INFERENCES OF MARTIAN ATMOSPHERIC DUST AND WATER ICE CONTENT DERIVED FROM RADIATIVE TRANSFER MODELS OF PASSIVE MSL OBSERVATIONS BY MASTCAM. E. M. McCullough[1], J. E. Moores [1,2], R. Francis[1], and the MSL Science Team. [1]Centre for Planetary Science and Exploration (The University of Western Ontario, London, ON, Canada, emccull2@uwo.ca), [2]Now at: Centre for Research in Earth and Space Sciences (CRESS, York University, Toronto, ON, Canada).

Introduction: While the Mars Science Laboratory (MSL) Spacecraft was not designed primarily as a vehicle from which to study the martian atmosphere, the recent landing of MSL's rover Curiosity has provided opportunities to extend the science return of the existing instrument complement to include observations of atmospheric water ice and dust.

The participating science project “Observations of Water Ice and Winds from the MSL Rover” [1], included proposed atmospheric measurements using several MSL imagers. To date, several such data products have been acquired by Curiosity. Here, the discussion will focus on one aspect of this project: Using bispectral photographs of the sky in combination with the output of an atmospheric radiative transfer model to determine the relative amounts of ice and dust in the atmosphere, and to estimate the sizes of these particles.

Synergy with other MSL observations: Curiosity has an excellent suite of instruments for near surface measurement of humidity, pressure, wind speed, downwelling radiation and the hydration state of the surface (REMS and DAN) [2]. The creative use of other MSL instrumentation allows an expanded atmospheric monitoring capability.

Description of the approach: Dust and water ice have different scattering efficiencies for different wavelengths of light. Rayleigh scattering from tiny particles varies as λ^{-4}, blue light being scattered more efficiently than red light. Mie scattering from larger particles is less wavelength-dependant, but more particle-size-dependant. Scattering efficiency also depends on sun angle and viewing angle.

A comparison of sunlight scattered by the atmosphere toward the rover at two widely-separated wavelengths can indicate the relative contributions of ice and dust during the scattering process.

We use a radiative transfer model for sunlight through Mars's atmosphere to calculate, for various combinations of dust and ice, the ratio of blue to red light expected in images from Curiosity's cameras. The calculated ratios are compared to the observed ratio, and the dust and ice content of the atmosphere is inferred.

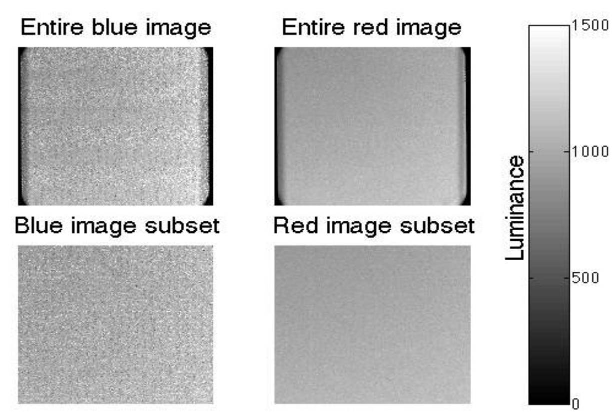
Instruments and Filter Choice: MastCam's left and right cameras each have filter wheels with 8 positions allowing wavelengths between 440 nm and 1035 nm, but only four wavelengths are available in both cameras [3]. The 440 nm and 750 nm combination of wavelengths was chosen because this ratio is the least ambiguous for distinguishing ice from dust.

The MastCam's left and right cameras can be used simultaneously to image the sky, with a 440 nm blue filter on the right camera and a 750 nm red filter on the left. Alternately, sequential images taken in both wavelengths with a single camera (typically MastCam Left), can be used. The latter is the simplest case with which to begin as many camera-specific parameters will be identical for the pair of images.

Scaling by total atmospheric optical depth measurements, a blue-to-red (B/R) ratio is produced which can be compared with modeled B/R ratios.

Sample data set from Curiosity: The “sky-spot” images presented here are a first example of the measurements which are useful for this study. They were acquired on Sol 24, with the camera pointed toward the southern sky during Martian mid-afternoon (at 15:29 local true solar time).

Both images [4] are 1152 x 1536 pixel, 100 μs exposures from MastCam Left, and have been radiometrically calibrated, but not linearized nor white balanced.



