SURFACE ROUGHNESS AND RADAR SCATTERING PROPERTIES OF PERIGLACIAL TERRAIN: GEOLOGIC APPLICATION OF PERSONAL MOBILE LiDAR SCANNING. M. Zanetti[1], C. D. Neish[1], A. Kukko[2], B-H Choe[1], G. R. Osinski[1,3], N. Mahathantila[1], [1]University of Western Ontario, Dept. of Earth Sciences/Centre for Planetary Science and Exploration, 1151 Richmond St, London, Canada, N6A 5B7. [2]Centre of Excellence in Laser Scanning Research, Finnish Geodetic Institute. [3]University of Western Ontario, Dept. of Physics and Astronomy. (Michael.Zanetti@uwo.ca).

Introduction: This study seeks to better understand the surface scattering properties of multi-frequency synthetic aperture radar (SAR) data of planetary surfaces. Using spaceborne quad-polarimetric SAR data from Radarsat-2 (C-band, 5.5 cm λ) (Fig. 1a) and ALOS PALSAR (L-Band, 23.6 cm λ), as well as field measurements of surface topography from a cutting-edge backpack mounted personal mobile LiDAR scanning (PLS) system, we investigate the surface roughness and radar backscatter properties of periglacially modified terrain in and around the Haughton impact structure on Devon Island, Nunavut, in the Canadian High Arctic. The PLS instrument allows for measurement of the surface roughness at the centimeter scale, below the wavelength of C-band SAR, over large areas of the ground (>2,500 m^2) with vertical accuracy ~5 mm. By quantifying the surface roughness over large areas, we can better understand the radar scattering properties, which are measured at lower spatial resolution than the PLS (5-40 m/pixel vs. 2.5 cm/pixel). Results of this study are being used with other remote-sensing datasets to evaluate the potential of quad-pol SAR as a tool in remote-predictive geologic mapping of hard-to-access terrains, as well as to better understand radar scattering properties of planetary surfaces throughout the Solar System.

Datasets and Methods: Radarsat-2 is a commercial Earth observation satellite operated by MacDonald, Dettwiler and Associate, Ltd. Fourteen scenes of Fine-Quad fully polarimetric SAR data (5m/pixel) covering more than 13,000 km^2 of Devon Island were acquired during the summer of 2015. Publicly available Level 1.1 quad-polarimetric data from JAXA's ALOS PALSAR data (30x10m/pixel) covering 7,000 km^2 collected in 2007 and 2010 over Haughton Crater was downloaded from the Alaska Satellite Facility (ASF). Both Radarsat-2 and ALOS PALSAR quad-pol data were calibrated, multi-looked (range 2, azimuth 3), speckle-filtered (refined Lee, 5x5), georeferenced and terrain corrected using a combination of ESA's Sentinel-1, PolSAR-Pro, and ASF MapReady processing software. Additional processing was done to calculate the circular polarization ratio (CPR; the ratio of the same-as-transmitted vs opposite-as-transmitted polarization signal), and derive the Freeman-Durden and Pauli Decomposition maps.

Personal Mobile Lidar Scanning (PLS) System: Ultra-high resolution topography measurements were made using the AKHKA-R3 backpack-mounted PLS system developed by A. Kukko and H. Kaartinen at the National Land Survey of Finland [1]. It consists of a Reigl VUX-1-HA laser line scanner coupled to a tactical grade inertial measurement unit (IMU) and a GPS/GNSS receiver antenna. Absolute global position is determined by GPS/GNSS and operator/scanner azimuth pointing is given by the IMU. As the operator traverses the ground the surface is scanned by the laser at 1 million points and 120 lines/sec, and ground range to the scanner is measured. Post-processing by solving for operator and laser trajectories results is an ultra- dense point cloud representation of the surface in 3D. Further processing converts the point cloud to a triangulated irregular network mesh (TIN) and a raster digital elevation model (DEM). Point cloud spatial resolution within 20 m of the scanner is on the order of 5 mm (depending on distance from the scanner), with vertical accuracy <2cm and absolute global position <10 cm. Data collection time for a 50 m grid with 2.5cm/pixel resolution is ~10-15 min.

