A SHARAD'S EYE VIEW OF MARTIAN DUNES. N. E. Putzig, Planetary Science Institute, 1546 Cole Blvd, Suite 120, Lakewood, CO 80401, nathaniel@putzig.com.

Introduction: The Shallow Radar (SHARAD) on the Mars Reconnaissance Orbiter (MRO) transmits radio pulses swept from 25 to 15 MHz, yielding a range resolution (wavelength) of 15-m above the surface and lower in the subsurface (e.g., ~8.5 m in water ice, ~5.5 m in basaltic materials) and a lateral resolution of ~3–6 km, reducible along-track in processing to 0.3–1 km [1]. Transmitted signals reflect from dielectric interfaces and are recorded back at the spacecraft. The strongest returns typically come from the nadir surface, and these may be followed by later returns from subsurface geologic boundaries and off-nadir surface topography. Roughness at interfaces within the footprint of the radar signal can induce scattering that may greatly reduce the power and coherence of the returns. The vertical scale of many dune forms is on the order of the radar wavelength, so such scattering effects are often encountered in SHARAD observations of dunes on Mars. If the scattering is pronounced, it typically precludes obtaining subsequent returns from interfaces that may exist below the surface of the dunes. Where dune forms are smaller or missing (e.g., sand sheets), SHARAD obtains a stronger surface return and sometimes subsurface returns.

Data and Methods: SHARAD has been operating at Mars for over 10 years and has acquired substantial coverage (32% globally and 85% in the polar regions at the 3-km scale). Due to their scattering effects, dunes have not been extensively targeted with SHARAD. However, dunes often occur in conjunction with known or expected layered materials that are being targeted, and the SHARAD Team is working toward infilling coverage globally to assess surface roughness. As a result, most larger dune fields across the planet have at least some coverage, and those in the polar regions have dense coverage.

For each observation acquired, the SHARAD team produces radargrams, which are profiles of returned power along-track vs. signal delay time. Several processor variants exist, and for the work shown here, I use radargrams from the processor developed at the Jet Propulsion Laboratory (i.e, that used by [2]). Because off-nadir surface topography often produces returns (termed *clutter*) in the radargrams that may interfere with or be mistaken for subsurface returns, the team also creates *cluttergrams* using a digital elevation model (DEM) of the surface, usually produced from Mars Orbiter Laser Altimeter (MOLA) observations [3]. True subsurface returns seen in a radargram will not have a corresponding feature in the cluttergram.

To assess SHARAD observations over Martian dune fields, I compare radargrams against cluttergrams as well as imagery (typically a THEMIS image mosaic [4]) and the MOLA DEM to provide context. In some instances, I find features in the radargrams at delay times later than the surface return with no corresponding cluttergram features, and these often are nearly parallel to the surface, suggestive of layering.

Results: Many dunes across the southern hemisphere, ranging from those found in Valles Marineris near the equator to those seen atop the south polar layered deposits are of a scale well below the SHARAD wavelength, and these produce strong surface returns. In some instances, such as for dunes found in Lowell crater (Fig. 1) and in Ganges Chasma, subsurface returns below the dune surfaces are evident in the

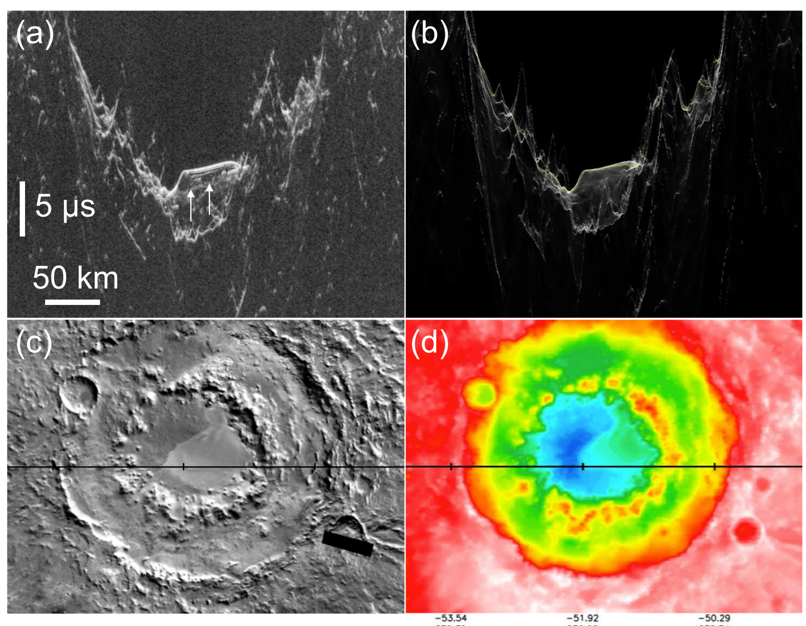

Figure 1. Radargram (a), cluttergram (b), THEMIS image mosaic (c), and MOLA DEM (d) for a portion of SHARAD observation 16080-01 over Lowell crater (279°E, 52°S). The dune field at the crater's center yields a strong surface return that is followed by a more diffuse return (at arrows) at a delay of ~1.4 μs (86 m for a typical sand dielectric of 6) that could represent either the crater floor beneath the dunes or another geologic boundary (e.g., ground ice).

SHARAD radargrams. Here, I find a repeated sequence of very shallow reflections (the shallowest may be sidelobe artifacts [5]) and, in Lowell crater, a later more diffuse return that could be the base of the dunes or some other interface such as the top or base of ground ice within the dunes.

