Mapping Water Ice Clouds with MRO/MARCI

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Introduction

The Mars Color Imager (MARCI) instrument on-board the Mars Reconnaissance Orbiter (MRO) obtains near-global coverage of Mars on a daily basis [1]. This degree of spatial and temporal sampling offers one the ability to characterize seasonal and inter-annual variations of atmospheric processes. Of specific interest for water ice cloud studies is the presence of the ultraviolet (UV) channels. These bands were chosen to exploit the reduced surface contrast and increased atmospheric contribution (via scattered radiance), as well as for the sensitivity (in one channel) to the Hartley ozone band. Consequently, MARCI observations can provide global maps of water ice optical depth (and ozone column abundances) on a daily basis. Applications of these MARCI data products include their use in dynamical modeling studies and atmospheric remote sensing (i.e., gas abundance) retrievals. The goals of this presentation are: to provide a brief overview of the methodology involved; to illustrate the end-products of the "daily" retrieval process, including several example applications; and to advertise the desire to create custom products and public repository of useful water ice retrieval products.

Retrieval Methodology

The MARCI instrument and its performance/calibration have been described elsewhere, including the the UV channels [1,2,3]. The specific details relevant to the water ice retrievals involve "Band 7", which has a centroid of 321 nm, a radiometric accuracy of ~6-8%, and a radiometric precision of 2-3%. The intrinsic spatial sampling of Band 7 provides near-global daily coverage at ~8 km/pixel (nadir). To a large extent, the individual components and prescriptions for the relevant atmospheric state variables have been previously developed and discussed [3,4]. Here, we present only a schematic overview and a summary of recent updates to the calibration:

1.An on-the-fly calibration of the MARCI data from Data Number to I/F is performed for each strip, typically 12 or 13 per mapping day.

2.The "backplanes," or metadata, are generated for each pixel in the I/F images: photometric angles, elevation, surface pressure map, dust optical depth (i.e., need to prescribe everything EXCEPT water ice).

3.The water ice optical depth retrieval is performed using the Band 7 data. This done through a LookUp Table constructed using the DISORT library [5,6] and a wide-range of possible atmospheric state variables.

4.A polar mask is calculated from the results of Step 5 and imposing latitude and I/F cutoffs values.

5.Each mapping strip and associated metadata are "stored" for use to generate mapping and derived "products."

Updates

CRISM Dust Climatology. Dust is one of the quantities that must be prescribed as part of the cloud retrieval process. Analyzing the approximately 20,000 emission phase function (EPF) observations made by the Compact Reconnaissance Imaging SpectroMeter (CRISM) with the retrieval algorithm of [5], one can construct a database of "concurrent" dust optical depths. As can be seen in Figure 1, the coverage offered by this EPF dataset contains gaps even within a zonal-bin representation. Gaps are "filled" using interpolation and annual-averages.

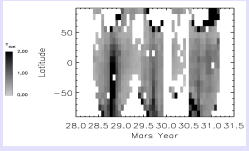


Figure 1

Surface reflectance map. Using a spatially-fixed surface reflectance model, one can observe patterns of water ice cloud opacity that appear to correlate with visible surface albedo features. To investigate this, we created a Hapke function "w" parameter map using a modified version of the cloud algorithm. The results can be seen in Figure 2, and appear quite striking, at least with respect to the ***anti-correlation*** with visible albedo features. The retrieval "improvement" is primarily restricted to the MARCI retrieval for low ice conditions (< 0.03-0.05).

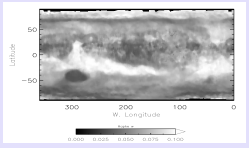


Figure 2

Basic Products / Public Database

An example of the daily coverage can be seen in Figure 4, which is the map-projected "mosaic" all the "tau" strips from day 222 of 2010 (Ls=131°, MY 30). This mosaic also highlights the weakness of the current retrieval in that surface ice is "aliased" as cloud opacity. Such pixels are flagged (but not eliminated) in the polar region during a post-processing step.. However, at this resolution (8 PPD), the resulting dataset is > 220 GB for all retrievals (and a minimal set of metadata) through the end of July 2018 (mid-MY 34), even when stored as compressed (scaled) integers. More practical higher-level datasets/products are needed.

