SHARAD RADAR ALTIMETRY AND GEODESY. G. Steinbrügge, K.M. Scanlan, D.A. Young, C. Grima, S.D. Kempf and D.D. Blankenship. Institute for Geophysics, University of Texas at Austin, 10100 Burnet Road, Building 196, Austin, TX 78758.

Introduction: On Earth, radar altimeters are most commonly used to monitor sea levels and measure land heights. Examples for such systems include the radar altimeter RA2 aboard ESA's Envisat mission [1] or SIRAL aboard CryoSat-2 [2]. In planetary science, orbital radars function typically as either imaging radars or sounding radars. However, for geodetic purposes, lasers are usually the method of choice because of their higher geodetic accuracy. Exceptions are planetary missions where no laser has been present, such as the Cassini mission where the radar [3] proved to be a very versatile instrument. Onbaord Cassini, the radar functioned as both an imaging radar [4,5,6] and as well as an altimeter [7,8].

While the Cassini radar's main purpose was imaging, Mars is currently orbited by two sounding radars. The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) [9] instrument is the first time an orbital radar has been used as a sounder since the Apollo era. Carried aboard ESA's MarsExpress Mission [10], it has, for example, been used to detect buried basins underneath the surface [11]. Since 2006, MARSIS has been complemented by the SHAllow RADar sounder (SHARAD) aboard NASA's Mars Reconnaissance Orbiter [12]. SHARAD has been successfully used to study the Martian polar caps [13] and found numerous other applications.

Although designed primarily as a subsurface sounder, the 20 MHz center frequency and 10 MHz bandwidth allows SHARAD to be treated as a radar altimeter. Its inherent range resolution in vacuum is 15m. Despite these opportunities, the altimetry capabilities of SHARAD have not yet been exploited. Combining SHARAD altimetry measurements and a co-registeration of the ground tracks with digitial terrain models derived from MOLA, would allow for the global topographic model of Mars to be enchanced by closing gaps and providing improved temporal coverage. The latter point is especially relevant for the north and south polar deposits of Mars, since SHARAD provides 12 years of data against 2 years of MOLA.

Methods: For the processing of PDS SHARAD EDR data, we follow the approach introduced by Campbell et al. [14] whereby a synthetic reference chirp with similar characteristics as the true SHARAD signal is used in pulse compression. Pulse compression is required in order to remove the effects SHARAD's chirped radar signal and recover surface and subsurface reflections. SHARAD emits a chirped radar signal as opposed to a pulsed signal in order to maximize transmitted power. While the processed data published to PDS by the Italian SHARAD processing team is based on a ground measured reference chirp, we find that better results are achieved using the synthetic chirp (similar to the US SHARAD processing team; US RDR data products). The synthetic reference chirp used in this study is linearly swept at uniform amplitude through the SHARAD bandwidth (from 15 MHz to 25 MHz) over the 85.05 μsec pulse duration.

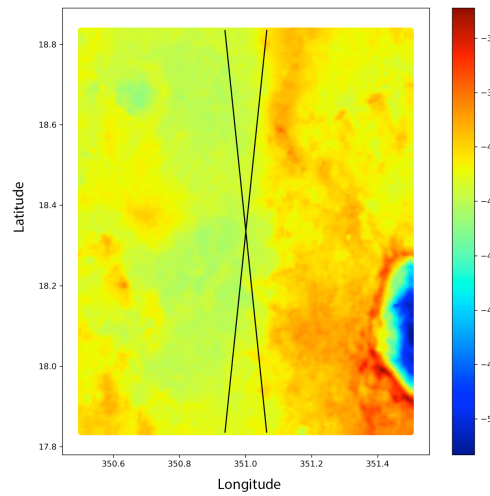

Figure 1: Subsample of the HRSC MC11E DTM with two selected SHARAD groundtracks and a sample cross-over point in the center of the figure.

An advantage of utlizing the synthetic chirp is that it is easier to manipulate, which is especially useful when correcting for ionospheric phase distortions [14]. The ionosphere between MRO and the Martain surface causes dispersion in the radar chirp, leading to slower radar wave propagation and echo de-focusing after range compression. The goal of ionospheric correction is to estimate the relevant properties of the ionosphere (most notably the total electron content (TEC) along the radar path length) such that these effects can be removed and the received echoes properly positioned and sharply focused.

Following Campbell et al. [15,16], the dispersive effects of propagating through the ionosphere can be considered equivalent to a phase modification introduced into the reference chirp during pulse compression. This is one advantage of using a synthetic reference chirp whose properties are relatively easy to modify. In this study, we use a family of reference chirp filters, each with slightly different ionospheric phase modifications. We then evaluate the change in the signal-to-noise ratio (SNR) of the strongest echo as a function of ionospheric conditions, under the assumption that dispersive ionospheric effects are correctly accounted for when the SNR of the dominant echo is maximized. The reference chirp filter that maximizes echo SNR corresponds to a specific ionospheric TEC that can then be used to account for group delay effects. Similar to the US RDR SHARAD data products, the ionospheric correction is considered to be constant over some along-track length (30 km is to be used in this study). Post-correction, SHARAD's inherent range resolution is equal to 15 m.

