MARCI GLOBAL DAILY OZONE MAPPING AND COMPARISON TO LMDGCM SIMULATIONS: POLAR DYNAMICS, HELLAS BASIN, AND HETEROGEOUS CHEMISTRY

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Introduction:

The Mars Color Imager (MARCI) on Mars Reconnaissance Orbiter (MRO) has obtained daily global image maps of Mars in two UV filters since 2006 (figure 1), supporting Hartley band mapping retrievals for Mars atmospheric O_3 columns[1,2].

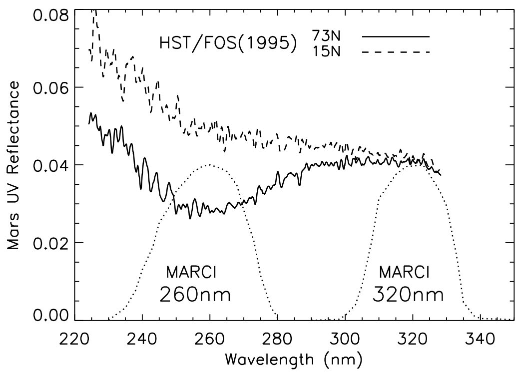

Figure 1. MARCI two UV bandpasses presented against Hubble Space Telescope spectra of Mars O_3[1].

Here, we present three specific subsets of this extensive (~10^{10}) measurement set, in comparison with Laboratoire de Météorologie Dynamique (LMD) Global Climate Model (GCM) simulations of Mars photochemistry[3,4]. We focus on aspects of the MARCI O_3 data set pertaining to polar dynamics, striking seasonal variations within Hellas basin, and the possibility of heterogeneous chemistry on Mars clouds[4]. In the context of these comparisons, we include MARCI cloud optical depth[5] and SPICAM O_3 column[6] measurements.

Polar Dynamics:

Mars atmospheric odd-oxygen, of which O_3 is the primary daytime constituent, is rapidly destroyed by odd-hydrogen products of daytime water vapor dissociation[7,8]. This enforces a well established inverse relationship between Mars atmospheric O_3 and water vapor[9,10] In particular, maximum O_3 columns (10-50 μm-atm) are presented at Mars high latitudes in colder seasons (late fall, winter, early spring) when atmospheric water columns fall below 1 pr-μm[3,6,9]. As MARCI retrieval sensitivity (>1 μm-atm) limits low latitude O_3 measurements to the aphelion season[2,6] and the polar MRO orbit maximizes daily image coverage at high latitudes, cold (non-summer) polar regions provide optimal occurrence and resolution of O_3 spatial and seasonal variations. To first order, these variations are driven by planetary wave deformation of sharp latitudinal gradients in O_3 columns associated with the polar vortex boundary to the cold, isolated polar air mass[3]. Consequently, MARCI daily polar imaging of polar O_3 variations supports a spatially contiguous, well-resolved (~10km) definition of polar wave activity on a daily basis over portions of 5 Mars years (MY28-32, and counting).

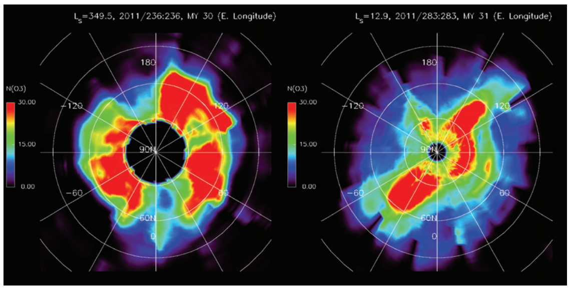

Figure 2. Two MARCI north polar O3 maps obtained in northern early spring (L_s=350° and 13°, MY30/31) display wavenumber 3 and 2 planetary wave structures[2].

In figure 2, we present a pair of MARCI polar projected maps indicating the degree and variable character to which such waves are displayed in MARCI O_3 column measurements. The contoured O_3 columns exhibit polar distributions associated with wavenumber 3 and 2 distortions of the polarvortex boundary.

