Physics and Instrumentation of Atmospheric Aerosol Measurements Across Maryland July, 2011
Communicating Scientific Research Methods to High School Physics Students

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What are aerosols?

Aerosols are tiny particles of solids, liquids, or gases which become temporarily suspended in the air for varying lengths of time. Many particles, become airborne through natural means, but a significant portion of aerosols, especially the smaller ones, are anthropogenic: caused by Man.

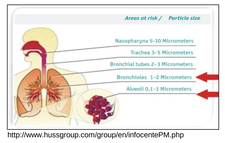
In the atmosphere, aerosols can:

The size of aerosols can indicate their source and potential behaviors in the atmosphere, and their affects human health.

- Affect visibility
- Form cloud condensation nuclei
- React with other particles forming hazardous compounds
- Scatter, or absorb and then re-emit energy from photons
- Contribute to radiative forcing, an anthropogenic change in the radiation budget of the planet

In the biosphere aerosols can cause:

- Interference with the processes of plant respiration and photosynthesis
- cardiovascular disease
- Irregular heartbeat
- Aggravated asthma
- Decreased lung function
- Irritation of the airways
- Coughing
- Difficulty breathing



http://www.hussgroup.com/group/en/infocentePM.php

PM_{10} are aerosols with diameters less than 10μm. Particles such as water, sand, pollen, soil, and sea salt are usually generated by natural events and tend to be classified as PM_{10} . They fall from the atmosphere after only a few hours or even minutes, giving them less opportunity to interact with the environment.

$PM_{2.5}$ are aerosols with diameters less than 2.5μm. The majority of anthropogenic aerosols are classified as $PM_{2.5}$. Due to their small size, they can remain in the air for days, weeks or even months giving them increased opportunity to react with other substances in the atmosphere often with deleterious effect. $PM_{2.5}$ are able to travel deep into the organs and tissues, remaining there for long periods of time and causing, or exacerbating, a host of health issues. $PM_{2.5}$'s longevity and potential for serious harm make it important to study and understand as, being largely anthropogenic, there are steps that can be taken towards positive change.

References

•Cohen, Robert A. Readings to accompany the Physics of the Atmosphere, Physics Department East Stroudsburg University January 18, 2011 Version 5.4 ©2011 by Robert A. Cohen retrieved 19 June, 2013 from http://www.esu.edu/physics/cohen/phys305/textbook/readings.5.4.pdf
•Hanna, Steven R., et al. **"Air Pollution."** *McGraw-Hill Encyclopedia of Science & Technology*. 10th ed. Vol. 1. New York: McGraw-Hill, 2007. 292-309. *Gale Virtual Reference Library*. Web. 22 June 2013.
•Document URL
http://go.galegroup.com/ps/i.do?id=GALE%7CCX3057500168&v=2.1&u=fair35939e&it=r&p=GVRL&sw=w
•Zawar-Reza, Peyman. "Atmospheric Particulates Across Scales." *Encyclopedia of Geography*. Ed. Barney Warf. Vol. 1. SAGE Reference, 2010. 149-151. *Gale Virtual Reference Library*. Web. 22 June 2013.
•Document URL
http://go.galegroup.com/ps/i.do?id=GALE%7CCX1788300073&v=2.1&u=fair35939e&it=r&p=GVRL&sw=w
•Rollin, E. M. "An introduction to the use of Sun-photometry for the atmospheric
•correction of airborne sensor data." NERC EPFS Department of Geography University of Southampton
•Southampton, Electronic version retrieved from http://www.ncaveo.ac.uk/site-resources/pdf/cimel.pdf
•*Holben, B. N.*, et al. AERONET—A Federated Instrument Network
•Data Archive for Aerosol Characterization. REMOTE SENS. ENVIRON. 66:1-16 (1998) Retreived from http://aeronet.gsfc.nasa.gov/new_web/PDF/afi.pdf
•BAM-1020 Operators Manual. From http://www.metone.com/aerosoldocs/BAM_3-sytem_training.pdf
"Atmosphere." *Encyclopedia of Public Health*. Ed. Morton Lippmann, Lester Breslow. Vol. 1. New York: Macmillan Reference USA, 2002. 88-90. *Gale Virtual Reference Library*. Web. 22 June 2013.
Document URL
http://go.galegroup.com/ps/i.do?id=GALE%7CCX3404000078&v=2.1&u=fair35939e&it=r&p=GVRL&sw=w
"Aerosols." *The Gale Encyclopedia of Science*. 4th ed. Vol. 1. Detroit: Gale, 2008. 62-65. *Gale Virtual Reference Library*. Web. 22 June 2013.
•Document URL
http://go.galegroup.com/ps/i.do?id=GALE%7CCX2830100048&v=2.1&u=fair35939e&it=r&p=GVRL&sw=w
•NASA Discover-AQ website http://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html
•"Radiative Forcing." *Environmental Science: In Context*. Ed. Brenda Wilmoth Lerner and K. Lee Lerner. Vol. 2. Detroit: Gale, 2009. 680-682. In Context Series. *Gale Virtual Reference Library*. Web. 22 June 2013.
•Document URL
http://go.galegroup.com/ps/i.do?id=GALE%7CCX3233900193&v=2.1&u=fair35939e&it=r&p=GVRL&sw=w
•http://teaching.shu.ac.uk/hwb/chemistry/tutorials/molspec/beers1.htm

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Aeronet and Discover AQ
Maryland EPA for sharing data
And the best last minute what equation do I use website ever: http://asd-www.larc.nasa.gov/SOLAR/experiment-index.html

Aeronet DRAGON (AOT)

Cimel-318 Automatic Sun Tracking Photometer
Spectral extinction of direct beam radiation

Aerosol optical thickness data is calculated by measuring voltage generated within a UV enhanced silicon detector of known surface area.

