Comparison of Handheld Atmospheric Instruments for GLOBE

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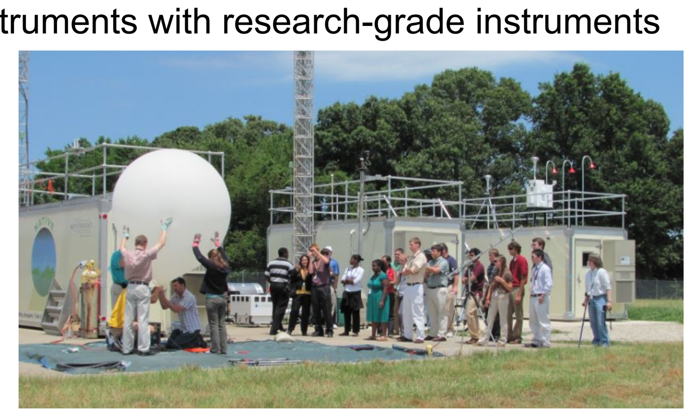
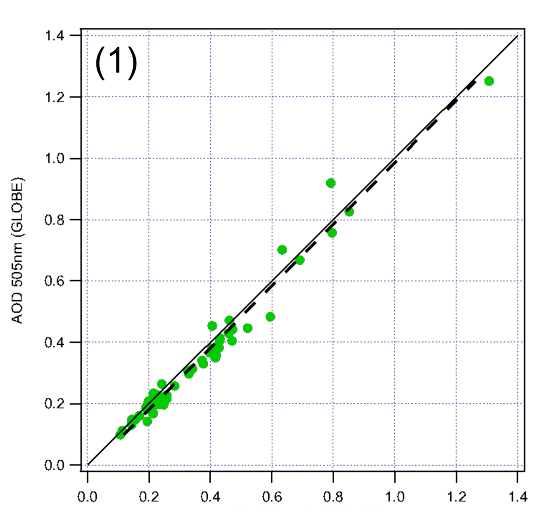
Background

Worldwide, students of Global Learning and Observation to Benefit the Environment (GLOBE) certified educators measure many different atmospheric parameters. Measurements are uploaded to the GLOBE server which is accessible to all participating GLOBE schools. A participating member can access this data and use it for classroom inquiry-based investigation. Advancements in technology such as miniaturization and improvements in sensor capabilities have provided opportunities for alternative measurement systems for GLOBE. A comparison of new sensors and existing GLOBE instruments with research-grade instruments at the NASA Langley Chemistry and Physics Atmospheric Boundary Layer Experiment (CAPABLE) site co-located with Virginia Department of Environmental Quality (VA DEQ) air-monitoring station is presented.



Aerosols

Aerosols are small particles that can remain suspended in the atmosphere for a period of time. The GLOBE aerosols protocol utilizes a passive handheld remote-sensing sun photometer to measure Aerosol Optical Depth (AOD)—how much of the sun's light is scattered or absorbed by aerosols. The GLOBE sun photometer performs well, however manufacturing constraints make it difficult for GLOBE schools to participate in the aerosols protocol. During the summer of 2013, the Solar Handheld Aerosol Determination Equipment (SHADE) spectrophotometer was tested to determine its potential as an alternate GLOBE instrument.



-A correlation between GLOBE AOD at 505nm and AERONET (a network of research-grade sun photometers) 500nm AOD readings at the CAPABLE site.

-(L) the SHADE spectrophotometer utilizes photodiodes to measure a voltage which is then used to calculate AOD on-board. http:// shade.ubicode.com/

-(R) & (1) the GLOBE sun photometer utilizes light emitting diodes to measure voltage which is recorded and used to calculate AOD.

