Weak Signatures of Water Ice at High Northern Latitudes: Aerosols, Frosts and Ice Outcrops

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Introduction: The South and North polar relief has been shown to be mainly constituted of water ice by the MARSIS and SHARAD sounding radars [1,2]. The extent of regions where the subsurface ice reservoir reaches the surface is an important parameter for evaluating the role of sublimation in the mass budget of the perennial caps. Spectral imaging in the near IR has been shown to be diagnostic of the presence of surface water ice with OMEGA [3,4,5] and now with CRISM (see e.g. the abstracts presented by W. Calvin and T. Titus, this conference).

The north polar layered deposits (NPLD) exhibit an intermediate albedo (0.3 to 0.4) with temperatures exceeding 200 K at noon in summer, which are not compatible with a major areal coverage of exposed perennial water ice free of dust. Weak water ice signatures are observed over a large fraction of these regions. They can correspond to outcrops of perennial water ice strongly contaminated by dust (~ 30 wt% in SPLD's, [6]). A wide range of alternate possible origins needs to be investigated: water ice aerosols, a contribution of nearby ice-covered areas due to aerosol scattering, or a daily cycle of frost deposition and sublimation.

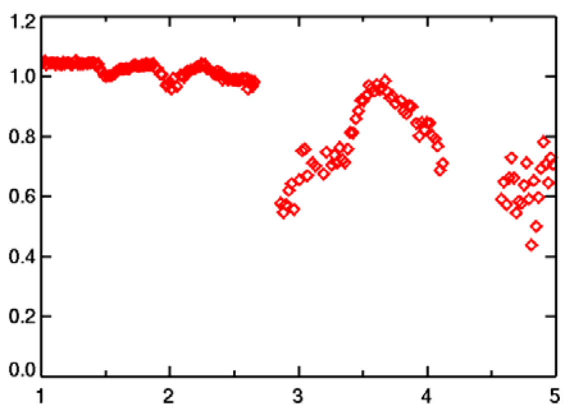


Fig. 1: ratio between the near-IR spectrum of a region covered by the edge of the northern polar hood close to the spring equinox (Ls ~ 3.3°) and that of a nearby region free of ice signatures

Water ice aerosols: observations with TES on MGS [7] demonstrated that water ice aerosols were present in the atmosphere of Mars, in particular at low latitude close to aphelion as "polar hoods". Water ice rich aerosols in equatorial clouds have been observed in the near IR by OMEGA [5]. The small size of the grains (typically 1 – 4 µm [7]) results in a much larger band depth at 3 µm than at 2 µm or 1.5 µm. The same behavior is observed for the polar hood (Fig. 1). The relative strength of the water ice bands at 1.5 µm, 2 µm and 3 µm can therefore be reliably used for discriminating signatures of water ice arerosols from weak signatures of surface water ice in polar regions.

Contributions from nearby areas due to aerosol scattering: Photons can be detected by a nadir pointing instrument after being first scattered by the surface outside the IFOV, then scattered by aerosols within the IFOV. Using a Monte-Carlo model [8], it is possible to determine the fraction of such photons originating from beyond a given distance in the observed signal. If one assumes homogeneous mixing with a scale height of 11.5 km close to the surface, very few photons originate from regions at several scale heights from the IFOV (Fig. 2). However, 13% of photons come from regions more than 10 km away with an optical thickness of 0.68, which is typical for wavelengths of ~ 1 µm shortly after summer solstice.

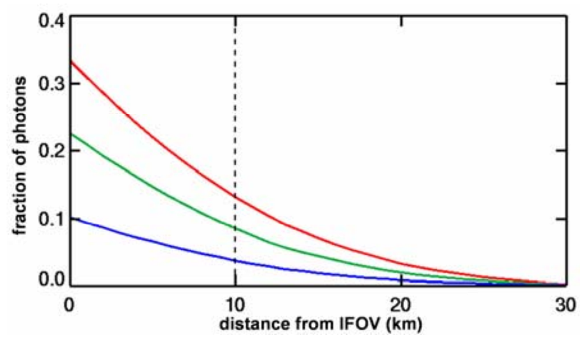


Fig. 2: proportions of photons reaching the instrument after being scattered by the surface farther than a given distance from the IFOV, then scattered by aerosols with an optical thickness of 0.68 (red), 0.37 (green) and 0.13 (blue).

This contribution can enhance the ice signatures for "dry" troughs in the North polar cap surrounded by ice covered regions (Fig. 3). For µm-sized aerosols, It decreases by a factor of 4 between 1 µm and 4 µm as scattering becomes less effective, contrary to sub-pixel areal mixing between ice-free and ice-covered regions, which is independent of wavelength.

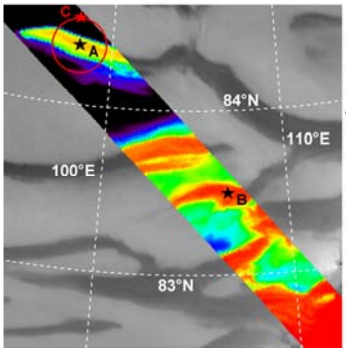


Fig. 3: map of the water ice signature at 1.5 µm (red: 0%; black: 60%) for L_s 95.1° in 2006. region A shows stronger water ice signatures than for other NPLD areas (B). Ice covered Regions (C) whithin 10 km (red circle) contaminate spectrum A due to aerosol scattering.

