AN ANALYSIS OF FREQUENCY-DEPENDENT RADAR CHARACTERISTICS IN SHARAD DATA.

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Introduction: The north polar layered deposits (NPLD) are a region of water ice and dust intermixed together at the Martian north pole. The layers of the NPLD are interpreted to be the result of deposition and sublimation, due primarily to the orbital obliquity of Mars from the past 5 million years [1]. The NPLD layers are therefore thought to preserve a history of the Martian climate over that time.

Optical data show visible stratigraphic layers exposed in trough walls [1], and it is hypothesized by some researchers that these reflectors correspond to reflectors seen in radar data [2]. The resolution between radar and optical images is not the same, however. The SHARAD vertical resolution is on the order of several to ten meters [4] while layers observed in optical data can resolve < 1 m thick [10]. On this principle alone, it cannot be assumed that the radar reflectors correlate directly with a stratigraphic layer.

Radar reflectors correspond to dielectric constant interfaces, caused by changes in porosity and material composition. At these interfaces radar "reflectors" would appear as layers in radar returns [3]. Examples of such boundaries might be variations in dust and ice content in the NPLD as well as where such layers meet underlying bedrock. The reflectors in the NPLD exhibit characteristics that, when analyzed through wavelengths of different sizes, sometimes show different scattering characteristics than simple attenuation as a function of depth.

Here, we use radargrams (two-dimensional cross sections of the subsurface arranged as columns along the scanned track with the vertical axis representing time) from the Gemina Lingula region of the NPLD, and one-dimensional (1D) simulations to analyze the frequency dependence of the radar reflectors in SHARAD radargrams. The goal is to explore causes of frequency dependence in radar data, and the extent that dependence changes based on frequency.

Data and Methods: For example, we ask whether reflectors are present in the same location in high and low frequency data. We use radargrams created from high and low frequency portions of the SHARAD bandwidth (also known as "split chirp" data) [11], individual reflectors can be compared across both frequency bands. The low-frequency data are created from the 15-20 MHz range of the SHARAD chirp, and the high-frequency band is created using 20-25 MHz portion of the chirp. Evident between the low and high-frequency bands is the presence of "jumping" reflectors, which are reflectors that appear in one frequency band, but not the other. Power values from seven columns of pixels in a radargram were averaged together in each frequency band. These power values were collected (Fig. 1) to identify differences between each band. Peaks in power can be seen in one band where the other band has troughs – an example of a "jumping" reflector.

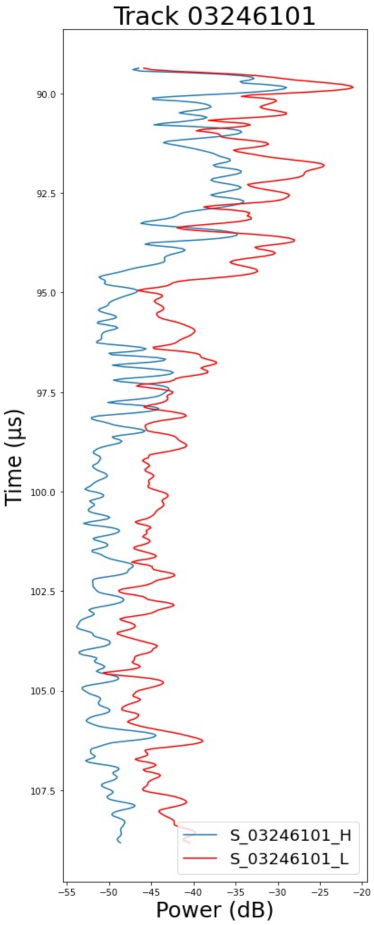

Figure 1: Depth profiles of power collected from the same location in Gemina Lingula using two separate frequency bands. The blue indicates a high-frequency (20-25 MHz), while the red is the low frequency band (15-20 MHz). These data are from SHARAD track 03246101.

We focus our efforts on jumping reflectors. To study the frequency dependencies leading to these reflectors the SHARAD 1D simulator [12] was used. This simulator takes in various parameters (number of stratigraphic layers, layer thickness, dielectric constant, loss tangent, etc.) and generates profiles representing what the radar reflections would be expected to look like given the input parameters passed into the simulation.

The 1D simulator was run to generate two datasets: a high and low-frequency band, in order to demonstrate the expected differences in power with depth between those bands. The two bands were normalized, showing regular deviations from one another. Then simulator-generated data, the simulator was automated to generate reflections for many different layer-thickness regimes. These simulations are meant to explore the parameter space to determine which variables, layer thickness or dielectric constant, control the observed power profiles. The total depth of simulated material was held constant at 2000 m (the approximate thickness of Gemina Lingula), while each iteration ran with a different assigned layer thickness. Layers in a given iteration are all the same thickness. The dielectric constant varied by layer between 3.4 to 2.8 in order to both generate reflections, while maintaining an average dielectric constant consistent with NPLD observations [5].

