# THE $H_2O$ CONTENT OF THE MARTIAN SURFACE AS SEEN BY MARS EXPRESS OMEGA.

R. E. Milliken[1], J. F. Mustard[1], F. Poulet[2] J.-P. Bibring[2], Y. Langevin[2], B. Gondet[2], and S. Pelkey[1], [1]Dept. Geological Science, Brown University, Providence RI 02912 USA, [2]Institut d'Astrophysique Spatiale, Baitment 121, Orsay, France. Email: ralph_milliken@brown.edu

**Introduction:** Recent results from the Mars Exploration Rovers and the Mars Express OMEGA VIS-NIR spectrometer have shown that liquid water interacted with the near-surface multiple times in the early history of Mars to form hydrated clays and sulfate salts [1,2,3]. OMEGA (and NASA's upcoming CRISM spectrometer onboard MRO) provides high spatial and spectral resolution VIS-NIR data from 0.3 – 5.0 $\mu$m, covering the fundamental $H_2O$ stretching and overtone $H_2O$ bend absorptions in the 3 $\mu$m region. The presence of these absorptions are indicative of water physically adsorbed on grain surfaces and/or bound in a mineral structure, though it is not possible to differentiate the two using this wavelength region. Previous estimates of surface hydration using Phobos-2 ISM data suggested the 3 $\mu$m band varies in strength over the equatorial regions of the martian surface, with dark red soils having the strongest absorptions [4,5]. These data could be converted to apparent absorbance and used to make semi-quantitative or relative estimates of water content [5] if values were tied to the measurements of soil hydration as measured by the Viking landers (1-2 wt. %). The Viking estimates, however, are known to have large uncertainties [6].

For this study, we apply three approaches to derive absolute water content from Mars Express OMEGA data: band depth, apparent absorbance, and a new laboratory-derived model relating the strength of the 3 $\mu$m band. While all three methods capture the broad hydration properties of the surface, the first two are strongly correlated to albedo and require assumptions for surface water content. The new model requires no *a priori* knowledge of surface composition, is valid for both high- and low-albedo surfaces, and has uncertainties on the order of ±1 wt. % $H_2O$ [7,8]. Here we present a first look at the current hydration state of the uppermost fraction of the martian surface.

**Methods:** Most of Mars has a low albedo (typically 0.15–0.4), resulting in a nonlinear compression of absorptions relative to brighter, high-albedo materials of similar composition or water content. Commonly used spectral parameters such as band depth or apparent absorbance will show a strong correlation to albedo when derived from reflectance spectra [8]. This gives the false impression that brighter surfaces have stronger absorptions than dark surfaces, an important factor when trying to relate absorption strength to physical properties such as water content. Our laboratory-derived model suggests a linear relationship between the effective-single-particle absorption thickness (ESPAT, [9]) and absolute $H_2O$ contents < 12 wt. %, where [8]:

$$\text{wt. \% } H_2O = \text{ESPAT}_{2.9\,\mu\text{m}} \cdot 3.88 \qquad (1)$$

Converting data to single-scattering albedo minimizes much of the apparent albedo effect and laboratory data show the ESPAT parameter yields smaller residuals than band depth or apparent absorbance when estimating absolute water content. To solve for the ESPAT function, OMEGA reflectance spectra are converted to single-scattering albedo, *w*. This is accomplished by converting OMEGA spectra to radiance, subtracting the contribution of thermally emitted radiance, dividing the by the solar spectrum to produce I/F, and dividing by the cosine of the incidence angle to produce BRDF spectra. These spectra are related to *w* as described by Hapke [9]. Input variables are incidence angle, emergence angle, and BRDF values for each pixel; we assume no opposition surge ($B(g)=0$) and isotropic scattering ($p(g)=1$, for both bright and dark regions), where $g$ = phase angle. We account for differences in continuum slope by defining the ESPAT function as: $\text{ESPAT}_{2.9\mu m} = (c_{2.9\mu m} - w_{2.9\mu m})/w_{2.9\mu m}$ (2), where $c$ is the value of the continuum slope at a given wavelength. This is based on the assumption that the scattering efficiency ($Q_E$) is equal to the continuum, not unity, when the water content is zero (*i.e.* when there is no water absorption).