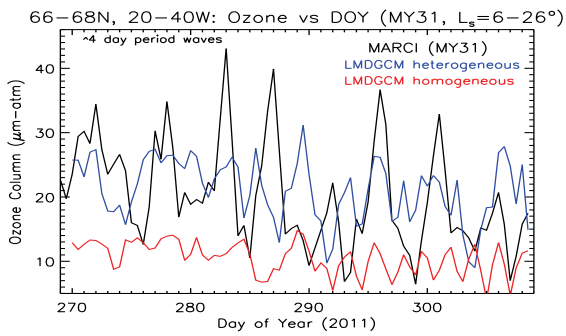

Figure 3. Observed (black) and modeled (color) periodic variations in high-latitude O_3 columns (northern spring)[2].

In figure 3, we plot the variation of O_3 at 66-68N, 20-40W over L_s=6-26° (MY31), in which a ~4-day period of planetary wave activity is apparent the MARCI observations (solid black line), and to a varying degree in LMD GCM simulations with (blue line) and without (red line) heterogeneous chemistry.

The observed variability in high latitude O_3 abundance contributes partly to the argument for heterogeneous chemistry on clouds[4], as discussed later in this abstract.

Hellas Seasonal O_3 Variation:

Hellas basin presents significantly increased surface pressures, up to several times those exhibited by much of the elevated southern hemisphere of Mars.

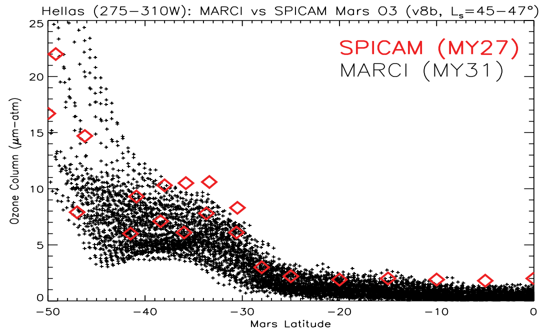

Figure 4. The latitudinal distribution of Mars O_3 over Hellas longitudes during southern late spring. Increased O_3 in MARCI (black) and SPICAM (red) measurements appears at the southern edge of Hellas.

As O_3 is formed by three-body reaction including CO_2, Hellas O_3 abundances are generally enhanced. Figure 4 presents a latitude cross-section of MARCI[2] and SPICAM[6] O_3 column measurements over the Hellas basin longitudes, demonstrating this effect as well as the general agreement between MARCI and SPICAM O_3 retrievals.

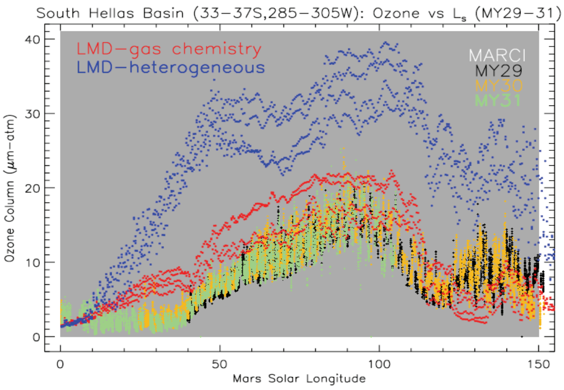

Figure 5. The fall-to-winter seasonal behavior of Hellas basin O_3 columns is presented for MY29-31 MARCI measurements and LMD GCM simulations[2].

Figure 5 presents the seasonal (L_s) variation of O_3 within Hellas (specifically, 33-37S and 285-305W), as measured by MARCI over MY29-31 (black, yellow, green) and simulated by the LMD GCM with (blue) and without (red) heterogeneous chemistry on clouds. Minimal O_3 inter-annual variation is apparent in the MARCI measurements. Two distinct seasonal peaks in Hellas O_3 are centered at L_s of 90° and 135° in the observations and models (and a third peak in the heterogeneous chemistry model at 55°). The sharp decrease in Hellas O_3 after L_s~100° extends into the northern hemisphere and reflects a seasonal/orbital transition in the distribution of upper level (above 10-20 km) atmospheric water vapor distribution.

