Constraining the Mars General Circulation Model with realistic distributions of polar ice

Luís F. A. Teodoro1,2, Richard C. Elphic3, Jeffery I. Hollingsworth2, Robert M. Haberle2, Melinda A. Kahre2, Vincent R. Eke3, Ted L. Roush2, Giuseppe A. Marzo4, Adrian J. Brown5, William C. Feldman6, Sylvestre Maurice7; 1BAER Inst., NASA Ames Research Center, Moffett Field, CA 94035-1000 (luis@astro.gla.ac.uk); 2Planetary Systems Branch, Space Sciences and Astrobiology Division, MS 245-3, NASA Ames Research Center, Moffett Field, CA 94035-1000, USA; 3Department of Physics, Durham University, Science Laboratories, South Road, Durham DH1 3LE, UK; 4ENEA, Rome, Italy; 5SETI Institute, Mountain View, CA 94043, USA; 6Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson, AZ, 85719, USA; 7Université Paul Sabatier, Toulouse, France

Introduction: Much of our current knowledge about the climate and the global circulation of the atmosphere of Mars stems from measurements taken by landed missions from Viking through Phoenix. These observations, however, lacked the temporal and spatial coverage required to fully understand the general circulation of the martian atmosphere. Thus for many years the details of atmospheric circulation were studied using numerical general circulation models (GCMs). These have been successful in reproducing most of the available observations.

Recent spacecraft exploration of Mars has produced a wealth of new data. More than ever, general circulation models are going to play a central role not only in analyzing the existing datasets but also in the planning and execution of upcoming missions.

The Mars Odyssey Mission carries a collection of three instruments whose main aim is to determine the elemental composition of the top layers of martian surface materials. Among them, the Mars Odyssey Neutron Spectrometer (MONS) has produced a wealth of data that has allowed a comprehensive study of the overall distribution of hydrogen on the surface of Mars. In brief, deposits ranging between 20% and 100% Water-Equivalent Hydrogen (WEH) by mass are found pole-ward of 55 deg. latitude, and less rich, but still significant, deposits are found at near-equatorial latitudes. These results assume that the hydrogen distribution is uniform throughout the top meter of the martian soil. The Mars Reconnaissance Orbiter-Compact Reconnaissance Imaging Spectrometer for Mars (MRO-CRISM) has identified numerous locations on Mars where hydrous minerals occur (e.g.[3]). The information collected by MRO-CRISM samples the top few mm’s to cm’s of the martian soil. This independent information can, perhaps, help to impose additional constraints on the 3-D hydrogen distribution inferred from the MONS data. For instance, the absence of a correlation between the WEH wt% drawn from the MONS epithermal neutrons and the CRISM products at a location where the neutron data indicate high WEH implies the presence of a 3-D structure that is characterized by a top layer in which there is an absence of water, either in ice or hydrated mineral, and some buried layers where the concentration of hydrogen is higher than that expected from the MONS data alone.

However, MONS has a spatial resolution with FWHM of ~550 km whereas MRO-CRISM has a spatial resolution of ~ 20 – 200m. Hence, associating WEH with geologic features and mineralogy observed independently, must assure the MONS instrumental smearing is properly understood and removed. Usually, in the presence of noise, this is an ill posed problem that requires the use of a statistical approach [5]. Teodoro et al [6] have carried out a preliminary study of the martian polar regions applying such a methodology to Martian epithermal neutrons.

Here we present the most recent results of applying a Pixon image reconstruction approach to the Mars Odyssey epithermal neutron data coupled with information regarding the distribution of water and hydroxyls, including hydrous mineralogy. An exciting prospect is that this approach can provide more robust estimates of the real extent or the original volume of surface water ice. Such estimates can then be used to constrain the Mars General Circulation Model.

Pixon image reconstruction methods: In the presence of both some experimental noise, \(N\), and instrumental blurring, \(B\), the measured data, \(D\), can be related to the input image, \(I\), via

\[ D = B \ast I + N, \]  

(1)

where \(\ast\) denotes the convolution operator. The main goal of an image reconstruction algorithm is to choose a reconstruction, \(I'\), that both avoids spurious complexity and produces a residual field,

\[ R = D - B \ast I' \]  

(2)

that is statistically equivalent to the anticipated experimental noise. The pixon reconstruction [4, 5] can be perceived as an “adaptive smoothing”
Figure 1: **Top left panel** MONS epithermal count rates data in 40×40 km bins. The dark circle in the top left corner represents the MONS point spread function. **Top right panel** Pixon reconstruction of the MONS data without a priori constraints. The red area is the CO2 polar cap. While the dark blue regions indicate the presence of ice. The three white circles in the two top panels represent −85°, −80° and −75° latitudes. **Bottom panel** South polar mosaic of CRISM MSP images from $L_s = 295-003$ (see [7] for more details). The red region delineates the CO2 cap.

Figure 2: MONS WEH %wt data in 40×40 km bins. Left panel: North pole MONS data. Right panel: North Pole Pixon WEH reconstruction. The two white circles represent 70°, 80° latitudes.

Example of a CRISM prior on a MONS reconstruction: In figure 1 we illustrate how one can use CRISM information to constrain the MONS count rates at a given locale of the Martian surface. In the top right panel, the pixon reconstruction without any prior constraints clearly shows the CO2 cap in the immediate vicinity of the south pole: red region centered a few degrees from the center. In the bottom panel we present a figure extracted from [7] delineating the same CO2 cap as derived from CRISM. Although the CRISM data also depicts the CO2 cap this has a slightly different shape. We are using this latter geometric information to improve upon the estimates of MONS count rates.

Constraining the Ames Mars GCM: The Ames Mars GCM depends on several important physical parameters associated with the atmosphere and surface properties. One key property is the thermal inertia, which depends importantly on the presence of water ice near the poles. Replicating the Viking and later mission atmospheric pressure histories requires taking into account near-surface water ice content and spatial distribution at high latitudes. To the extent that these can be constrained by Mars Odyssey neutron measurements, the results of the GCM can be tied to physical parameters that characterize the near-surface materials at high latitudes. In particular ice content is directly related to thermal conductivity and thermal inertia, and spatial variations of these govern the input and release of energy (and water vapor) seasonally. Deviations from a uniform ice distribution poleward of 80N may thus influence local circulation and precipitation. Perhaps more important is what the derived distribution of polar ground ice tells us about recent climatic trends.

**References:**