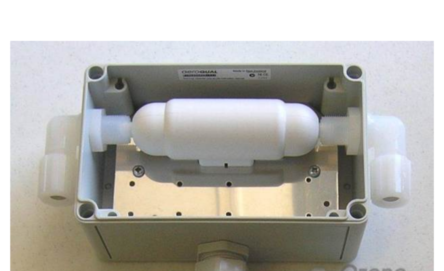
Ozone

Ozone is a pollutant in the troposphere that is harmful to humans, plants, and animals. Currently, the GLOBE surface ozone protocol uses the Zikua/ test card instrument system manufactured by Vistanomics, Inc. for hourly-averaged in-situ ozone measurements. Availability concerns and quality control issues with the test cards make participating in the surface ozone protocol challenging for GLOBE schools. The handheld Aeroqual Series 500 ozone monitor was evaluated to determine its potential as an alternate GLOBE instrument.

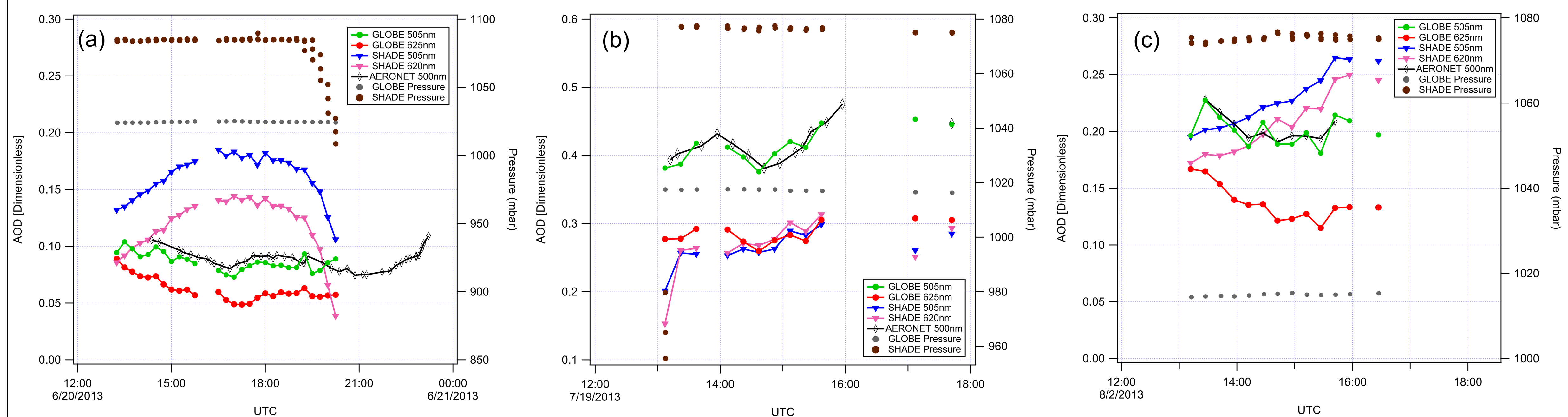
- (L) The Zikua instrument acts as a simple spectrophotometer to measure the absorbance of the exposed test card treated with tin (II) diphenylcarbazide which chemically reacts and changes color in the presence of ozone (Lambert, et al., 1982).

- (L) The Aeroqual Series 500 monitor produced by Ozone Solutions, uses a tungsten oxide semiconductor to measure a voltage producing an instantaneous ozone reading.

