Martian CAT scan: Three-dimensional imaging of Planum Boreum with Shallow Radar data

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We will present a preliminary three-dimensional (3-D) subsurface volume created from Shallow Radar (SHARAD) observations of Planum Boreum, the 3-km-high mound of icy layered deposits in the north polar region of Mars. Our goal is to allow the identification and mapping of subsurface features in SHARAD data in regions that are presently obfuscated by complex surface topography and subsurface structures, thereby enabling a better understanding of the nature and timing of the layered deposits and their relationship to climatological cycles.

In the medical field, computed axial tomography (CAT scan) involves taking a series of 2-D X-ray images of a body around an axis of rotation and applying geometric processing to generate a 3-D image of the interior. Similarly, SHARAD has taken a set of 2-D radar images (radargrams) on more than 2500 passes of the Mars Reconnaissance Orbiter (MRO) across the north polar region of Mars, and we have used a subset of those radargrams to develop and test a means of generating 3-D images of the polar layered deposits. While the sets of radargrams over both polar regions have been very fruitful scientifically (e.g., Putzig et al., 2009, *Icarus 204*, 443–457; Holt et al., 2010, *Nature 465*, 450–453; Phillips et al., 2011, *Science 332*, 838–841), examination of 3-D subsurface structures has been restricted to identifying and tracing those structures on the radargrams and then “connecting the dots” by interpolation. Identification and tracing of structures is limited to the trajectories of the spacecraft’s nadir track and is hampered by “clutter,” or signals returned from off-nadir surface or subsurface features that often interfere with signals returned from the nadir surface and subsurface. Clutter becomes a severe impediment to structure interpretation in areas of high topographic variability, such as the trough-rich regions of Planum Boreum.

Given a sufficient number of observations from a range of lateral offsets, radar signals from nadir and off-nadir can be partitioned, and the off-nadir returns can be repositioned to their actual source locations within a 3-D volume, thereby removing the clutter from one place and promoting it to signal in another. Such 3-D imaging techniques are well developed not only in the medical field but also for terrestrial subsurface radar and seismic data, where they are commonly referred to as “migration.” Available 3-D imaging software requires that the data first be binned into a 3-D grid and co-registered to a common datum. For SHARAD data, a complication is introduced by the Martian ionosphere, which significantly distorts and delays the radar signals on the sunlit side of the planet. To address the phase distortion, we apply an autofocus correction (Campbell et al., 2011, *IEEE Geosci. Remote Sens. Lett. 8*, No. 5) that relies on an empirically derived phase correction of the SHARAD signal and optimization of an image-quality metric over 100-km segments of the radargrams. This method also allows us to estimate the delays introduced by the ionosphere in each radargram, which typically vary inversely with the solar zenith angle. We remove any residual delays using a correlation technique applied to the data subsequent to the 3-D binning step. At that point, we proceed to migration of the data, yielding a geometrically corrected 3-D volume of SHARAD data.

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