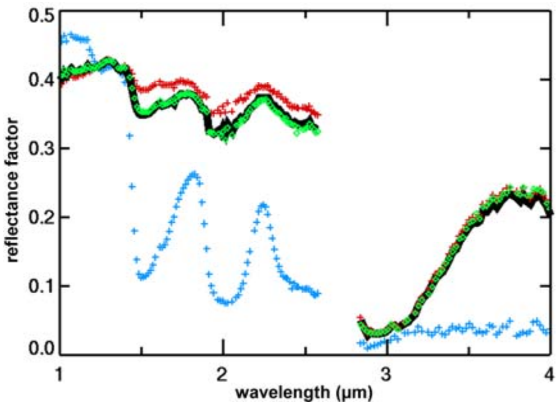


Fig. 4: model (black) of the reflectance spectrum of region A (green) assuming a contamination of the reflectance spectra of region B (red) by that of region C (blue) due to aerosol scattering.

As shown in Fig. 4, the spectrum of NPLD surrounded by ice (A) can be modelled by combining a spectrum of NPLD farther from strong ice signatures (B) with a contribution from nearby ice-covered areas (C) which decreases with wavelength. The very weak ice signatures in spectrum B could already result in part from a contribution of nearby ice-covered areas (with ice signatures weaker than that of region C).

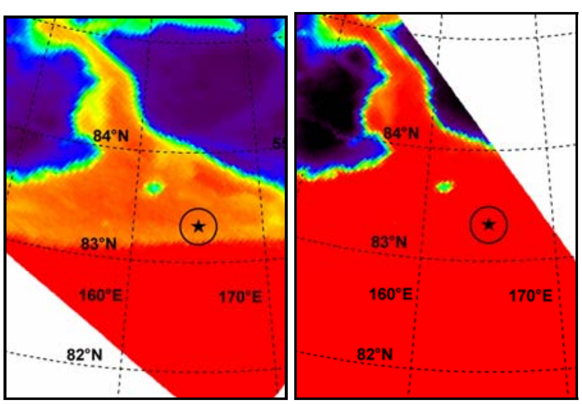
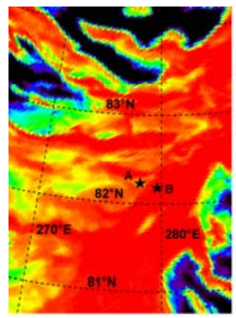


Fig. 5: water ice signature at 1. 5µm observed the same day (27/11/2004) at local time 5h25 AM (left) and 12h00 noon (right).

Frost condensation and sublimation: water ice signatures over NPLD vary significantly over two consecutive orbits at Ls 121° in 2004 (Fig. 5). This behaviour is attributed to condensation of small-grained frost (< 100 µm) at low sun elevations from the large supply of water vapour in the atmosphere in early summer [9] followed by sublimation as the sun rises.

Admixture of large-grained ice: The diagnostic signatures of large grained ice (> 200 µm) are the saturation of the 1.5 µm and 2 µm band and the presence of a significant absorption at 1.25 µm. Such weak signatures are observed in NPLD in mid-summer (Fig. 6) when seasonal frost has completely sublimated.



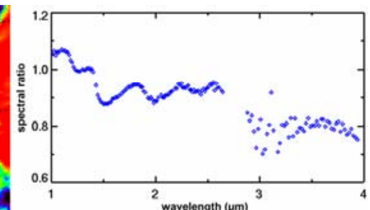


Fig. 6: weak water ice signatures observed at Ls 120° (noon) in NPLD correspond to large grains (top : spectral ratio betweeen areas A and B)

The large size, the relatively weak 3 µm features and the lower temperature all point to an admixture of ~ 15% (in aeral coverage) of perennial ice in NPLD material at the subpixel scale (< 2 km) or to dust contaminated perennial ice.

Conclusion: The wide variety of processes which can result in a weak water ice signature in polar regions could be discriminated by OMEGA on the basis of their time evolution and by their spectral characteristics, so as to identify outcrops of perennial ice in NPLD during summer. CRISM will observe these regions in August 2008 (L_s ~ 120°) at a much higher spatial resolution (20 m). The full FOV of CRISM in HR mode (12 km) is similar to the scale height of aerosols. Wider field observations will be useful for assessing potential contributions from nearby ice-covered regions.

References: [1] Plaut et al., Science 316, 92-95 (2007); [2] Seu et al., Science 317, 1715-1718 (2007); [3] Bibring et al., Nature 428, 627-630 (2004); [4] Langevin et al., Science 307, 1581-1583 (2005); [5] Langevin et al., J. Geophys Res. 112, CiteID E08S12 (2007); [6] Douté et al., Planet. Space Sci. 55, p. 113-133 (2007) [7] Clancy et al., J. Geophys. Res. 108, citeID: E002058 (2003) ; [8] Vincendon et al., J. Geophys. Res. 112, CiteID E08S13 (2007); [9] Encrenaz et al., Astron. Astrophys. 441, p. L9-L12 (2005)