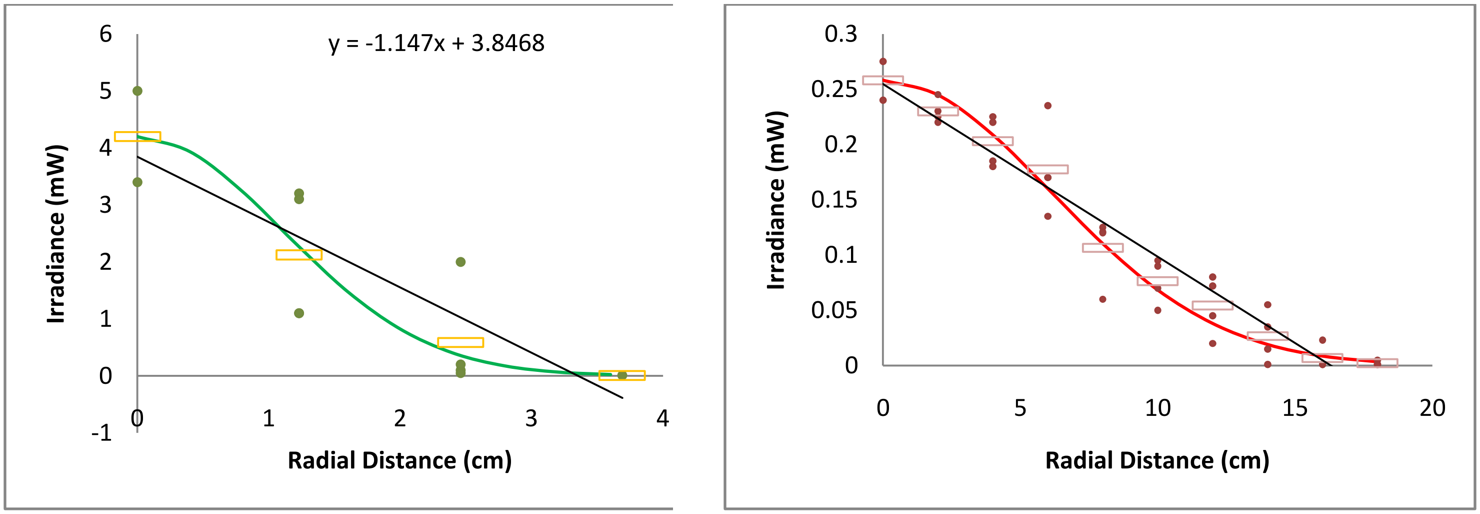
Figure 2. These are camera images of the incident beams. On the left are the 532nm beams, on the right are the 655nm beams. Angular asymmetries are clear, especially in the red. The top images belong to the April data, the bottom are from the May 1st run. The images are not in any sort of relative scale.

Figure 3(A)-(D). Plots of the distant beam flux data for each night against distance from the center of the beam. Also shown is the fit, or step function, used to calculate total intensity. Shown along with the data in (A) and (B) are the linear and Gaussian fits. In (C) and (D) the average point is shown at each radius, and the fits are performed on those data.



(A) April 11th, 2009 532nm

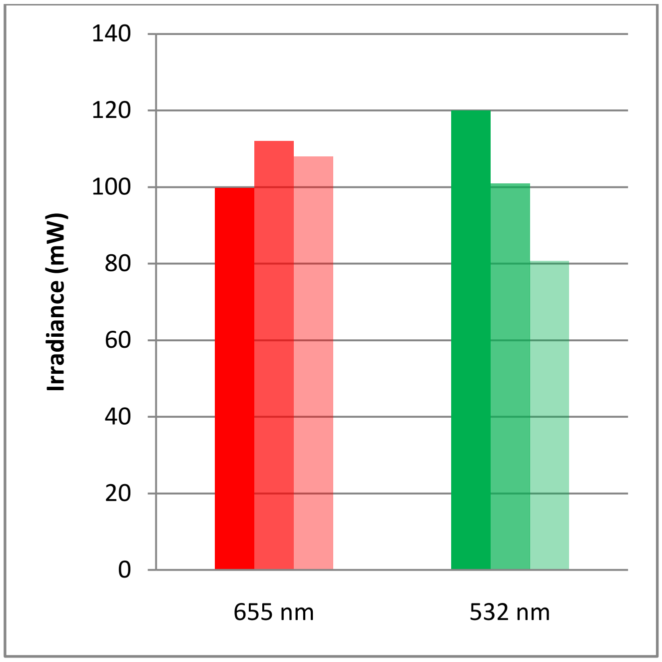
(B) April 11th, 2009 655nm



(C) May 1st, 2009 532nm

(D) May 1st, 2009 655nm

Figure 4(A)-(B).Below is shown the integrated irradiance at the beam expander, as well as the distant target. Two bars are presented for the final irradiances, one for each of the fits. The initial is the leftmost of each set, linear fits result is in the middle, and the rightmost is the Gaussian result. Clearly, an error was made in the initial irradiance of the 655 during the April 11th run. The May value is used for transmittance calculations.