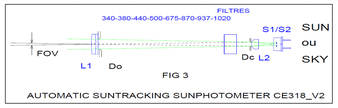


Fig 1

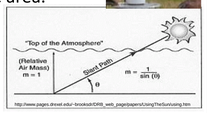


Fig 2

•The azimuth of the instrument adjusts automatically to keep the sun within the field of view (FOV in diagram above), and records the solar zenith angle, (*Θ)* (Fig2)
•Optical air mass, (m), is calculated, (equation1)
•Solar radiation passes through the first of two lenses,L_1(Fig1)
• A disc housing 8 monochromatic filters is rotated in the path between the two lenses, L_1 and L_2 (Fig1)
•The wavelength of light through each filter is recorded, (λ)
• The silicon detector measures voltage generated by the incident image, (v)
•Extraterrestrial voltage, (v_0), is a calibration term determined using data collected from reference instruments at NOAA's Mauna Loa Observatory in Hawaii
•The Aerosol Optical Thickness is calculated using Beer's Law (equation 2)

(eq1) $$m = \frac{1}{\sin\theta}$$

(eq2) $$\tau_\lambda = \frac{\ln(v_\lambda - v_{0\lambda})}{m}$$

τ_λ = *optical depth λ*
v = digital voltage
v_0 = *extraterrestrial voltage*
m = optical air mass
λ = wavelength
Θ = solar zenith angle

EPA Continuous $PM_{2.5}$

BAM-1020 Continuous Particulate Monitor
Beta-I

•Absorption per unit area is pre-determined during calibration (F_{cal})
•Filter tape is exposed to radiation source
• A semi-conductor detector measures the intensity of beta ray transmission through the clean filter tape, (I_0)
•Air, at a controlled rate (V), is filtered through the tape allowing $PM_{2.5}$ to accumulate for the duration of the measurement, (t)
•The semi-conductor detector measures the intensity of beta ray transmission through the dirty filter tape, (I)
•The concentration of $PM_{2.5}$ is calculated using the form of Be

$$c = \frac{F_{cal}}{Vt} ln\left[\frac{I_o}{I}\right]$$

C = concentration $PM_{2.5}$
F_{cal} = calibration factor (mass density)
V = measured mass flow rate
t = measurement duration
I_o = beta ray intensity at pre-exposure filter
I = beta ray intensity at exposed filter

What Is This Thing We Call Data?

The data obtained from NASA and EPA websites are not measured as simply as reading distance from a meter stick or time from a stopwatch.

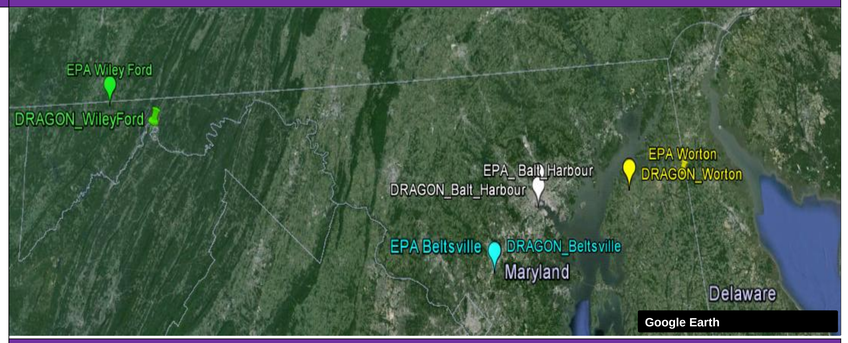
•The connection between measurement and data processing is the physics behind the instrumentation. Taking the time to understand that connection provides the researcher with a far greater comprehension, and appreciation, of what that data represents.

•The Aeronet sun photometer column measurement and the EPA surface particulate monitor both provide indirect measurements of aerosol data each using different applications of Beer's Law

Beer's Law

The amount of radiation absorbed or transmitted by a compound in a medium is proportional to the concentration of that compound present in the medium.