Preliminary Results: With large amounts of model-generated data, patterns of frequency-sensitive differences between the two bands are observed (Fig. 2). Radar echoes can be seen in the low-frequency bands as the signal travels deeper into the layers. This echoing behavior is shown at a certain threshold depth, which increases as a function of layer thickness in the 1-dimensional model data, beneath which a series of oscillations, consistent in frequency and intensity, can be seen. These oscillations do not align with layer interface-labeled depths. The layer thickness used in the simulation impacts how deep the signal can travel before the low-frequency band begins to experience this “echoing” phenomenon (shown in Fig. 2). The larger the layer thickness, the deeper the low-frequency band signal travels without reaching an echoing threshold distance. In the combined, full bandwidth simulation data (models generated by the 1-D simulator that has a radar sounder bandwidth of 15-25 MHz, i.e. the full SHARAD instrument bandwidth), these echoes contribute to interference in the full bandwidth model-generated data.

The high-frequency band exhibits little-to-no observed echoing. This is relevant as higher-frequency data attenuates quicker than lower-frequencies, implying that at greater depths the lower-frequency band is more reliable. Further, constructive and destructive interference is seen in the full-bandwidth (15-25 MHz) model-generated data (Fig. 2). This interference is a direct function of the presence of a high density of reflections in the thickest regions of the low-frequency band data, which is a function of stratigraphic layer thickness.

The presence of jumping reflectors in split chirp data, especially those seen at depth in radargrams, will be compared with the depth at which potential echoing can be expected. To do this, we will use machine learning techniques to match the 1D simulator output to reflectors in SHARD radargrams with known jumping reflectors.

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References: [1] Phillips, R. J. et al. (2008) Science, 320, 1181-1185. [2] Putzig, N.E. et al. (2009) Icarus, 204(2), 443-457 [3] Seu, R. et al. (2007) JGR, 112(E5). [4] Picardi, G. et al. (2005) Science, 310, 1925(2005). [5] Grima, C. et al. (2009) GRL, 36(3). [6] Phillips, R. J. et al. (2011) Science, 332, 838-841. [7] Lalich, D.E. & Holt, J.W. (2017) GRL, 44(2), 657. [8] Nunes, D.C. & Phillips, R.J. (2006) JGR, 111. [9] Christian, S. et al. (2013) Icarus, 226(2), 1241-1251. [10] Fishbaugh K.E. et al. (2010) GRL, 37, L07201. [11] Campbell, B. & Morgan, G. (2018) GRL, 45, 1759–1766. [12] Courville S, Perry M. (2020). RadSPy 1-Dimensional Simulator.

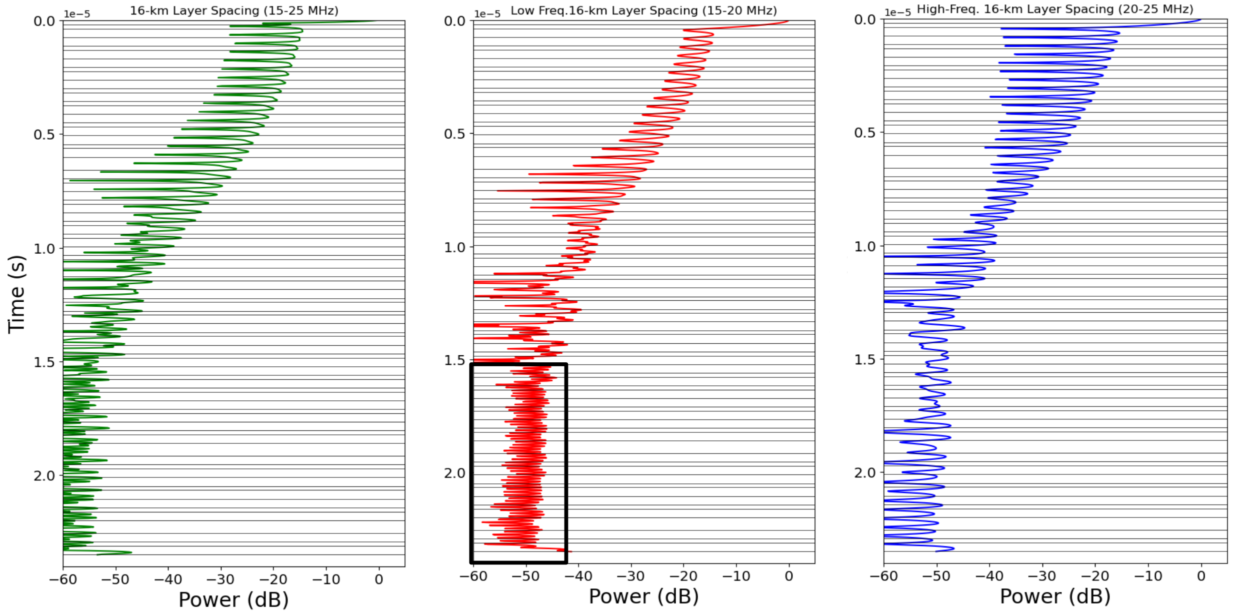

Figure 2: 1-D simulations of the full (15-25 MHz) bandwidth (left), low-frequency (center) and high-frequency (right) reflections. Horizontal black lines represent the 16-m interval spacing between layers. Low-frequency "echoing" (shown in the black box) combines with some faint signals from the high-frequency data to produce reflections that may or may not correspond to actual layers in the full bandwidth data.