The second seasonal peak over L_s=130-150° may reflect additional seasonal variation in atmospheric water vapor over Hellas at this time[11]. However, CRISM water vapor column retrievals[12] over non-Hellas basin longitudes (but the same latitudes) present monotonic increases after L_s=100°. Furthermore, MARCI O_3 columns at non-Hellas longitudes do not show such an L_s=130-140° peak, whereas they do exhibit O_3 decreases after Ls=90° similar to Hellas O_3 behavior at this time. Alternatively, it is possible that polar condensation enrichment processes are related to this Hellas basin O_3 increase. For example, condensation-enriched O_3 from winter polar regions may be transported into the deep Hellas basin as the southern polar vortex begins to weaken with the advancing southern spring season.

Two Hellas basin CO mixing ratio retrievals from MEX OMEGA L_s=132-140° observations exhibited 50-100% increases relative to other observed L_s periods, and to northern latitudes in the same season[13]. This behavior was also reflected in LMD GCM simulations and attributed to condensation enrichment of CO at winter high latitudes[14]. MRO CRISM CO mixing ratio measurements[12] over Hellas basin (lower panel in figure 6) also exhibit significant L_s variations relative to other longitudes (top panel in figure 6, noisier due to lower surface pressures), with peak values over L_s=150-160°. However, there is a significant gap in CRISM CO (and H_2O) observations over L_s=80-150° that limits clear comparisons to the MARCI O_3 (or OMEGA CO) variations. We are planning new CRISM measurements for coverage in this season.

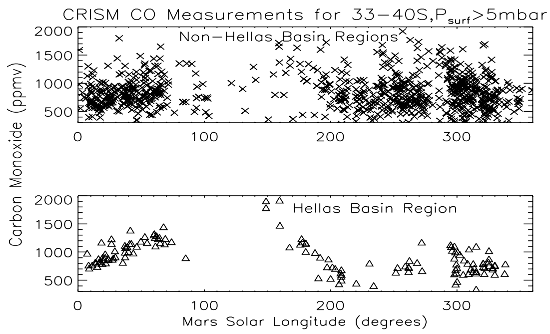

Figure 6. The seasonal (L_s) dependence of CO mixing ratios outside (top panel) and within (bottom panel) Hellas basin, for 33-40S latitudes and surface pressures > 5 mbar.

Of course, the LMD GCM simulates the key processes and reproduces the observed Hellas O_3 (and possibly CRISM CO) variations reasonably well. This suggests good constraints may soon be placed the specific atmospheric processes that lead to the observed Hellas O_3, H_2O, and CO variations.

Heterogeneous Chemistry on Clouds:

The role of heterogeneous chemistry on Mars clouds in removing HO_x (thus increasing O_3) has been proposed to account for LMD GCM model disagreements with O_3 and H_2O_2 measurements[4]. Comparisons of MARCI to LMD GCM O_3 columns show improvement with heterogeneous chemistry in some cases (figure 3), but substantially reduced agreement in other cases (figure 5). This variable level of agreement between MARCI and model O_3 columns, associated with implementation of heterogeneous chemistry, is further displayed in figure 7. In this case, observed and modeled O_3 columns at 70-74N are plotted over L_s=0-100°, encompassing the seasonal decrease high latitude O_3 from northern early spring to summer. Heterogeneous chemistry on clouds (blue) leads to larger O_3 abundances in early spring, in accordance with the MARCI observations (black). However, these enhanced model O_3 columns persist later in season (L_s=60°) than indicated by the MARCI observations (L_s=30°).