The resulting hydration estimates from all OMEGA data are gridded at 64 pixels per degree (Figure 1) to provide a global view of the surface hydration; higher resolution grids are made for areas of specific interest. The OMEGA data have been corrected for atmospheric gases but still contain effects due to aerosols and clouds. Pixels with a 1.5 $\mu$m band depth >2% were excluded to minimize the effects of seasonal surface frost and water ice clouds, but some of these effects still remain.

**Results:** The most noticeable aspect of the global hydration (Figure 1b) is the increase in water content at high latitudes in both the northern and southern hemispheres. The northern plains, specifically in the Acidalia region, are generally more hydrated than the southern highlands and have water contents in the range of 3 – 5 wt. %. Poleward of 60° N, the water content increases rapidly up to values of 6-12 wt. %. Similarly, latitudes poleward of 60° S also show a distinct increase in hydration, though the absolute values are slightly less than those observed in the north (Figure 2). This is in agreement with observations made by the Mars Odyssey GRS, which showed a strong increase in $H^+$ content poleward of 60° in both hemispheres [10]. The GRS instrument also observed an area of increased hydrogen content centered over Arabia Terra. Though the OMEGA data do not show an increase in hydration over this region as a whole, there are localized exposed outcrops in craters and other areas of high thermal inertia with water contents up to 6-8 wt. %. [11].

Also of importance is the lack of correlation between albedo (Figure 1a) and hydration derived using the ESPAT function with the assumptions listed above, opposite of what is found when reflectance-derived band depth or apparent absorbance are used to estimate hydration. This method suggests bright, dustier regions commonly have similar hydration values as darker regions. Volcanic materials in the Syrtis Major complex have some of the lowest hydration values (~1-2 wt. %), but are adjacent to phyllosilicate-rich areas indicative of hydrolytic alteration in Nili Fossae [12]. These phyllosilicate deposits, and others near Mawrth Vallis

[2] exhibit water contents of 5-7 wt. % using the method described here. Sulfate-rich regions in Meridiani Planum are only slightly more hydrated than the surrounding terrains (3-4 wt. %), but higher resolution data may reveal exposed outcrops of increased hydration such as those seen at the Opportunity landing site.

**Conclusions:** Laboratory and numerical experiments show that the ESPAT parameter, as defined by Hapke [9], provides an accurate method for estimating water content (±1 wt. %) of high- and low-albedo materials. Parameters such as band depth and apparent absorbance are strongly correlated to albedo when derived from reflectance spectra and are not reliable for estimating absolute water contents. Applying our model to OMEGA data reveals 1) an increase in hydration poleward of 60° in both hemispheres, 2) bright areas are typically not more hydrated than dark areas, 3) most of Martian surface has a water content of 2-4 wt. %. Spatial variations in hydration may represent local equilibrium between the porous regolith and atmospheric water vapor abundance (readily-exchangeable $H_2O$, adsorbed on grain surfaces), variations in type/amount of hydrated phases with non-exchangeable water (such as palagonite), or variations in type/amount of hydrated phases which maintain equilibrium with atmospheric water vapor abundance, such as clays, zeolites, and sulfates [13]. Further corrections must be made to remove the effects of clouds and aerosols, but these results show that this method can be used with OMEGA and CRISM data to estimate absolute water content and track changes in surface hydration over seasonal cycles [14].