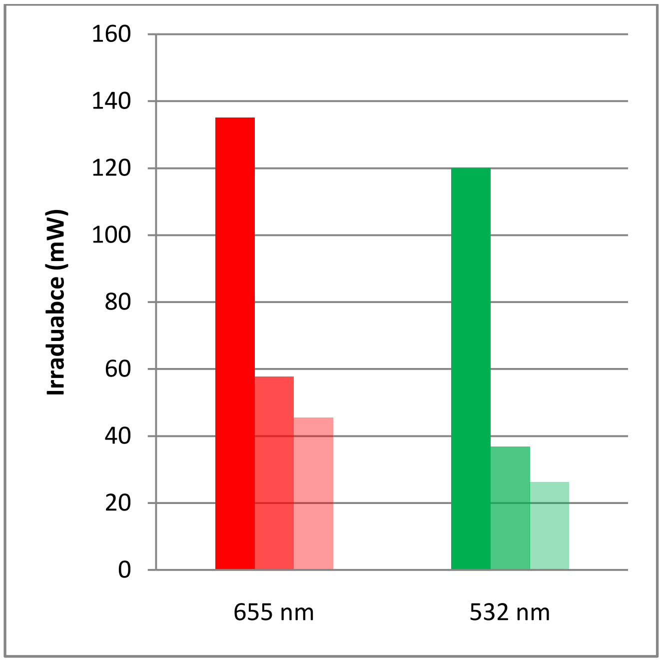
(A)The April 11th run.

$T_{655,\ \mathrm{linear}}$=.830

$T_{655,\ \mathrm{Gaussian}}$=.80

$T_{532,\ \mathrm{linear}}$=.842

$T_{532,\ \mathrm{Gaussian}}$=.673



(B) The May 1st run.

$T_{655,\ \mathrm{linear}}$=.427

$T_{655,\ \mathrm{Gaussian}}$=.337

$T_{532,\ \mathrm{linear}}$=.307

$T_{532,\ \mathrm{Gaussian}}$=.218

From here, using Bucholtz's coefficients, aerosol extinction coefficients are found for all cases.

λ	**fit**	**Date**	**T**	**$\alpha_R(km^{-1})$**	**$\alpha_S(km^{-1})$**
655	L	4/11/09	.83	$5.64*10^{-3}$	1.86
655	L	5/1/09	.42	$5.64*10^{-3}$	8.67
655	G	4/11/09	.8	$5.64*10^{-3}$	2.23
655	G	5/1/09	.337	$5.64*10^{-3}$	10.9
532	L	4/11/09	.842	$1.336*10^{-2}$	1.71
532	L	5/1/09	.307	$1.336*10^{-2}$	11.8
532	G	4/11/09	.673	$1.336*10^{-2}$	3.95
532	G	5/1/09	.218	$1.336*10^{-2}$	15.2

These α_S are extremely large for all cases, and clearly represent a fundamental flaw in the methodology. It was expected that the coefficient would be less than one, in the vicinity of 0.1 km^{-1}. This error is likely not mathematical, as all integrations point to the similarly bad results. Improvement must be made if the device is used in the future.

Discussion.

Serious improvements in the nature of data acquisition should be made. It is unclear whether the error occurred at the device, at the distant detector, or both. Part of the difficulty results from having to calculate the total irradiance either immediately beyond the beam expander or at the distant detector.

Two solutions are apparent. First, an elimination of the beam expansion element would result in a narrower beam, and thus less area to attempt to integrate over. A similar result could be obtained by a better collimating of the beams by the expander. Secondly, a collecting lens should be used to focus as much of the light into the detector at each measurement location.

Because of the severity of the data problems, few conclusions can be drawn. The most apparent trend is simply that there was significantly more extinction in April than in May. Because of the location at time of year, it is likely the presence of pollen which caused such a significant difference. Another observation would be that there was more aerosol scattering at 532nm than at 655nm. Since 532nm particles are smaller, this indicates a much higher density of 532nm aerosols.

Finally, in order to develop the most accurate measurements, it should noted that the Rayleigh scattering contribution is dependent on both temperature and pressure. Though this is a small detail in comparison to the large problems with the system, a measurement of these local characteristics will be necessary at some point in the future.

I'd like to thank Dr. Philbrick and Dr. Hallen for making this research possible, and providing me a chance to play with an optics system. I learned at lot from them and had a great experience through their efforts. Also, I thank Michael Carpenter and Tim White for their significant contributions to the work.

References

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Bodhaine, Journal of Atmospheric and Oceanic Technology, Vol. 16, No. 11, Nov. 1999