Mars Reconnaissance Orbiter Mars Climate Sounder Shallow Water Ice and Regolith Overburden Mapping in the Northern Hemisphere.

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Introduction: During periods of high obliquity, snow deposits form ice sheets at mid and low latitudes on Mars. When the climate changes, these units can become unstable, but they may nonetheless survive for millions of years under a lag of insulating fines. The current distribution of near-surface water ice on Mars is still partially unknown to this day. This is a topic of great interest to the Mars scientific and engineering communities in the context of the upcoming crewed exploration. Between October 2019 and June 2022, the Mars Climate Sounder [1] onboard the Mars Reconnaissance Orbiter acquired dedicated surface observations to map the distribution of shallow water ice and the overburden thermophysical properties in the Northern high and mid latitudes of Mars.

Methods: Water ice is characterized by a high thermal inertia (>1,800 $Jm^{-2}K^{-1}s^{-1/2}$), whereas typical martian fines are associated with lower values, i.e., 20-350 $Jm^{-2}K^{-1}s^{-1/2}$. For this reason, water ice essentially resists large and prompt temperature changes forced by diurnal and seasonal insolation changes. Shortly after the summer solstice (L_s~90°), surface temperatures are most influenced by the presence of shallow ice, which keeps the surface cool, in contrast with observations near L_s~180° where the overburden thermal properties are primarily controlling surface temperatures [2,3]. With a pair of surface temperature observations at these two pivotal seasons, ice depth and overburden properties can be retrieved when analyzed in conjunction with a thermal modeling [4].

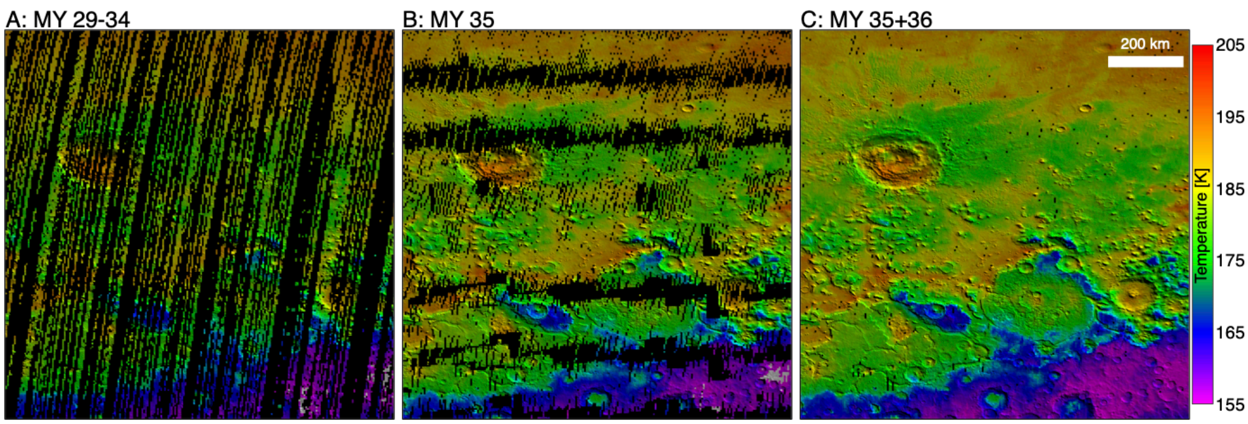

Figure 1: MCS surface temperature coverage for a representative region in the Northern mid-latitudes, centered near 47.2°N 38.3°E. The largest crater is Lyot. A: available coverage at 100° < L_s < 120° and 160 °< L_s < 180° before the start of the mapping campaign (MY 29-34 combined). Colors indicate temperatures at 100° < L_s < 120°; B: same as A but using data acquired by the end of Phase 1 in MY 35; C: same as A using data acquired by the end of Phase 2 in MY 36, filling the gaps remaining after MY 35. Black dots indicate no data. MOLA shaded relief background.

An MCS observation campaign was designed to generate regional (i.e., 30-80°N) temperature coverage at native resolution (~9 ppd, equivalent to ~7 km at 30°N) within these two seasonal windows (Phase 1: 96°<L_s<124° and Phase 2: 155°<L_s<186°) while maintaining the atmospheric climatological record. Fig. 1 illustrates the coverage gained by this mapping activity: while over 5 Mars Years (MY) of regular MCS operation provided largely incomplete coverage, only 2 MY of dedicated observations yielded near-complete coverage at the desired seasons (Phases 1 and 2). These MCS data were analyzed with a thermal model [5] to generate surface temperature lookup tables for Mars at the corresponding local time, season, coordinates, and for the atmospheric state at the time of the MCS observation pairs, with the overburden thermophysical properties and the ice depth left as free parameters. For each MCS observation pair, the lowest RMS is identified to determine the overburden thermal inertia and ice depth.

Overburden: The overburden thermal inertia is generally in good agreement with values published elsewhere [6-9]. When converted to approximate grain sizes [10], these thermal inertia values show that the properties of the surface layer range from non-load bearing silt-size material to coarse, possibly cemented and rocky units. This new information will be useful for future studies concerned with regolith diffusivity, surface mobility, or pre-landing assessment of load bearing properties at potential exploration sites [11-14] where the presence of shallow water ice is required.