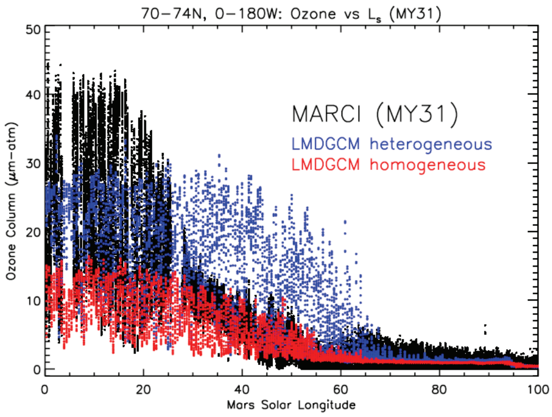

Figure 7. The seasonal dependence of Mars O_3 columns over 70-74N and 0-180W longitudes as observed (black-MARCI) and modeled (LMD GCM, blue-heterogeneous versus red-homogeneous chemistry).

MARCI measurements also support cloud optical depth retrievals (λ~320 nm) coincidentally with the column O_3 measurements[5]. However, MARCI cloud measurements are valid only over non-surface-ice regions. Under this restriction, we have searched for possible correlations in MARCI cloud and O_3 measurements. In figure 8, we plot northern fall (L_s=180-200°) MARCI O_3 column versus cloud optical depth measurements for 66-68N (all longitudes). No obvious correlation is presented between cloud and O_3 MARCI measurements at this time.

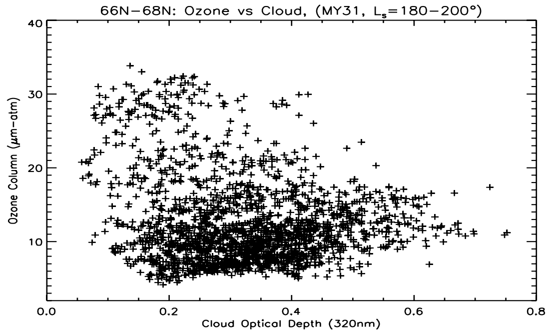

Figure 8. MARCI O_3 column and cloud optical depth measurements do not exhibit a notable correlation at high northern fall latitudes in MY31.

In figure 9, we compare MARCI observed ~5 day variations in southern fall O_3 columns (top panel) over a limited region (48-52S, 130-160W) with coincident cloud optical depth variations (bottom panel). As indicated by vertical yellow bars, dates of peak O_3 columns do not correspond to peak cloud optical depths. For both figures 7 and 8, the observed O_3 variations are dominated by large-scale waves in the presence of strong latitudinal gradients for O_3 columns. We point out that no clear correlation is present between MARCI cloud and O_3 abundances observed over L_s=90-100° in Hellas basin (figure 5), when seasonal and latitudinal trends in Hellas O_3 and clouds are at a minimum. However, surface ice is present over regions within Hellas basin at this time.

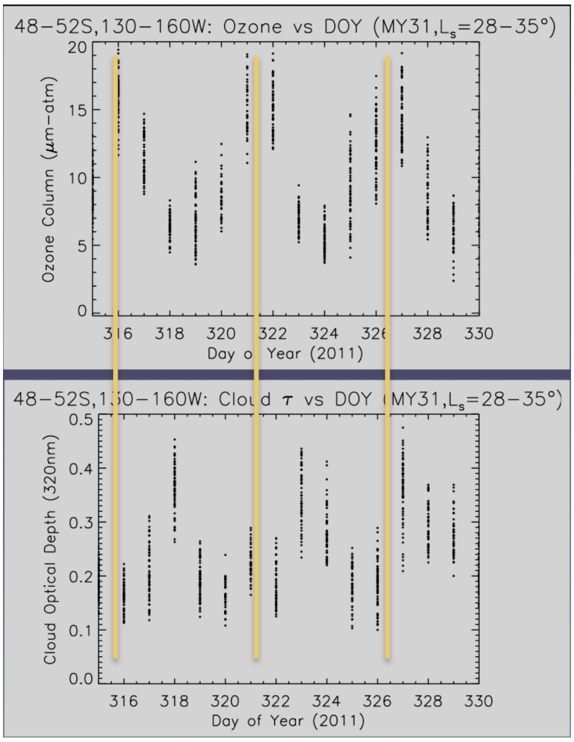

Figure 9. Periodic variations in southern high latitude MARCI O_3 columns (~50S, 145W for southern fall) are compared to coincident cloud optical depth variations[2].

