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Martian Surface NIR Spectral Modeling for Ice Cloud Optical Depth Retrievals using CRISM Mapping Data

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Abstract

One goal in the study of Mars is to understand its water cycle and the total water budget. As part of this, I am working on trying to measure water ice content in Martian clouds. The catch is that in order to measure the water abundance in clouds using near-infrared (NIR) spectra, one must know the surface spectrum, since it is an input for radiative transfer modeling—but to get the surface spectrum, one must be able to remove the effects of the atmosphere and aerosols.

I will present four primary methods of modeling away the surface in order to retrieve the ice cloud (and dust) optical depth and compare and contrast them for both ease-of-use and apparent accuracy.

1. Introduction

Observations of Mars across all major wavelength bands continue to confirm the presence of the tropical aphelion cloud belt. Many of these studies have also begun characterizing the clouds and measuring cloud optical depth. In the NIR, this is more difficult due to both a complicated surface spectral response, and the greater effect of scattering by aerosols. The primary task of trying to calculate ice cloud optical depths has thus become an exercise in finding a good method of characterizing the surface spectra. Once a model, or set of models to be linearly combined, are in hand, they become the surface reflectance parameter for a full radiative transfer model from which ice cloud optical depths are retrieved.

The methods investigated here will be: 1. using principal components analysis (PCA) to identify in-data surface endmember; 2. creating "pure" spectral endmembers from PC linear combinations via target transformation (TT) [1, 2]; 3. creating a "look-up" table of model spectra of given surface reflectance across multiple optical depths and finding the one that best fits each data-spectrum; 4. taking linear combinations of the model spectra in order to better characterize the surface spectral response.

2. Surface Recovery Methods

In previous work with ground-based data [2, 3] I have been able to show that PCA finds at most 3–4 significant dimensions for spectral data cubes of up to 105 input wavelengths. One dimension is tied to surface ice and clouds, the remaining are related to either "bright"/"dark" and then other surface variation. These PC's are fairly constant across all seasons. More recent work with the MRO CRISM mapping data [4, 5] shows similar results (Fig. 1)—the higher spectral and spatial resolution does add one more significant dimension.

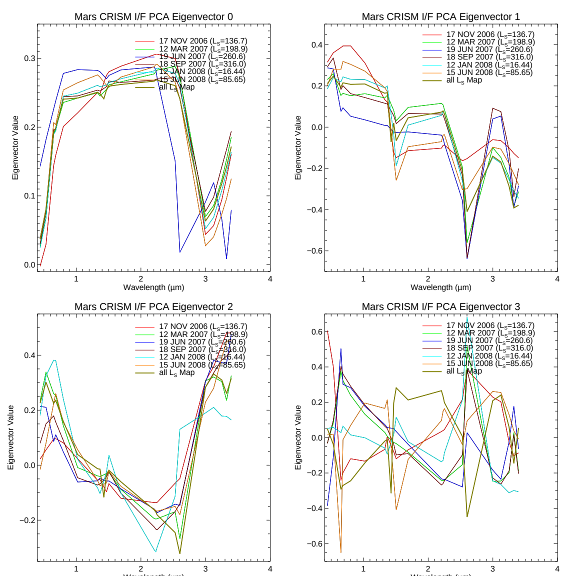

Figure 1: PC's from MRO-CRISM data. The first three are repeatable across seasons. The last significant PC appears related to higher order surface effects.

The first method of endmember recovery is to simply plot all the Mars data points in PC space and take those points at the extrema of the new dimensions as spectral endmembers. A model surface can then be recovered as a linear combination of them. The second method is similar, but instead of limiting the endmember choices to just the in-data points, it seeks to create synthetic endmembers from linear combinations of the PC's. The combinations are created via best fits to all the spectra in a mineral library. I find only a small number of distinct shapes returned—these shapes are than taken as the spectral endmembers.

For the final two methods, a look-up table of model spectra are created using a full radiative transfer program [6] developed from the DISORT [7] subroutines. The models are created using only three variable parameters, τ_i (ice cloud optical depth), τ_d (dust optical depth), and A_L (Lambert albedo)—I am currently ignore parameters such as surface altitude and specific incidence and emission angles. The latter two are more-or-less constant for all the CRISM data due to its Sun-synchronous orbit and the first mostly affects only the $2\,\mu$m absorption band, which I am not currently modeling to save on complexity. The optical depths range is 0–4.0 in steps of 0.1 and the albedo range is 0.01–0.6 in steps of 0.01.

The third method will simply find the best fit model to each data point wheres the fourth method will find the best fit linear combination across all model values of A_L for a fixed set of optical depths. In effect, these methods bypass the idea of surface modeling as a separate task. These latter two methods are computationally much faster than the first two; it is presumed the gain in time will come at the cost of reduced accuracy.

3. Summary and Conclusions

Method 1, using in-data recovered endmembers, did not provide satisfying results. I believe that this is due to the fact that none of the actual data spectra can be considered a "pure" spectral endmember; that every region is still a linear combination of all the PC's. As such, this method was abandoned. The results for method 2, using PCA and TT to recover spectral endmembers, can be seen in Fig. 2. The modeling recovers the three endmember coefficients as well as the ice and dust optical depths for a region beneath the aphelion cloud belt,Tyrhennum, and one north of it, Isidis. The values recovered are consistent with previous results [8].

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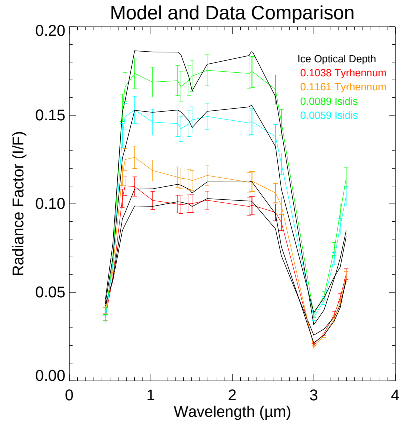

Figure 2: Results from method 2 showing comparison of model (black lines) to the data (colored lines) and the recovered ice optical depths.

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