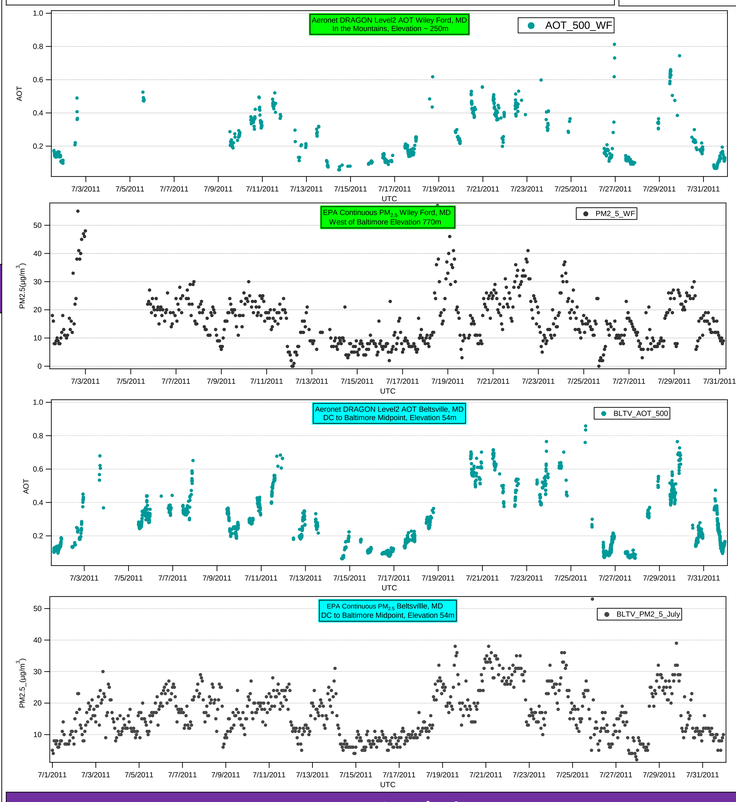
Matched PM2.5 and AOT Collection Sites

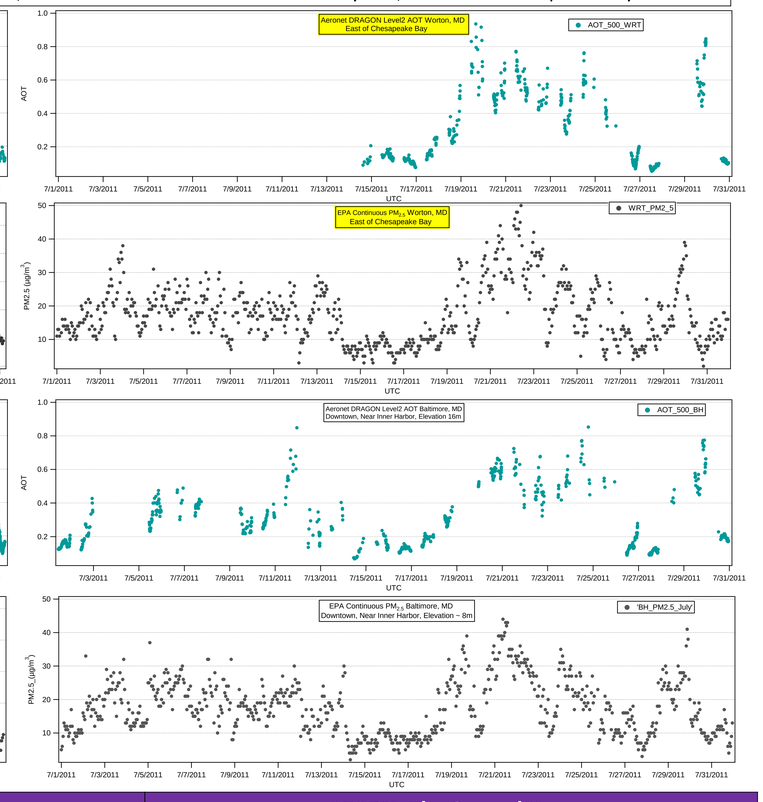


Site Selection

The location of selected EPA and Aeronet DRAGON sites travels the width of the state of Maryland representing four distinct regions:

- Wiley Ford, a rural area far to the west in the mountains
- Beltsville, midway along the highly industrialized traffic corridor between DC and Baltimore
- Baltimore Harbor, Downtown area around an active seaport
- Worton, rural area on the eastern shore of Maryland, across the Chesapeake Bay





Conclusions

•The graphed data suggests a strong correlation between the Aeronet and EPA measurements. The explanation of the importance of the data, the differences between what was actually measured, and the similarities between the data processing methods provides non or neo-scientists with more background information and so more understanding of the final product.
•Providing comprehensible details of the instrumentation, physics, and math of processes of data collection and reporting can make that data more accessible to a wider range of viewers.
•Making these tangible connections between science and the physical world can be used to teach the real scientific method to high school science students or even seize and hold the attention of a committed climate change skeptic.

LEARN: The Second Year

1. The teacher project will focus on a more detailed analysis of the Aeronet data for these Maryland sites looking at the speciation, distribution, sources, and consequences of lofted aerosols.
2. Physics students will propose, or be assigned, science fair projects within the scope of the teacher project
3. Remote sensing data retrievals and current research methods will be included as curricular content in the physics classroom.
4. Students will learn valuable and marketable skill sets better preparing them for internships and their eventual undergraduate studies.