Grid Locations: LiDAR measurements in 50 m square grids (2,500 m^2, designated with letters) (Fig 1a, b) were made at 35 representative target surfaces within and around the Haughton impact structure (Fig. 1a). Surfaces included most of the geologic units exposed within the crater (e.g. impact melt breccia, Eleanor River Fm, Allen Bay Fm, Fluvial deposits, etc.) [2]. On average, grids contained more than 200 million LiDAR point measurements, resulting in Digital Elevation Models (DEMs) with 1 – 2.5 cm/pixel resolution (Fig 1b, higher resolution Fig. 1d). LiDAR grids were geolocated within an ESRI ArcGIS map package containing the SAR data (calculated CPR, σ^0 for HH, HV, VH, VV channels) and zonal statistics [3] were extracted for both C- and L-band data from the 50 m measurement area, and a larger 200 m (0.04 km^2) surrounding region (for increased radar sampling statistics). For brevity, here we only report results of CPR extracted from the 200 m grids (Fig 1c).

Determining Surface Roughness Properties: Describing the roughness properties of a surface is non-trivial, and quantification of roughness parameters is often scale-dependent [REF]. Drawing from Metrology Science standards for evaluating surface roughness in 2D and 3D, we calculate our surface roughness parameters using International Standards Organization (ISO) 25178 (for 3D area parameters [5]) and ISO-4287 [6] (2D roughness and waviness parameters) using industry standard Digital Surf MountainsMap 7, and SPIP Image Metrology software. As per the metrology standard parameters, (e.g. *q* (RMS height), *dq* (RMS gradient), *fd* (fractal dimension)) are calculated over a defined sampling length (aka cut-off or evaluation length). 3D areas

are denoted with S (i.e. Surface) and evaluated over the entire length of the scene. 2D profiles are filtered at sampling length intervals (from 10 cm to 1m) by fitting a Gaussian curve (the Waviness profile (W)) to the primary raw profile (P). The difference between the W profile and the P profile results in the Roughness (R) profile, and parameters are calculated at a user defined sampling length (i.e. the R*q* reported in Fig. 1c represents the RMS height of the roughness profile evaluated at 25 cm). East-West and North-South 2D profiles from each of the 2.5cm/pixel grid DEMs (~4,000 profiles/grid) were concatenated and averaged.

Preliminary Results and Discussion: We find that RMS height as a measure of surface roughness is correlated with block sizes proportional to the radar λ, and that the roughness profile is very sensitive to the defined sample length. Figure 1c compares the RMS height (R*q*) calculated at a sample length of 25 cm for 12 grid locations (labeled in Fig. 1a) for C-band (orange dots) and L-band (blue dots). The clustering of grids with low CPR values and small RMS heights in the bottom-left Fig 1c are mostly correlated with relatively poorly sorted units of impact melt breccia. Grids K, L, Z, and AB are dominated by well-sorted periglacial patterned ground with block sizes, and unexpectedly, stone-circle diameters sensitive to C-band λ (Fig.1d). The shift from high CPR at C-band to low CPR at L-band (Fig. 1c, red arrow) shows that these surfaces have relief that is essentially invisible to L-band λs. This emphasizes the importance of using multi-frequency radar sensors when investigating the roughness properties of planetary surfaces.

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References: [1] Kukko, A. (2013) Kirkkonummi, PhD thesis, 247p. [2] Osinski, G. R. (2005) MaPS 40(12) (suppl) [3] ESRI ArcGIS Help – How Zonal Statistics Works [4] Shepard, M. K. et al., (2001) JGR 106 E12 [5] ISO25178-2:2012 Surface texture: Areal [5] ISO4287:1997 Surface texture: Profile

