MARTIAN SEASONAL CO_2 FROST INDICATING DECAMETER-SCALE VARIABILITY IN BURIED WATER ICE. M. T. Mellon[1], C. J. Hansen[2], S. C. Cull[3], R. E. Arvidson[3], and M. L. Searls[1,4], [1]Laboratory for Atmos. and Space Physics, Univ. of Colorado, Boulder; [2]Planetary Science Inst., Tucson; [3]Dept. of Earth and Planetary Sciences, Washington Univ., St. Louis; [4]Dept. of Earth and Atmos. Sciences, Univ. of Nebraska.

Introduction: Several new lines of evidence indicate that subsurface water ice (ground ice) on Mars is more complexly distributed, and in variable concentrations, than previously envisioned. Understanding the current distribution of ground ice is a fundamental part of understanding how this ice was emplaced and the recent past climate conditions under which icy deposits formed and subsequently evolved. In this work we examine the seasonal defrosting of CO_2 observed by HiRISE as an indicator of decameter-scale ground-ice heterogeneity. Our current focus is on the Phoenix landing site as this site is well characterized by lander and HiRISE imaging, but results are broadly applicable to middle and high latitude regions of Mars.

Background – Ground Ice: Middle and high latitude ground ice has been long predicted to be stable in the current martian climate [1]. Numerical studies have shown that below an "ice table" the soil pore space would quickly become saturated with water ice, by vapor diffusion and condensation [2]. In contrast, the soil above the ice table remains ice free. Theoretical studies, collectively spanning decades, have pointed only to the formation of pore ice, ice in soil interstice.

Spacecraft observations over the past decade have shown that ground ice is indeed located in the predicted geographic locations [3,4], and that the ice table generally occurs at a depth consistent with diffusive equilibrium with atmospheric vapor and the martian climate [3,8]. These observations have also shown that ground ice exists in highly-variable concentrations, often greatly in excess of the soil pore space [5,7].

Mars Odyssey gamma ray and leakage neutron observations (spatial resolution of 300-600 km) detected abundant hydrogen (water ice) [6,7]. Hydrogen concentrations indicated that averaged over this large foot print some locations contain ~90% vol. ground ice.

The lander Phoenix uncovered two distinct types of ice in the high latitude subsurface within the two-meter wide excavation workspace [8]. One type of ice is best described as pore ice as was predicted, while the other consists of relatively pure light-toned ice with 1% soil content [9]. The light-toned ice was also observed to be friable and may contain open pores. No gradation was observed between these two icy end members [8].

Recent meteorite impacts around the northern high latitudes exposed subsurface ice at shallow depth [10]. While the concentration of exposed ice is currently debated, these impacts may have expose ice comparable to the light-toned ice at the Phoenix landing site.

The collection of these observations are at odds with the theoretical predictions of pore ice. In addition to the puzzle of high ice concentrations, the spatial distribution and the scale of ice variations is not clear. In this work we examine the effects of ground ice on seasonal CO_2 frost as an indirect indication of water-ice variability on decameters-to-meter scales.

Background – CO_2 Frost: It is well known that CO_2 dry ice accumulates on the martian surface in winter. The amount of dry ice and the time it spends on the ground depends strongly on surface properties. A readily observable attribute is the "crocus date", the season (Ls) when CO_2 sublimates, exposing the soil surface.

Many factors can affect the crocus date, but perhaps most important are the properties of CO_2 frost and of the surface. Soil thermal inertia and albedo control the storage of summer heat. Stored heat, along with the albedo and emissivity of the dry ice, balance latent heat of CO_2 of sublimation. The depth of the ice table and thermal inertia of the icy subsurface are also important.

Background – Key Previous Studies: Numerous studies have also shown that the observed ground-ice depth is controlled by diffusive equilibrium with atmospheric water vapor in close agreement with the current martian climate [3,8,13]. *Haberle et al.* [11] showed the depth of ice-rich ground below the dry-soil layer strongly influences the seasonal CO_2 cycle on a global scale. *Titus et al.* [12] examined TES seasonal temperatures at the Phoenix landing site to predict the depth of ground ice. In fitting the data (averaged over ~60 km) they found that the icy substrate needed to have a lower thermal inertia than expected for ice-saturated soil. *Searls et al* [14] examined CO_2 frost persisting in the troughs of polygonal ground near the Phoenix site and considered a host of possible causes including: aeolian transport, ice-table depth, and topography. *Kossacki and Markiewicz* [15] modeled CO_2 frost in southern polygon troughs and concluded that the occurrence of ground ice plays a significant role.

Observations: In this work we focus on analysis of a seasonal sequence of HiRISE images of the Phoenix landing site spanning a full Mars year. These images show decameter-scale variability in the CO_2 frost and local crocus dates over Ls 25º-55º. We also utilize TES temperature and albedo observations, and CRISM spectral observations over the same range of seasons.