A central 800 x 1000 pixel subframe of each image is used to exclude the dark-pixel areas of the images. The mean luminance is found for the blue image (1034 +/ 61) and for the red image (1008 +/ 130). The ratio of these mean values provides the blue to red ratio for the observation: B/R = 1.0252 +/ 0.1434. B/R ratios equal to within 0.5% of these values were obtained using the linearized product versions of the same images.

The Radiative Transfer Model: We have adapted a doubling-and-adding 2-layer hemispherical radiative transfer model for sunlight through Mars's atmosphere to MSL's viewing geometry to calculate, for various combinations of dust and ice, the B/R ratio expected in images from Curiosity's cameras.

Code History: The main code for this model is a Matlab interface running part of the University of Arizona Phoenix-Group Atmospheric Model and coordinating between the DISR Atmospheric UV code (FORTRAN) and a C++ go-between component. Various iterations of this code, beginning with an IDL code by R. Tanner and N. Spanovitch, have been used for modeling the atmospheres of both Titan and Mars. It was updated in 2004 by J. E. Moores to accommodate polar Martian viewing-geometry and atmospheric parameters for the Phoenix landing site [5].

In 2012, the code was updated by E. M. McCullough to include viewing-geometry appropriate to the MSL's Gale Crater equatorial landing site and the filter-pair wavelengths available for MastCam. The refractive indices of dust are currently being updated to reflect recent measurements of Martian dust composition, as are the size parameters of both dust and ice.

Code Approximations: Currently, the two-layer model assumes that all dust is in the lower layer, and all ice in the upper layer. The Martian surface is modeled as a Hapke surface, with options to use fits to various specific pallagonite surfaces, based on experimental UV spectral analysis by A. Shuerger at Kennedy Space Center and N. Spanovich [5].

Code Output: The code outputs solar zenith angle, downward flux, upward flux, and optical depth of the lower and upper layers at each of several wavelengths. These are converted to an expected B/R ratio.

Model parameters for the sample data set: The model is run at the same two wavelengths as the filters used during the Sol 24 observation: 440 nm and 750 nm. Solar zenith angle and camera pointing are matched to those of the images under comparison. The composition, and thus the indices of refraction, of the scattering particles is not particularly well-known; this leads to most of the variability in model outputs.

Water Ice: The indices of refraction for spherical water ice particles are well-known. The size of ice particles previously included in the model was 10 um, generally in concentrations up to 0.1 mg/m^3 [6]. Lower bounds on mean ice radii are given by Lemmon [7] as 1.47 µm at Gusev Crater and Heavans [8] as 1.41 µm. Following the Phonix lidar observations [9], a reasonable upper limit on ice particle radius aloft is 35 µm. Three ice particle sizes (1.5 µm, 10 µm, and 35 µm) will be considered in the radiative transfer model described here.

Dust: There is no consensus in the literature concerning the composition of dust aloft in the Martian atmosphere. Precise real and imaginary indices of refraction are required for the radiative transfer model, and this uncertainty in dust composition introduces a large source of uncertainty in the model output. Suggestions for the primary component of atmospheric dust include: Pallagonite ("any hydrous reaction product of mafic glass alteration" which can have any of a number of optical properties [10]), montmorillonite (whose indices of refraction vary considerably with the amount of water it contains [11]), titanium oxide, magnetite, and various pure mineral and nanophase iron oxides (whose indices of refraction vary by more than an order of magnitude [12]). The current measurements by the ChemCam, SAM and CheMin instruments onboard Curiosity are already helping to narrow down the possibilities for the primary dust composition at Gale Crater. The radiative transfer model here will use these new results to refine the number of matches to the observed B/R ratios.

Interpretations of B/R ratio: In the past, B/R > 20% above the modeled value has been taken to indicate ice aloft, while a B/R ratio of about unity implies that there is no ice present [6]. This interpretation will need to be updated for the geometry of the Gale Crater location, and to explore a larger ice size and dust composition parameter space than has hitherto been considered.

Planned refinements and future observations:

In cases where the modeled result is ambiguous, with several combinations of particle number densities and sizes leading to the same blue-to-red ratio, further analysis may be undertaken using alternate filter pairs. Further exploration of the dust composition is required.

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