DECIPHERING THE MARTIAN SURFACE AND NEAR-SURFACE WITH RADAR STATISTICS.

C. Grima[1], G. B. Steinbrügge[1], K. M. Scanlan[1], D. A. Young[1], N. E. Putzig[2], M. R. Perry[2], B. A. Campbell[3], S. D. Kempf[1] and D. D. Blankenship[1], [1]Institute for Geophysics, University of Texas at Austin, Austin, TX 78758, USA, [2]Planetary Science Institute, Lakewood, CO 80401, USA, [3]Center for Earth and Planetary Studies, Smithsonian Insitution, Washington, DC 20569, USA.

Introduction: Over the last decade Mars' interior has been actively probed using orbital radar sounders to unveil the planet's subsurface morphology [1, 2]. However, radiometry of the planet's surface return is an underused, yet rich, approach to decipher the Martian surface/near-surface. The echo strength of the surface return contains information about the crust's roughness, its composition, and the structure of the upper decameters (the near-surface) where the materials are preserved from weathering.

This variety of contributions provides a unique terrain signature unlike those provided by other remote sensing technologies that are usually sensitive to a superficial skin altered by erosion and atmospheric exchange. Therefore, radiometry of radar surface returns can provide terrain classifications based on the surface texture and on the specific hidden materials and processes responsible for those returns, such as ground ice, regolith cohesiveness/density [3], or the presence of ice caves, lava tubes, and near-surface brines [4].

Leveraging the radar surface return has been attempted from orbital altimeters, scatterometers, sounders, and ground observations for Mars, the Earth, the Moon, Venus, Titan, and Galilean satellites. However, untangling the various surface and near-surface contributions is usually ambiguous without the support of other observation sources. We aim to overcome this issue using the Radar Statistical Reconnaissance (RSR) technique, initially developed for the investigation of the Earth cryosphere [3]. We provide some application insights and illustrative examples in Elysium Planitia using the Mars Reconnaissance Orbiter Shallow Radar (SHARAD) dataset [1].

The RSR has been applied in the Earth cryosphere [3, 4, 5], over Titan hydrocarbon's seas [6]. Its suitability for Martian terrains has been demonstrated by [7] before being applied locally for supporting the landing site selection of the NASA's InSight lander [8].

Principles: The RSR aims at providing two observables derived by breaking down the received energy in two parts: (1) the coherent energy (P_c) reflected by the regularly distributed dielectric gradients, and (2) the incoherent energy (P_n) scattered by the random discontinuities of the medium [9] (Fig. 1). The RSR is an improvement over other reflectometry techniques that usually derive dimensionless parameters, without strict quantitative bounds to near-surface properties [10].

P_c is modulated by the deterministic structure of the ground (i.e., composition, layering) and is rich in information related to the surface dielectric properties. Conversely, P_n is modulated by the non-deterministic structure (roughness, near-surface inhomogeneities like blocks or voids) and varies with the degree of disorganization and dimension of the elements making up the target at radar scales (i.e., up to meter scales and down to a fraction of the wavelength). Consequently, P_n is a random component of the surface return.

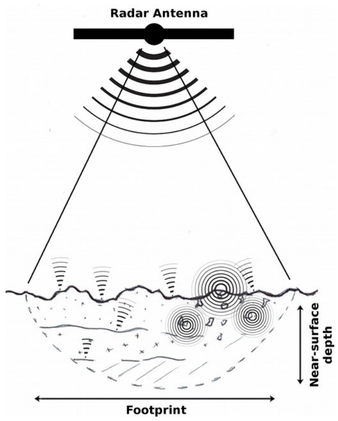

Fig. 1. The surface echo strength is the coherent summation of all the electric fields reflected and scattered at the surface and from the near-surface (< 10 m).

Technically, P_c and P_n are derived from the stochastic law describing the histogram of the surface return strength. This histogram is obtained from a set of echoes over a given geographic area. Then, the histogram is best-fitted with an Homodyne-K (HK) probability density function. The obtained shape parameters for the HK are P_c and P_n. HK statistics is a unique theoretical model for which the parameters keep their physical meaning in the limiting case [11]. It is a flexible and universal model that does not require the condition of large scatterer number to be fulfilled and allows the scatterers to be clustered (non-stationarity) within the radar footprint [11].

Fig. 2 shows where some studied terrains can be classified in the P_c-P_n space, and outlines the domains with expected solutions for typical terrains in Elysium Planitia, assuming a homogeneous near-surface. These radar properties provide a unique framework to feed various inductive approaches aiming to relate geologic units of similar structure and to discriminate between hypotheses for their formation and composition.