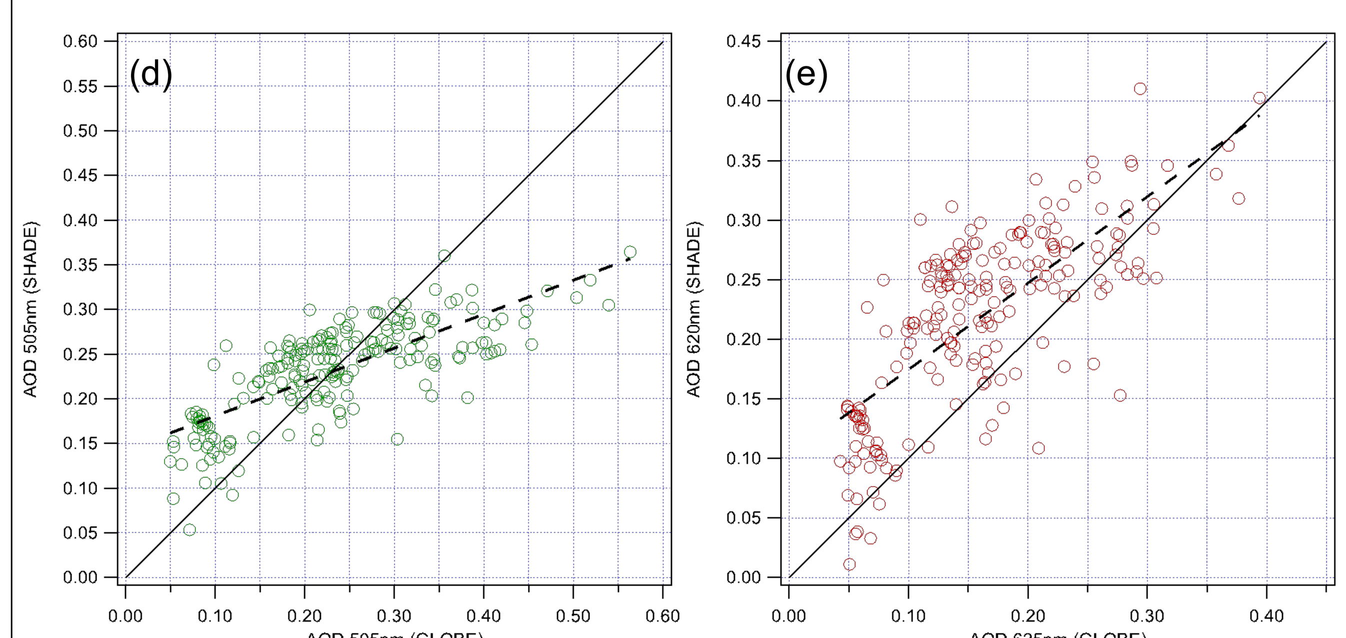
- (R) The R-13 weather resistant box for the monitor was also provided by Ozone Solutions.



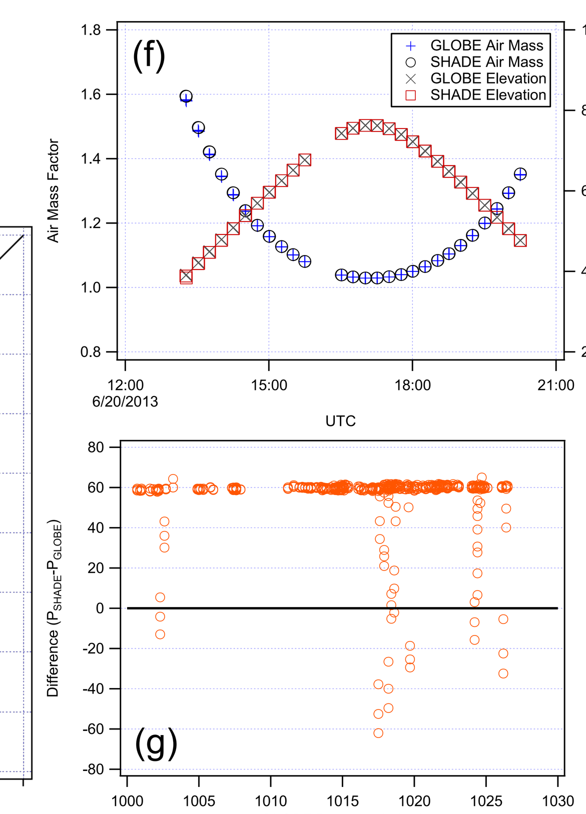
Comparing GLOBE, SHADE, and AERONET



During the summer of 2013, over 1200 side-by-side column measurements of AOD were taken with the GLOBE and SHADE photometers. The results were compared to each other and to AOD readings from AERONET at the CAPABLE site. Example results in figures (a)-(e) show that while GLOBE correlates well with AERONET, SHADE measurements are inconsistent.