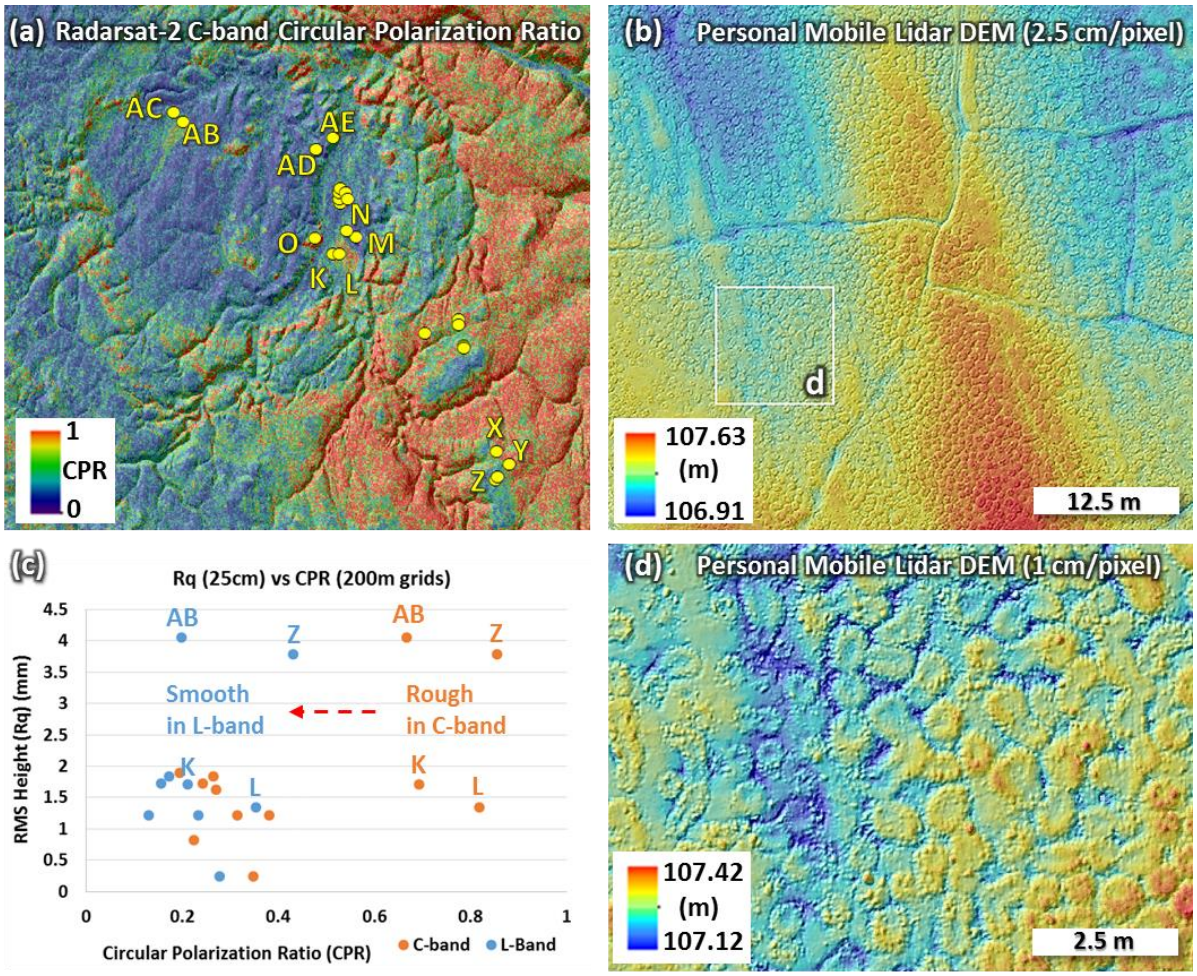

Figure 1: (a) Radarsat-2 C-band CPR data over the Haughton impact structure, Devon Island, Canada. Color denotes the type of scattering (Purple and Blue: specular, Green and Yellow: Volume/Diffuse, Red: Double bounce. (b) Example of a measured LiDAR grid (site L), with 2.5 cm/pixel resolution. (c) Preliminary results of RMS height (R*q*) at 25 cm sample length versus C-band and L–band CPR zonal statistics extracted from 200 m regions surrounding the LiDAR DEMs. Note the shift in apparent roughness of terrain when observed with 5.5 cm λ and 23.6 cm λ radar. (d) Example of 1 cm/pixel LiDAR DEM showing periglacial patterned ground stone-circles ~50-60 cm in diameter. Raster resolution is high enough to measure rocks at the 5.5 cm C-band λ.