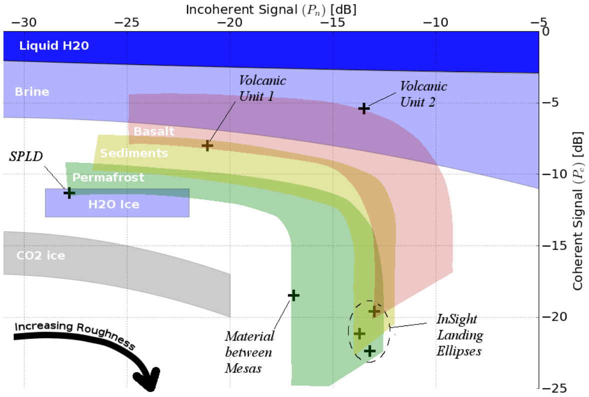

Fig. 2. Expected solutions, derived from the IEM backscattering model for typical geologic units: CO_2 ice (permittivity of 1.8-2.2), water ice (2.8-3.1), permafrost (3.1-4.2), sediments (4-7), basalt (6-14), brine-rich regolith (11-25), and liquid water (60-90) are represented by combining roughness with root-mean-square heights and slopes in the range of 0-2 m and 0-1° respectively, as estimated for Elysium Planitia and the South Polar Layered Deposits.

Application: Exploring the SHARAD surface return character through the RSR technique is a powerful way to detect unusual signal of interests that could be further studied through follow-on proposals. Fig.3 provides an example of such uncommon surface returns near Elysium Planitia where the RSR has been applied. Two units highlighted in the “radar” maps are not associated with any geologic units or altimetry landforms. Unit 1 is an East-West elongated unit within an early Hesperian terrain (eHt) and characterized by coherent and incoherent power higher than that of its surroundings. It falls into the “Basalt” classification in Fig.2 and might be attributed to a later lava flow. Unit 2 is an 80-km ring of elevated power within an Amazonian-Hesperian impact (AHi) unit, offset 20 km south of an eroded crater. Its high incoherent power might reveal the breached ejectas of an older buried impact.

References: [1] Croci et al. (2011) *Proc. of the IEEE* 99, 794-807. [2] Orosei et al. (2015) *PSS* 112, 98-114. [3] Grima et al. (2014) *GRL* 41, 6787–6794. [4] Grima et al. (2016) *GRL* 43, 7011–7018. [5] Rutishauser et al. (2016) *GRL* 43, 12502–12. [6] Grima et al. (2017) *EPSL* 474, 20–24. [7] Grima et al. (2014) *PSS* 103, 191–204. [8] Putzig et al. (2017) *SSR* 211, 135–146. [9] Ulaby et al. (2014) *The Univ. of Michigan Press*. [10] Campbell et al. (2013) JGR 118(3), 436-50. [11] Dutt et al. (1994) *Ultrason Imaging* 16(4), 265-87. [12] Tanaka et al. (2014) *PSS* 95, 11-24.

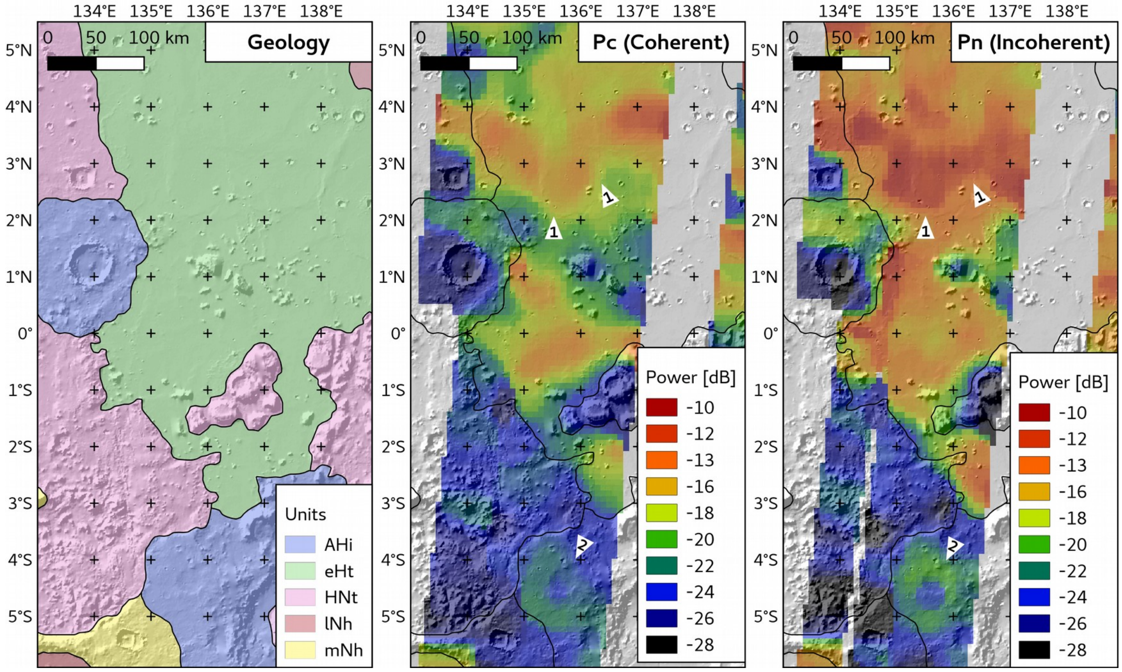

Fig. 3. (From left to right) Published geologic units [12], RSR-derived coherent and incoherent SHARAD surface power, South of Elysium Planitia. Arrows indicate an elongated unit (1) and a circular (2) unit not associated with previously mapped geologic or altimetric landforms (see text for details).