While the above comparisons of MARCI O_3 observations to LMD GCM O_3 and MARCI cloud optical depth measurements do not rule out heterogeneous reactions on Mars clouds, they do indicate it may be difficult to identify in O_3/cloud column measurements. Furthermore, a detailed comparison of data versus model O_3 and cloud columns has yet to occur. In particular, Mars GCM models (including the LMD GCM) do not accurately simulate Mars cloud columns[15]. For example, comparison of the heterogeneous and homogeneous LMD GCM simulations for Hellas basin in figure 5 indicates strong cloud activity beginning well before L_s=50°. By comparison, MARCI cloud optical depths remain very low until L_s=80°.

Conclusions:

The presented MARCI results for Mars column O_3 values represent a preliminary assessment of this new atmospheric data product. These MARCI data combine daily global mapping over ~4 MY with a quantitative column measurement uniquely sensitive to low water vapor conditions (high latitudes, Hellas) during cold seasons (fall-winter-spring, aphelion). They are also accompanied by quantitative cloud optical depth measurements, except over surface-ice[5]. MARCI O_3 data provide a new data set for investigation of Mars polar dynamics with uniquely resolving spatial/temporal coverages. Mars O_3 columns are very sensitive to variations in water vapor/temperature over low water vapor atmospheric (≤ 1 pr-μm) regions. Polar vortex wave activity is very directly reflected in MARCI O_3 polar maps.

Hellas basin presents less dramatic fall-winter-spring O_3 increases than do the polar regions. But it clearly exhibits both similar and distinctive seasonal variations, indicative of a distinct atmospheric environment on Mars. MARCI daily mapping O_3 and cloud measurements provide a new window into this environment. They also support unique sensitivity to potential heterogeneous chemistry on Mars cloud particles. A preliminary assessment does not indicate a strong observable signature from such chemistry, relative to current data and models comparisons. However, detailed model-data comparisons (including cloud optical depths, which the models do not simulate well) are required to assign limits on the specificity of MARCI O_3 measurements to heterogeneous chemistry. Finally, we note the significant potential for this distinctive global data set in defining new aspects of Mars inter-annual variability.

We encourage the Mars atmospheric science community to work with MARCI cloud and O_3 measurements. The large volume of these data sets presents format challenges. By the time of the meeting, we will be providing subsets of the data in NETCDF and "ddd" formats (along with sample IDL code for reading the latter structure) at:

https://gemelli.spacescience.org/twiki/bin/view/MarsObservations/MarciObservations/OzoneAbundances

Bibliography:

(1) Malin et al, Icarus, 194, 2008.
(2) Clancy et al, DPS BAAS 45, 2013.
(3) Lefèvre et al, JGR, 109, 2004.
(4) Lefèvre et al., Nature, 454, 2008.
(5) Wolff et al., DPS BAAS 42, 2011.
(6) Perrier et al., JGR, 111, 2006.
(7) Parkinson and Hunten, JAS, 29, 1972.
(8) McElroy and Donahue, Science, 177, 1972.
(9) Barth et al, Science, 179, 1973.
(10) Clancy and Nair, JGR, 101, 1996.
(11) Encrenaz et al., A&A, 484, 2008.
(12) Smith et al, JGR, 114, 2009.
(13) Encrenaz et al., A&A, 459, 2006.
(14) Forget, 2nd International Mars conf., 2006.
(15) Haberle et al, Fall AGU, 2011.