- (d) & (e) Correlation plots between GLOBE and SHADE AOD at similar wavelengths.



To investigate the inconsistent readings of SHADE, the on-board measured and calculated parameters of pressure, solar elevation angle, and air mass were compared with pressure readings from the CAPABLE site and calculations of air mass and solar elevation angle. While air mass and solar elevation angle are comparable (f), the pressure readings are very different (g). Atmospheric pressure readings at the CAPABLE site range from 1000.7-1026.5 mbar while SHADE's pressure readings range from 955.5-1089.7 mbar and become erratic when the batteries begin losing charge.

Calculating AOD for GLOBE

The formulas below are used to calculate AOD from the voltage readings produced by the GLOBE photometer.

$$AOD = \frac{[\ln(V_o/R^2) - \ln(V - V_{dark}) - a_r (p/p_o) m]}{m}$$

$$R = \frac{(1-\varepsilon^2)}{[1+\varepsilon \cos(360^0 \bullet d/365)]}$$

V_o= Calibration constant for each channel
R= Earth-Sun distance
Ɛ= Eccentricity
d= Day of year (Julian Day)
V= Voltage readings obtained with photometer
V_{dark}= Dark voltage readings obtained with photometer
a_r= Rayleigh scattering coefficient for each channel
P=Pressure at location and time of readings
P_o= Standard sea-level atmospheric pressure
m= air mass

Conventionally, air mass is defined as the secant of the solar elevation angle, however in 1994, Andrew Young derived a more accurate formula to be used for calibration. His formula proves to be more accurate than others at large zenith angles (Young 1994).

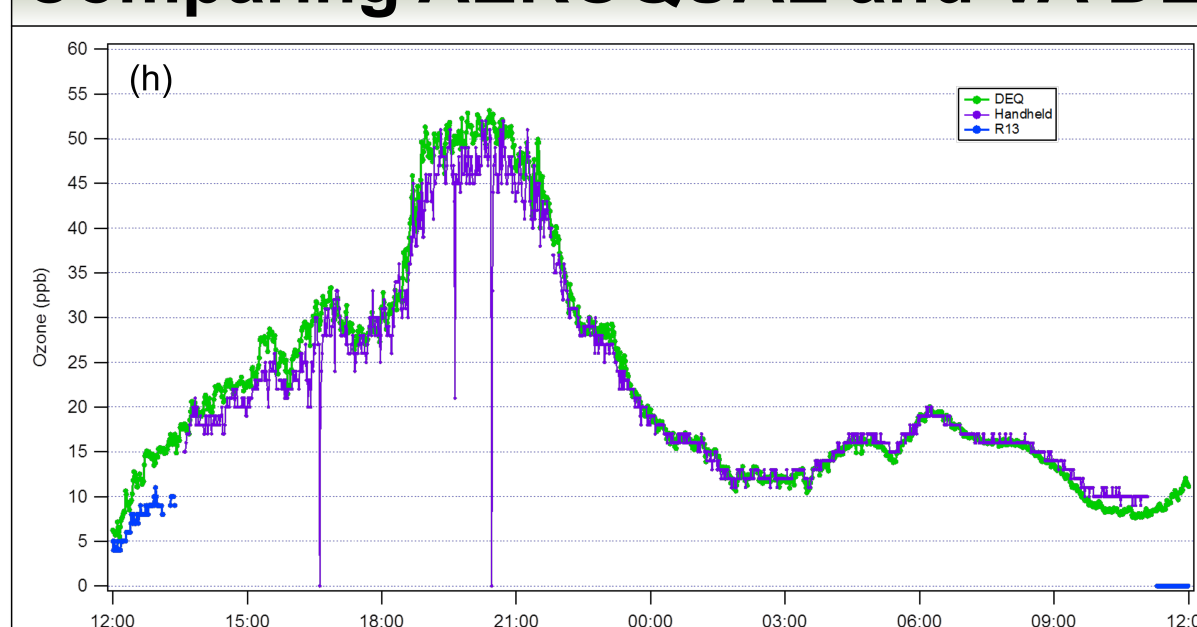
$$m(z) = \frac{1.002432\cos^2 z + 0.148386\cos z + 0.0096467}{\cos^3 z + 0.149864\cos^2 z + 0.0102963\cos z + 0.000303978}$$

The solar zenith angle is the complimentary angle to the solar elevation angle which can be calculated by the equation below.

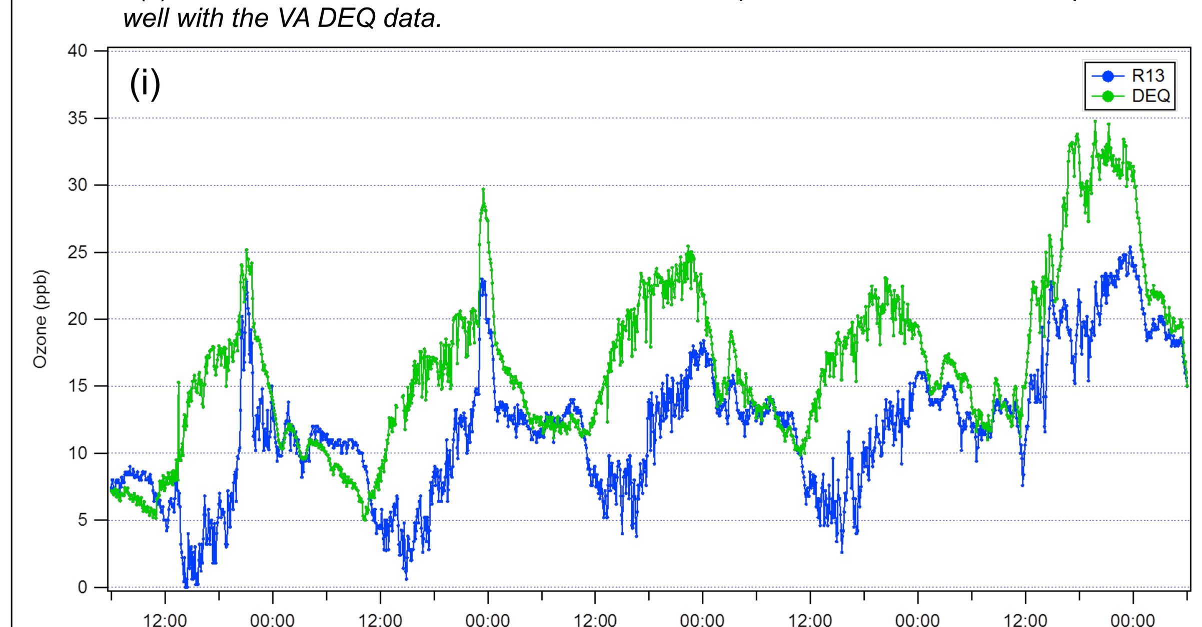
$$\sin\theta_s = \cos h \cos\delta \cos\Phi + \sin\delta \sin\Phi$$

Where $\boldsymbol{\theta_s}$ is solar elevation angle, ***h*** is the hour angle, $\boldsymbol{\delta}$ is solar declination, and $\boldsymbol{\Phi}$ is the latitude at the measurement site.

Comparing AEROQUAL and VA DEQ



- (h) Ozone measurements from the handheld Aeroqual Series 500 monitor compares well with the VA DEQ data.



- (i) A comparison between the Aeroqual sensor inside the R-13 box and the VA DEQ minute data averaged every five minutes displays the R-13's tendency to read consistently lower measurements than the VA DEQ due to calibration issues.

Adjusting ZIKUA Measurements

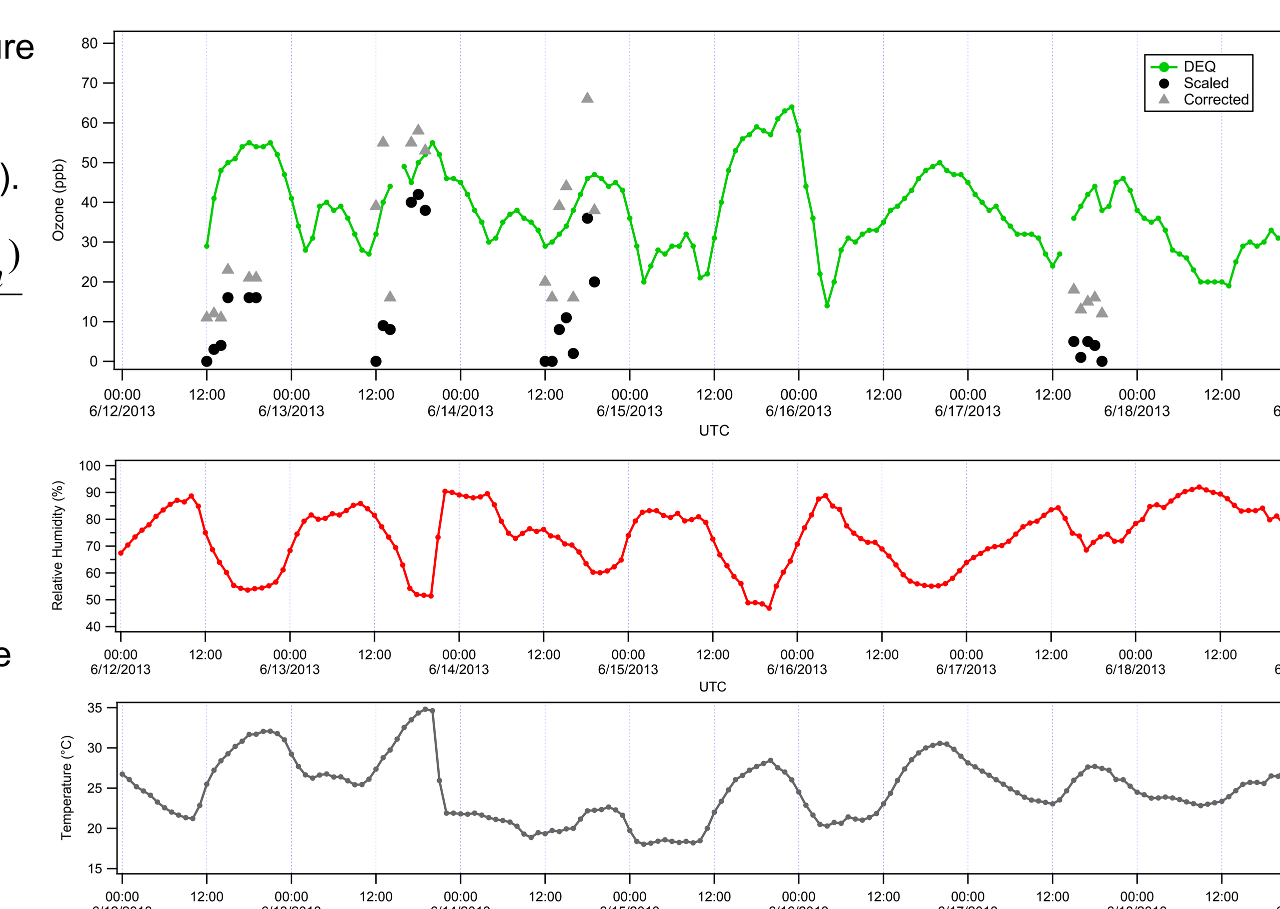
Using the derived calibration equation and table of constants below (Pippin et. al, 2007) for ozone concentration that accounts for temperature and humidity dependence, the hourly averaged Zikua/test card measurements were adjusted and compared to VA DEQ ozone measurements from the CAPABLE site (shown in the figures to the right).

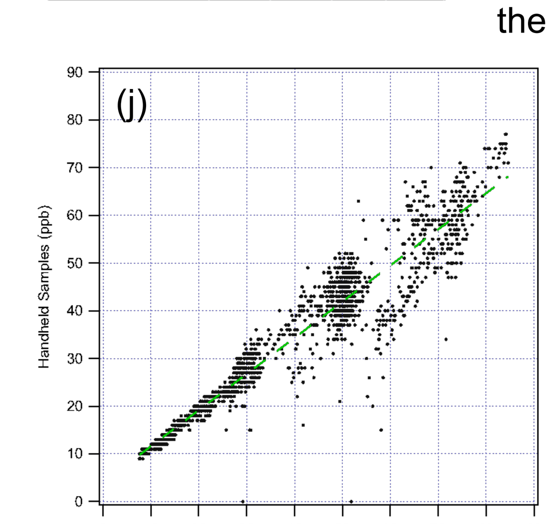
μ_{Abs}	42.88	σ_{Abs}	1.52
μ_T	30.46	σ_T	0.707
μ_{RH}	53.99	σ_{RH}	2.12
β_0	26.74	$\sigma_{\beta 0}$	0.4944
β_1	0.5862	$\sigma_{\beta 1}$	0.0526
β_2	-0.6507	$\sigma_{\beta 2}$	0.1425
β_3	-0.3035	$\sigma_{\beta 3}$	0.0518
β_{13}	0.00742	$\sigma_{\beta 13}$	0.0037

$$O_3 = \mu_o + \frac{A - \beta_0 - \beta_2 (T_c - \mu_t) - \beta_3 (RH - \mu_{rh})}{\beta_1 + \beta_{13}(RH - \mu_{rh})}$$

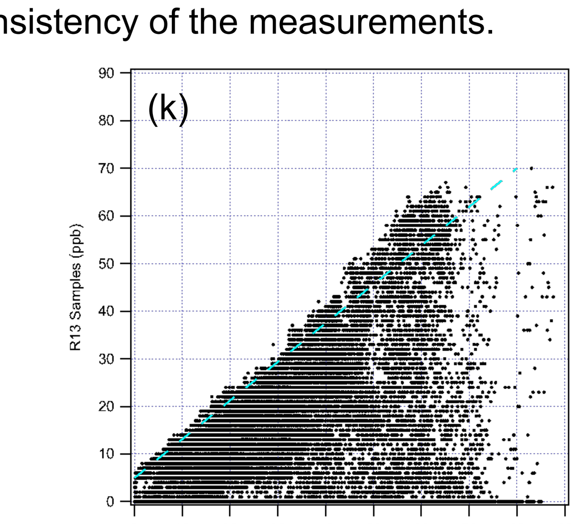
	2006		2013	
Data range	min	max	min	max
Temp (°C)	21.1	38.3	18	35
Ozone (ppbv)	16	81	0	81
% RH	30	87	47	97

The range of temperature, relative humidity and ozone experienced during the summer of 2013 were within the bounds of the derived calibration equation from 2006 as seen in the table to the left. High relative humidity inhibits the color change of the test cards. While the correction factor adjusts the data towards the VA DEQ values, the quality control of the test cards continues to impact the consistency of the measurements.





- (j) A correlation plot between the handheld Aeroqual Series 500 monitor and VA DEQ measurements shows relatively similar readings.



- (k) A correlation plot between the R13 weather resistant box and the VA DEQ data shows similar readings at the R-13's highest samples, but frequently lower measurements than the accepted values.

References & Acknowledgements

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