Figure 1 shows an example of the seasonal CO_2 defrosting around the Phoenix lander (center). As compete frost cover (Fig. 1a) transitions to discontinuous frost (Fig. 1b), some areas loose frost early in the spring while others loose frost later; in this way a range of local crocus dates describe the defrosting over the region. Of particular interest are decameter scale continuous frost patches (Fig 1b, arrows). Evidence indicates that the patterns and the timing of frost disappearance is generally repeatable from year to year, such that the substrate is controlling the crocus date.

Modeling: Comparison of these observations with numerical models of the seasonal temperatures and CO_2 defrosting [3] allows constraints to be placed on surface and subsurface properties such as ice-free-soil thermal inertia, ice-table depth, and the thermal inertia of the ice-rich ground below the ice table. Varying these and other parameters a match can be found to the observed range of local crocus dates.

Interpretations and Conclusions: Only CO_2 slab ice (solid, non-porous dry ice) is indicated throughout the observed seasons and at all spatial scales (down to meter scale), as evidenced by albedo (HiRISE and TES) and IR spectra (CRISM). Also, the low emissivity of fine particulate CO_2 frost would result in a crocus date much earlier than even the earliest observed.

Apparent year-to-year repeatability of CO_2 ice patterns, both in polygon troughs and decameter patches, along with a lack of topography nor aeolian redistribution, suggests that differences in the surface substrate is the root cause of the range of local crocus dates.

Two possible substrate differences are indicated by modeling: (i) the ice-table depth varies from atmospheric equilibrium, such that a thicker dry-soil layer occurs in disequilibrium where the CO_2 ice lingers longest; and (ii) the H_2O concentration at the ice table is less than pore filling, or light-toned “pure” ice contains open pores of air (open porosity). In the later case these CO_2 patches may be outlining deposits of the Phoenix light-toned ice. Neither case is predicted by current models of ground ice stability and dynamics.

Based on the combination of observations and modeling we rule out: variations in dry-soil or CO_2-ice albedo and emissivity, differences in dry-soil thermal inertia (with the ice table in atmospheric equilibrium), topographic effects, and rock distributions.

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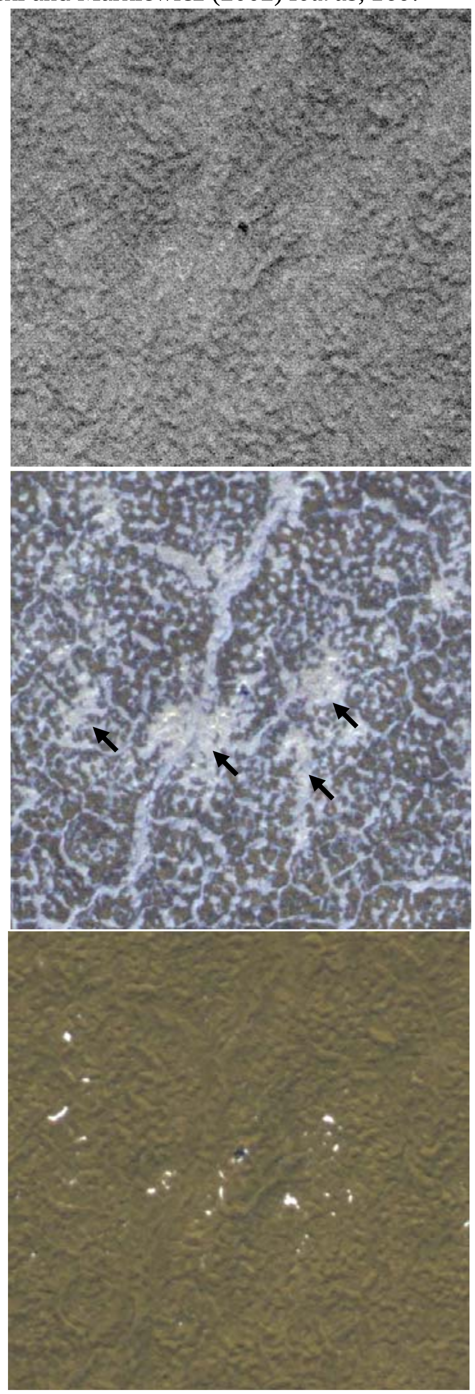

Figure 1. HiRISE view of 150x150m area around the Phoenix lander (center): (a) Ls 27º, ESP_15949_2485, continuous CO_2 slab ice; (b) Ls 34º, ESP_016160, a mix of bare ground and CO_2 slab ice, decameter scale CO_2 patches (arrows); (c) Ls 56º, ESP_016793, mostly CO_2-ice free except lingering patches where decameter patches existed in the previous frame (b).