Ice Depth: Ground ice is frequently detected within ~ one meter of the surface, but not everywhere at high or mid-latitudes. Lateral ice depth variability is locally high (Fig. 2), with no clear relationships to geological or morphological surface features. At mid-latitudes (30-40°N), a set of shallow ice interfaces is detected and corresponds to regions already known for their shallow radar signatures consistent with ground ice and ice-exposing craters.

However, several ground ice detections at these low latitudes are most likely associated with false positives because the analysis of thermal data alone cannot discriminate water ice from bedrock or strongly indurated materials. In addition, the radiative contribution of water ice clouds is not accounted for, and this warming effect at night mimics shallow ice deposits. Fortunately, contextual information generally provides a high level of confidence for most ice detections: shallow water ice mapped with MCS data approximately matches the distribution of icy impact craters [15], icy cliffs [16], latitude dependent mantle units [17], and Phoenix Lander observations [18].

Implications: Ground ice sheets within ~ a meter of the surface at latitudes approaching ~40°N (or lower) are not stable and are modeled to sublimate rapidly. Their presence bears several fundamental implications:
1. Water ice resources will be accessible for future crewed missions, even at mid- to low latitudes;
2. The distribution of Special Regions and current habitability require a community-wide re-assessment;
3. Current Mars is possibly much drier than typical late Amazonian Mars, even for periods of low obliquity;
4. The stability of shallow water ice might possibly be underestimated. At ~30-40°N, sublimation rates should reach several mm to cm per millennia [19-21] and should essentially lead to the rapid disappearance of any observable ice in the surface layer over geological time periods. Yet shallow ice sheets are still detected.

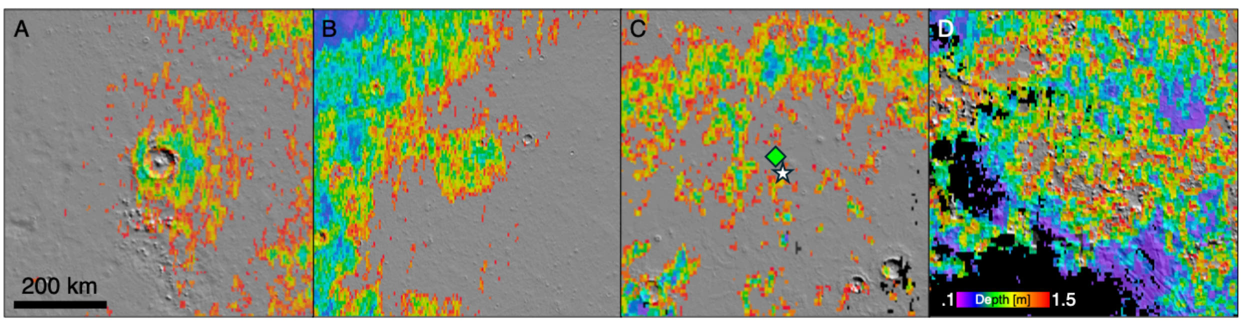

Figure. 2. Examples of local ice depth maps. A: Kunowsky (350.4°E, 56.8°N). B: West of Baltia (291.1°E, 63.1°N). C: in Utopia Planitia (112.0°E, 47.2°N). Green diamond: ice exposing crater. White star: fresh no-ice exposing crater. D: in Protonilus Mensae (52.1E, 43.5°N). Grey background is a MOLA shaded relief, no ice retrieved. Black units in D) indicate no ice retrieved because of the presence of diurnal CO_2 frost, or thick dust units.

Future Work: The analysis of MCS data continues; comparison with GCM results is underway. A similar campaign is for the Southern Hemisphere is scheduled.

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References: [1] McCleese et al., JGR 112 (2007);[2] Bandfield & Feldman, JGR 113 (2008);[3] Piqueux et al., GRL, 9 (2019); [4] Bandfield, Nature 447 (2007);[5] Kieffer, JGR 118, 451 (2013);[6] Putzig et al., Icarus 173, 325 (2005);[7] Mellon et al., Icarus 148, 437 (2000);[8] Christensen et al., JGR 106, 23(2001). [9] Piqueux et al., Icarus 419, (2024);[10] Presley & Christensen, JGR 102, 6551 (1997);[11] Golombek et al., SSR 211, 5 (2017);[12] Golombek et al., SSR 170, 641 (2012);[13] Golombek et al., JGR 108, 8072 (2003);[14] Golombek et al., JGR 102, 3967 (1997);[15] Dundas et al., JGRs 126, 28, (2021);[16] Dundas et al., Science 359, 199 (2018);[17] Head et al., Nature 426, 797 (2003);[18] Smith et al., Science 325, 58 (2009);[19] Mellon et al., Icarus 169, 324 (2004);[20] Mellon et al., JGR 102, 19357 (1997);[21] Mellon and Jakosky, JGR 100, 11 (1995);[22] Christensen et al., SSR 110 (2004).