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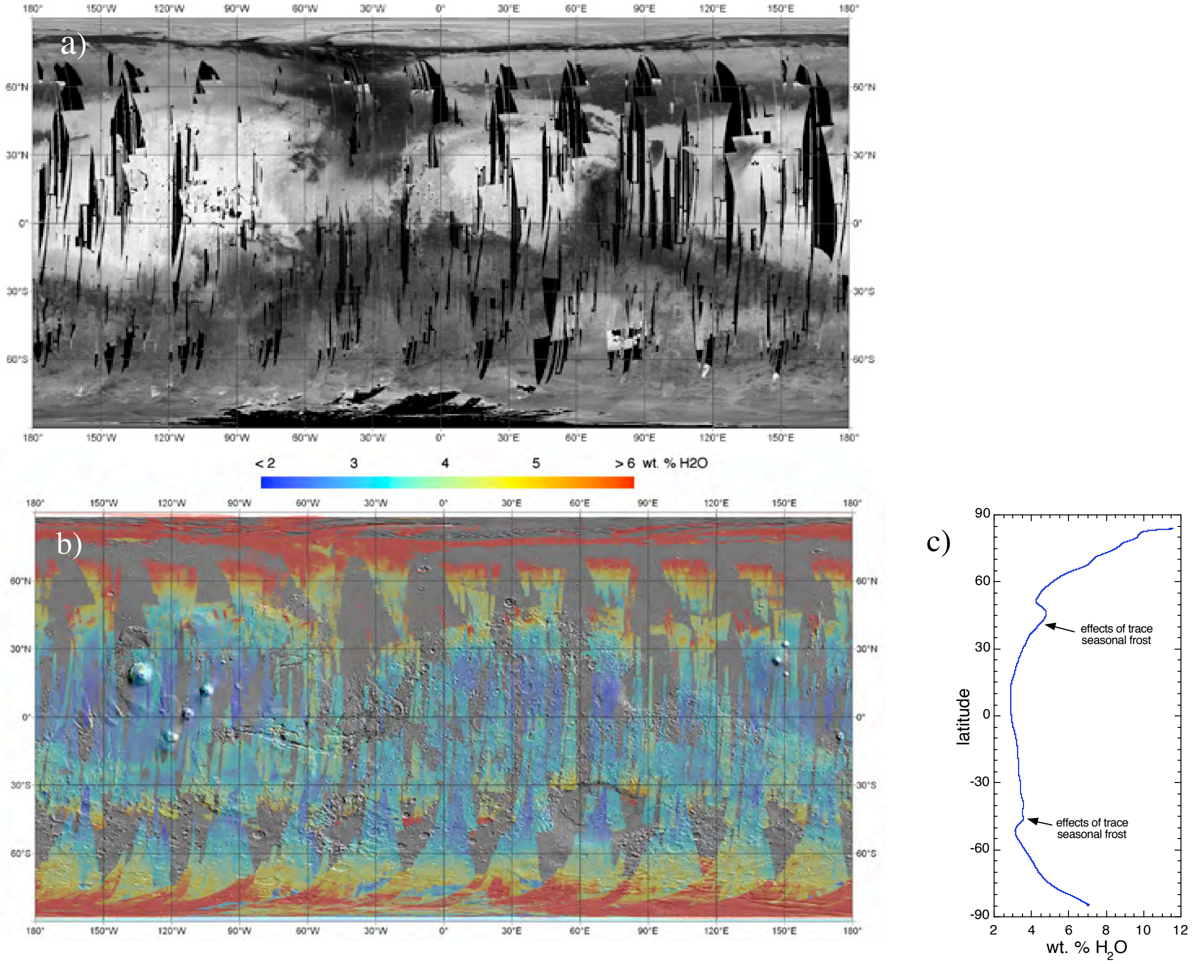

**Figure 1.** a) Albedo map derived from reflectance at 1.3 $\mu$m, b) map of estimated wt. % $H_2O$ derived using Hapke's ESPAT parameter. Hydration increases with latitude near both poles (up to ~12 wt. %), whereas equatorial regions have lower hydration values of 2-4 wt. %, c) wt. % $H_2O$ as a function of latitude, averaged over all longitudes. Trace amounts of seasonal surface frost are present in some orbits near 40-45° N/S (red areas), but frost-free orbits still show an increase in hydration with latitude.