In other areas, the dunes are of a scale similar to that of the SHARAD wavelength. As noted above, this can produce a lower power, diffuse return from the surface that is often followed by additional diffuse returns coming from off-nadir dune forms. SHARAD observations of the dunes in Richardson crater (Fig. 2) exhibit this character. Comparison of the radargram and cluttergram here leaves no indication of subsurface returns in the SHARAD data. There may well be interfaces at depth with strong dielectric contrasts, but no returns are obtained, due to the scattering and loss associated with the wavelength-scale dunes.

The largest dune field on Mars, Olympia Undae, abuts Planum Boreum at the north pole, and has very dense SHARAD coverage. Many of those observations exhibit the low-power, diffusive returns expected for these largely SHARAD-wavelength-scale dunes, with little or no evidence of subsurface returns. However, in areas where the dunes are small or covered by smoother terrain (e.g., Olympia Planum), SHARAD does often detect deeper returns (see Fig. 1 of [6]). In those rare instances, the deepest interface appears to correspond to the basal reflector found by the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) that extends under the entirety of Planum Boreum [7].

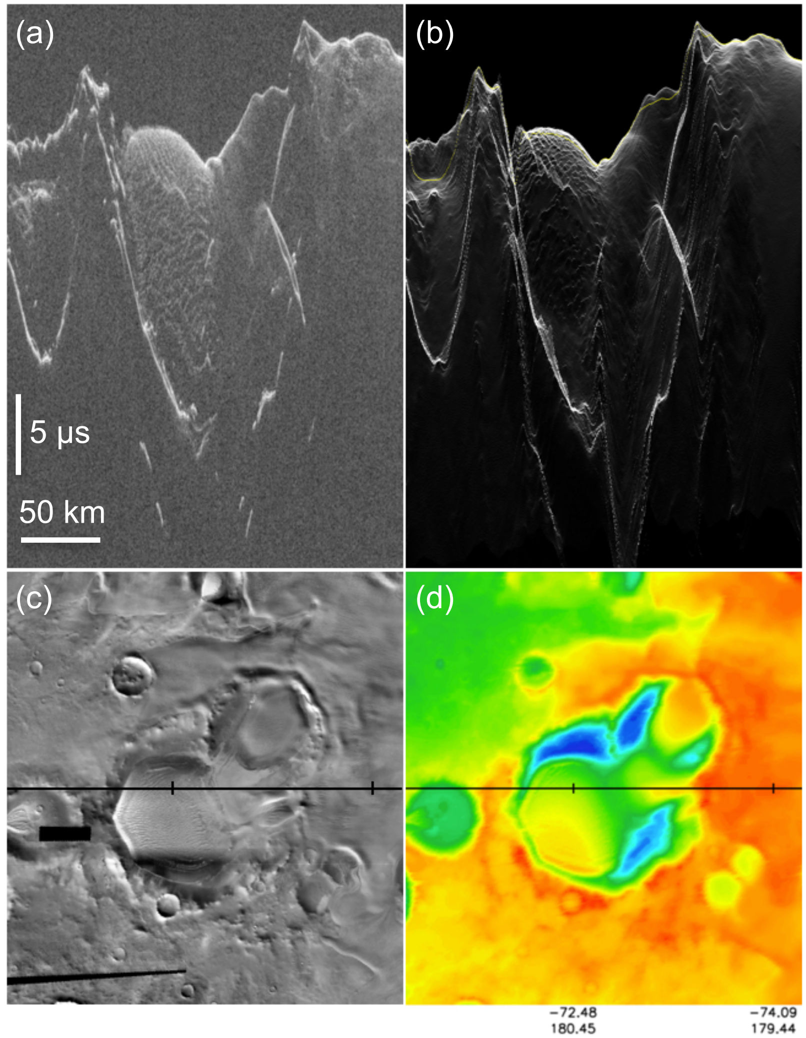

Figure 2. As in Fig. 1 for a portion of SHARAD observation 16024-01 over Richardson crater (180°E, 72.5°S). The dune field yields a diffuse surface return that is followed by more diffuse returns attributable to off-nadir dunes. Nearly all features in the radargram appear in the cluttergram.

Discussion: Due to the resolution of SHARAD data, the utility of that instrument to the analysis of dunes on Mars is limited to the larger dune fields. Moreover, scattering of the radar signal by wavelength-scale dunes often prevents detection of subsurface features. However, fields with smaller dune forms or sand sheets often allow the radar signal to penetrate into the subsurface and reflect off of interfaces below. These cases may yield useful information about layering within or beneath the dunes, and thereby provide data of relevance to dune formation and evolution as well as constraints on climate and its history where the interfaces can be related to presence of ice.

For this conference, I will present a global overview of dunes in SHARAD observations. The diversity of dune forms and their locations yields a broad spectrum of SHARAD results, and this largely untapped source of Martian dune data may hold new revelations about their formation and implications for climate.

References: [1] Seu R. et al. (1997) *JGR 112,* E05S05. [2] Plaut J. J. et al. (2009) *GRL 36*, L02203. [3] Choudhary P. et al. (2016) *IEEE Geosci. Remote Sensing Lett. 13*, 1285-1289. [4] Edwards C. S. et al. (2011) JGR 116, E10008. [5] Putzig N. E. et al. (2014) *JGR 119*, 1936-1949. [6] Phillips et al. (2008) *Science 320*, 1182-1185. [7] Selvans M. M. et al (2010) JGR 115, E09003.