Martian CAT scan: Three-dimensional Imaging of Planum Boreum with Shallow Radar Data

Nathaniel E. