# A QUICK LOOK ESTIMATION OF OPTICAL DEPTH MEASUREMENTS FROM THE ROVER ENVIRONMENTAL MONITORING STATION ULTRAVIOLET SENSORS

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**Introduction:** Optical depth is a necessary parameter for modeling the Martian atmosphere [1]. In particular, localized radiative transfer models for Gale Crater depend on optical depth information at the surface. This information is also useful in providing a "ground truth" measurement for orbiter data. The optical depth in Gale crater is currently estimated from observations taken by the Mast Cameras (MastCam) onboard the Mars Science Laboratory (MSL) Curiosity Rover in the 440 nm and 880 nm wavelengths. This gives a set of optical depths describing extinction in the visible and near infrared with a frequency of no more than twice per week. Typically AM-noon or AM-PM pairs are available on a weekly basis providing diurnal measurements, but regularity of cadence has been operationally constrained in the past. Optical depth depends both on local time and wavelength. During seasons where dust loading can vary, higher frequency observations for optical depth are desired. Currently, optical depth measurements are limited in both wavelength and measurement frequency.

The Rover Environmental Monitoring Station (REMS) onboard MSL Curiosity can provide optical depth information at a higher frequency while also extending this information into ultraviolet (UV) wavelengths. The REMS UV sensors suite consists of six photodiodes mounted onboard the rover deck [2,3,5]. Each photodiode records incoming ultraviolet irradiance in the form of voltage at a nominal wavelength. The voltage is converted to irradiance [$W/m^2$] and represents surface flux at a particular wavelength after sunlight has traveled through the atmosphere. Table 1 shows the nominal wavelengths in nanometers for each photodiode filter. The sensors cover a field of view of roughly 30 degrees. When the sun falls within this range relative to the zenith of the rover, the disk of the sun is fully contained within the field of view, and direct light is assumed to dominate over diffuse. For ideal viewing conditions, one could use Beer's law to determine optical depth in the UV. The rover zenith, $\mu$, differs from the zenith at the local level, $\mu_0$, due to the traverse of the rover through Gale Crater.

The ability to estimate optical depth using the REMS UV sensors is compromised by dust deposition on top of the sensor covers. Thus it is necessary to separate the contribution of settled dust to light extinction from that of atmospheric extinction. Previous work [3] by Smith et al. (2015) uses REMS data to estimate both an optical depth and the contribution of dust on the sensors. The analysis is comprehensive, and uses a robust radiative transfer model that links the MastCam tau to optical depth in the UV. The work also acts to 'fill in the gaps' between MastCam coverage. The data used in this study extends up to 1.75 Mars years, but the results do not extend past this coverage and are not updated regularly. It is our goal to extend the range of estimated optical depth through the current sol using a simpler analysis that can also potentially provide a 'quick look' view at UV optical depth and serve as a more frequent measurement.

**Table 1: Nominal wavelength and bandwidth of REMS photodiodes.**

| [nm] | Nominal | Low Limit | High Limit |
|---|---|---|---|
| UVA | 343 | 315 | 370 |
| UVB | 300 | 280 | 320 |
| UVC | 250 | 220 | 280 |
| UVD | 260 | 230 | 290 |
| UVE | 325 | 300 | 350 |
| UVABC | 285 | 200 | 370 |

**Model:** Light recorded by the sensor of each photodiode is 'acted on' by three distinct effects. First, light is extinguished in the atmosphere by absorption and scattering into and out of the direct collimated path of the sunlight. This is most directly known as Beer's Law, and dominates atmospheric extinction when the sun is in the field of view of the sensor. Second, the light passes through a dust coating on each sensor, which can be described using a dimensionless dust factor, $\tau_d$. Finally, each sensor records light according to a spatial response [2,5], which has been represented as a cosine function raised to some gain value unique to the sensor.

These effects can be combined into a modified form of Beer's Law shown in Equation 1. Here, the flux at the sensor, F, is the product of dust extinction, the spatial response, $\mu^y$, and atmospheric extinction. The modified form is dependent on MastCam 880 nm optical depth, τ, and a correction factor, x, which is the product of the wavelength dependence of optical depth and a scattering dependent correction factor that can be estimated. Thus the product xτ is the wavelength dependent optical depth for each filter. An expected correction factor can be calculated according to √(1-wg)√(1-w), or the correction factor for total radiance in a two stream approximation. Using values from Wolff et al. 2010, the expected value is 0.8.

Equation 2 shows the natural logarithm of Equation 1, where the log signal depends linearly on the inverse cosine of the solar zenith angle, $1/\mu_0$. Given both τ and lnF, three parameters remain unknown. These parameters are the log flux at the top of the atmosphere, $lnF_0$, the spatial gain, y, and the correction factor, x. Using a Levenberg – Marquardt least squares algorithm, these three parameters can be varied to determine a best fit for the dust factor. Initial parameters are supplied to the fitting program, which then seeks to minimize the error shown in Equation 3 for each sol. Once determined these parameters can be used to get dust factor and a derived value for the 880 nm optical depth, τ, on sols where this optical depth is not available through MastCam.

$$F = F_0 e^{-\frac{\tau_d}{\mu}} \mu^y e^{-\frac{x\tau}{\mu_0}} \qquad [1]$$

$$lnF_0 - lnF + yln\mu = \frac{\tau_d}{\mu} + \frac{x\tau}{\mu_0} \qquad [2]$$

$$e_i = \frac{(\tau_{d_i} - \overline{\tau_d})}{\sigma_i} \qquad [3]$$

**Tau 880nm Results:** The model was first run for the UVA band, and the derived 880nm optical depth is shown in Figure 2 for data up to sol 1470. This derived optical depth (black) is compared to that of MastCam (red). The result of the derived 880nm optical depth follows MastCam optical depth closely. A value of 0.67 was returned for the correction factor, which differs from the expected value. The detector term, y, results in a gain of 2.9 for UVA. In addition, Figure 1 shows the dust correction term up to sol 1470.

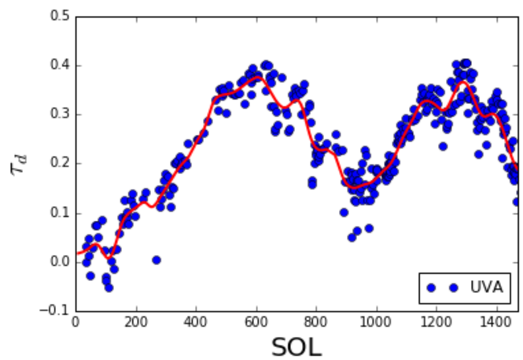


**Figure 1: Dust Correction Factor for UVA band over 1470 sols.**

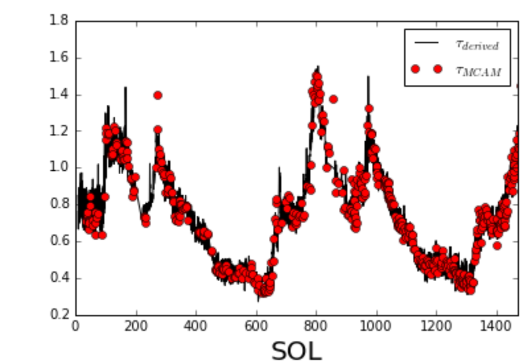


**Figure 2: MastCam optical depth for 880 nm (red) compared to the derived 880 nm optical depth from model results (black).**

**Diurnal Variation:** Figure 3 represents the difference between the optical depth at some time in LMST and the mean optical depth for each sol. The figure covers one Martian year starting from sol 10 of the mission. Darker colors represent earlier sols and brighter colors show later sols. There is a slight difference in shape as the color of the plot transitions from dark to light, however previous work [3] has discounted diurnal variations. Figure 3 does not necessarily correspond to real diurnal variation. It is our intention to investigate seasonally changing diurnal variation using the model outlined in this abstract to compare with previous work [3].

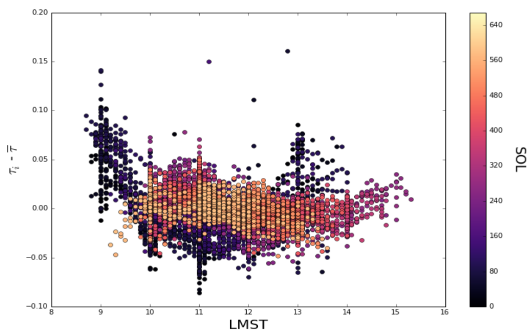


**Figure 3: Difference in optical depth to mean optical depth for each sol verses LMST. Values plotted range from Sol 10 to Sol 670.**

**Future Work:** The goal of this work is to provide a quick method for generating an estimate of UV optical depth as well as a dust factor and wavelength dependence that is consistent with previous work. We will present model results for three of the six filters contained in the REMS instrumentation, UVA, UVC, and UVE suite for data extending past the first 1000 sols and analyze, if any, the seasonal variability of diurnal effects.

**References:**


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