For altimetry processing, adjacent radar range lines are first incoherently summed together and then the derivative along the summed trace is calculated. The first instance of the derivative magnitude above some threshold is selected as the time sample corresponding to the surface return. The threshold is set as for each range line as a function of rms noise within the first 128 samples which are supposed to consist of noise only.

To verify the method we use the digital terrain model MC11E from the High Resolution Stereo Camera (HRSC) onboard MarsExpress [17]. The DTM covers the area from 330 to 360 degrees longitude and from 0 to 30 degrees latitude with 30 m / pixel resolution. Additonaly we study the differential heights at cross-over points as a proxy for the accuracy of SHARAD as a radar altimeter (Fig. 1).

Results and Outlook: We generally find a good agreement between the SHARAD surface picks and the HRSC DTM (Fig. 2). However, due to the classical problem of the radar altimeter being pulse limited instead beam limited, we find issues at steep slopes and occasional offsets between the return profile and the DTM. For the selected cross-over point in Fig. 1 (SHARAD groundtracks 1748102 and 1855601), the mean range difference is 4.9m. We average +/- 250 samples of both tracks around the cross-over to account for the larger radar footprint (a cross-over plate) as compared to a laser altimeters (a cross-over point).

Over its 12 years of operation, SHARAD has collected appoximately as many groundtracks as MOLA. The potential combination of both data sets would result in a significant increase the horizontal resolution of the global Mars DTM from the current ~600m/pixel down to about ~300m/pixel. At the poles, where the horizontal resolution is higher, the seasonal variations of the polar deposits could be understood in more detail. Taken together, MOLA and SHARAD represent almost two decades of altimetry data in the Mars polar regions. In future work we intend to constrain the volume of material exchanged during the Martian year between the atmosphere and the deposits, investigate possible long term trends within the polar deposit thickness, as well as identify and characterize anomalies (dust storms).

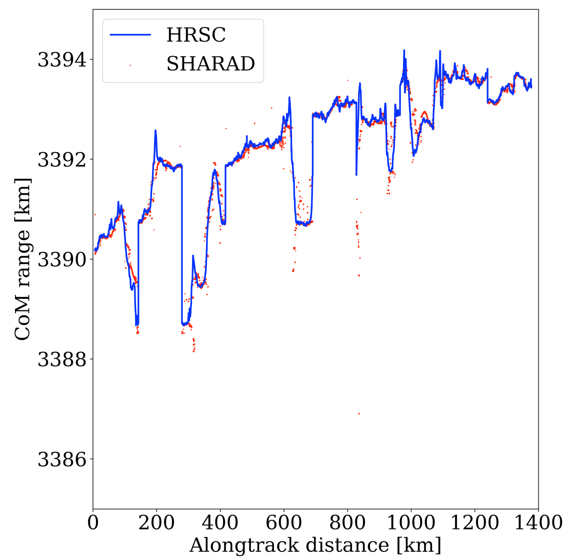

Figure 2: Comparison of track 1748102 over the MC11E region of the MC11E dtm [17].

References: [1] Beneviste et al. (2002), Proceedings of the SPIE, p.71-82 [2] Wingham et al. (2005) ESA Bulletin 122, p.10-17 [3] Elachi et al. (2004) Space Science Reviews 115, p.71-110 [4] Elachi et al. (2006), Nature 441, p.709-713 [5] Paganelli et al. (2007), Icarus 191, p.211-222 [6] Lopes et al. (2007), Icarus 186, p.395-412 [7] Zebker et al. (2009), Icarus 200, p.240-255 [8] Mastrogiuseppe et al. (2014), Icarus 230,p.191-197 [9] Jordan et al. (2009), Planetary and Space Science 57, p.1975-1986 [10] Chicarro et al. (2003), Sixth International Conference on Mars. [11] Watters et al. (2006), Nature 444, p.905-908[12] Seu et al. (2004) Planetary and Space Science 53, p.157-166 [13] Zurek et al. (2007), Journal of Geophysical Research (Planets) 112 [14] Campbell et al. (2011) IEEE Geoscience and Remote Sensing Letters 8, p.939-942 [15] Campbell et al. (2014) IEEE Geoscience and Remote Sensing Letters 11, p.632-635 [16] Campbell et al. (2016) Journal of Geophysical Research (Planets) 121, p. 180-193 [17] Gwinner et al. (2016), Planetary and Space Science 196, p. 93-138