HIGH RESOLUTION RADAR MAPPING AND DUST CONTENT ESTIMATION OF THE MARTIAN NORTH POLAR LAYERED DEPOSITS SADDLE REGION. D. E. Lalich[1], V. Poggiali[1], M. C. Raguso[2], A. G. Hayes[1], [1]Cornell Center for Astrophysics and Space Science (dlalich@astro.cornell.edu), [2]Jet Propulsion Laboratory

Introduction and Motivation: The North Polar Layered Deposits (NPLD) of Mars are composed of many layers of nearly pure water ice [1] almost 1000 km across and up to 2 km thick approximately centered at the planet's north pole [2]. According to ice stability and climate models based on orbital reconstructions, the NPLD are likely no more than ~4 million years old [3,4]. The surface of the NPLD is much younger, though it is difficult to say with certainty whether it is actively accumulating, ablating, or in equilibrium [5,6]. Within the NPLD, dozens of subsurface reflectors are observed in orbital radar sounding data collected by the Shallow Radar (SHARAD) instrument on the Mars Reconnaissance Orbiter (MRO) [7]. It is believed that these layers and reflectors are the result of changes in dust and ice accumulation rates over time, which are driven by varying orbital conditions similar to Milankovitch cycles on Earth [8,9,10].

Attempts to explicitly tie observable properties of layers or reflectors to paleoclimate conditions have, however, produced mixed results. Cyclic bedding has been identified in outcrop walls using measurements of layer protrusion [11], but the connection between protrusion and layer composition remains essentially unknown. Meanwhile, analysis of radar reflectors has typically been limited to large scale features, and efforts to connect those features to specific periods in Mars' orbital history have been inconclusive [7,12].

Recently, new techniques have been developed that enable the estimation of fractional dust content from individual radar reflectors [13]. So far, these new techniques have only been applied to a small subset of layers in isolated locations across the NPLD. They have also been limited by SHARAD's vertical resolution, which is larger than most layer thicknesses. We present here the next evolution of these analyses, which has the potential to culminate in a new, comprehensive climate record of modern Mars. Early results hint at a more complex relationship between visible layers and radar reflectors than was previously assumed.

Super Resolution Processing: One of the limitations of previous studies is that SHARAD's range (vertical) resolution is larger than most NPLD layer thicknesses. We have addressed this issue by applying recently developed advanced processing to existing data. SHARAD is a pulse-compressed radar, meaning it transmits a pulse over a designated frequency band and then convolves the received signal with the originally transmitted waveform to improve the vertical resolution. For such a system, the range resolution is inversely proportional to the total transmitted frequency bandwidth, meaning a larger bandwidth results in better resolution. Super resolution processing uses auto-regressive time series models to extrapolate the received signal to a wider bandwidth, effectively improving range resolution. Previous testing has shown that SHARAD's bandwidth can safely be extrapolated by a factor of three, resulting in a nominal resolution of ~2.8 m in water ice (Figure 1) [14]. Improved resolution allows us to more accurately identify and track reflectors, and will help constrain the necessary parameter space for future modeling.

For this work, we applied super resolution processing to over 600 radargrams in the saddle region of the NPLD, which connects the main lobe with Gemina Lingula. We chose the saddle region as our study area due to its flat surface, which limits a type of noise known as surface clutter, and also to facilitate comparisons to previous work.

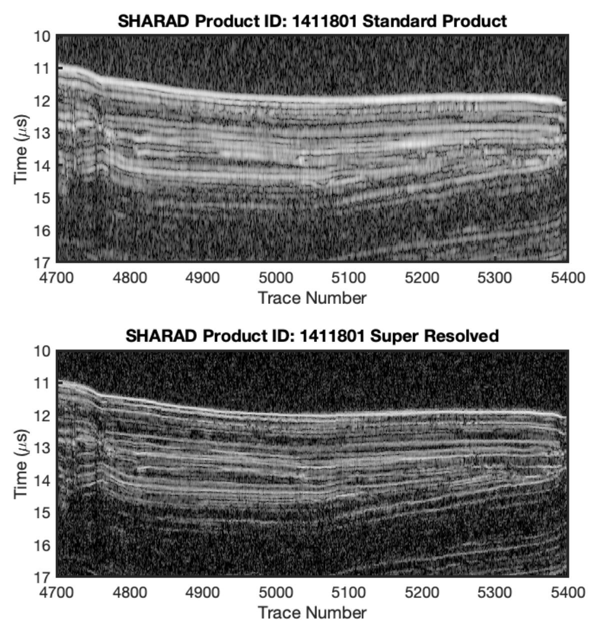

Figure 1: Top: Portion of a standard SHARAD radargram over the saddle region. **Bottom:** The same radargram after super resolution processing. Note the increased number of reflectors, the sharpness of reflectors, and the improved signal to noise ratio.

Reflector Mapping: We are currently in the process of mapping each uniquely identifiable reflector in the study area. The mapping procedure is semi-automatic and is carried out using the seismic interpretation software Seisware. The mapping tool traces the peak power along each reflector (Figure 2) and can export that power as a function of latitude, longitude, and time delay (depth).