Public Database. We are distributing retrieval (and metadata) products through a Twiki portal hosted at the Space Science Institute (a bit out-of-dated at the moment):

https://gemelli.spacescience.org/twiki/

(choose the "MarciObservations" web [7]). At present, we include a GIF mapping day (like Figure 3) and binned "snapshots" relevant to current Global Climate Models: 3° x 2° averaged over 10° in Ls. Snapshot files are available in NetCDF and text formats.

We need community feedback for designing additional formats and binning schemes (e.g., higher temporal/spatial resolution for common ROIs like USGS "quadranges"). Please contact us with your format "wish list"!

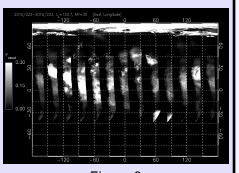
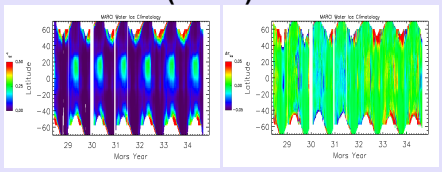


Figure 3

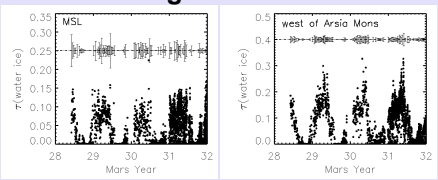
Annual (zonal) Behavior



Zonal Cloud Opacity MY 28-34 | Difference from "mean"

A zonally averaged quantity is often used to assess annual and interannual trends and variations. The above example is created by binning the retrievals to 2° in latitude and 5-days in time. The anticipated large-scale phenomena (LEFT PANEL) are clearly present, e.g., aphelion cloud belt, polar hoods. One's eye can pick up slight differences in the annual cycle from year-to-year. A more quantitative assessment of such variations can be obtained by removing a "mean" behavior from each year (RIGHT PANEL), where the "mean" year is the average of MY 30 through 34.

Point/Region Time-series

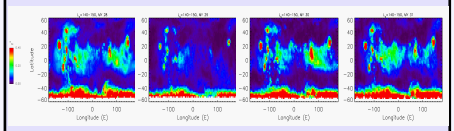


Time-series in 2° x2° box: (LEFT) centered on MSL site; (RIGHT) offset 1° west of Arsia Mons.

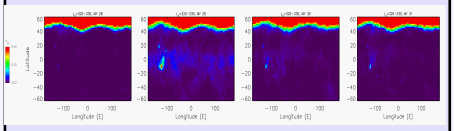
Obvious applications of the MARCI retrievals also include time-series for small regions, such as the location of surface assets (e.g., coordinated observations) and the regions of "interesting" dynamical activity (e.g., volcanoes). The "error bars" are meant to measure small-scale (1° spatially) variability and systematic error. The scatter above this level represents actual day-to-day variability in the water ice cloud activity.

This type of time-series can be quickly generated from any of the downsampled intermediate database products that we have created, such as a "daily" 1° x1° version (~4.4 GB).

Examples of Public Products



The decay of the "aphelion cloud belt" structure occurs primarily between Ls=140° -150°. Variability can be clearer here than in the zonal figure (MY 28-31).



Characterizing the meteorology of the polar hood and its associated wave structure requires spatial resolution. The type of behavior illustrated in this series of snapshots for Ls=320° -300°,MY 28-31 (as well as the series above) may be helpful for validating/providing context in dynamical modeling investigations.

REFERENCES: [1] Malin, M., et al., 2008, Icarus, 194, 501-512. [2] Bell, J. F. et al. 2009, Journal of Geophysical Research (Planets), 114, E08S92. [3] Wolff M. J., et al. 2010, Icarus, 208, 143. [4] i.e, Wolff et al., 2014, 5th MAMO, Wolff et al., 2018, Icarus, (almost) submitted). [5] Wolff et al., 2009, JGR, 114, E00D04; Wolff, M. J. et al. 2011, The Fourth International Workshop on the Mars Atmosphere, 213-216. [6] Stamnes, K. et al., Appl. Opt. 27, 2502–2509, 1988. [7] https://gemelli.spacescience.org/twiki/bin/view/MarsObservations/MarciObservations/WebHome

This work was supported by NASA through the MRO Project and a contract to Malin Space Science Systems (JPL Contract 1275776).