Previous reflector mapping in the NPLD was limited to either a handful of reflectors or small, isolated study sites. In contrast, we are able to map each identifiable reflector across hundreds of kilometers. Furthermore, the improved clarity and signal to noise ratio of super resolution data means we are able to map the entire stack of reflectors from the surface to the base.

Important differences between the standard and super resolution observations are already apparent. For example, it is possible to identify multiple closely spaced reflectors that appeared as single horizons in standard data. We can also accurately track deeper reflectors that were barely visible in standard observations. Many reflectors appear to pinch out and reappear later, implying either that layering is not as spatially uniform as previously thought or that the layers become too thin to be resolved even in enhanced data. The second case would be notable as marker beds, currently believed to be the source of reflectors, are generally much thicker than the enhanced ~2.8 m resolution achieved here. It may be that reflectors are caused by different types of layers than previously considered.

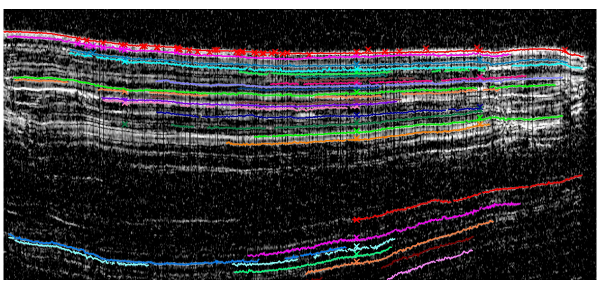

Figure 2: Section of radargram 0482201 showing currently mapped reflectors (colored lines). Mapping for this image is not yet complete, some reflectors will be added or extended based on comparisons to crossing observations.

Future Work: It is possible to estimate the dust content of an individual layer by comparing measured reflection power to a thin layer reflection model (Figure 3) [13]. One of the drawbacks to this procedure is the uncertainty regarding layer thickness. However, by using the super resolution data instead of the standard SHARAD observations, we can drastically reduce the layer thicknesses considered by the model, thereby improving the accuracy of our estimations.

Once our mapping is complete, relative dust content can be estimated for every point along every mapped reflector. This means that we can produce a three-dimensional map of how ice and dust accumulation rates changed across a wide region of the NPLD. Because ice and dust accumulation rates at the pole are related to climate conditions, this will in effect be a global climate record spanning the past 4 million years of Martian history.

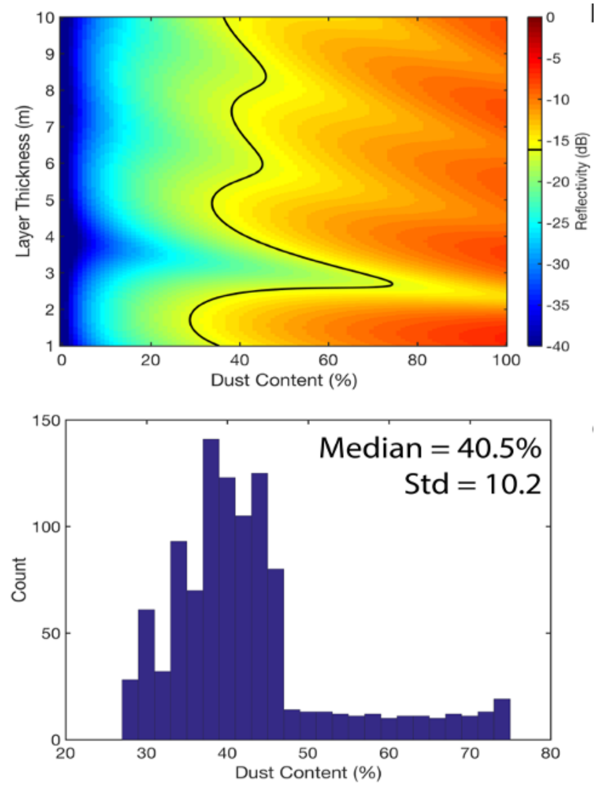

Figure 3: Example of how radar reflectivity is converted to dust content from [13]. **Top:** Measured reflectivity (black contour) compared to modeled reflectivity over a range of layer thicknesses and dust contents. Super resolution processing will allow us to place tighter constraints on layer thickness than shown here. **Bottom:** Distribution of dust contents retrieved from the above contour.

References: [1] Grima, C., et al., (2009) *GRL, 36* [2] Tanaka, K. L., et al., (2008) *Icarus, 196* [3] Levrard, B., et al., (2007) *JGR: Planets, 112* [4] Greve, R., et al., (2010) *Planetary and Space Science, 58* [5] Brown, A.J., et al., (2016) *Icarus, 277* [6] Landis, M.E., et al., (2016) *GRL, 43* [7] Phillips, R.J., et al., (2008) *Science, 320* [8] Toon, O.B., et al., (1980) *Icarus, 44* [9] Cutts, J.A, Lewis, B.H., (1982) *Icarus, 50* [10] Laskar, J., et al., (2002) *Nature, 419* [11] Becerra, P., et al., (2017) *GRL, 44* [12] Putzig, N.E., et al., (2009) *Icarus, 204* [13] Lalich, D.E., et al., (2019) *JGR: Planets, 124* [14] Raguso, M.C., et al., (2018) *5th IEEE Workshop on Metrology for AeroSpace*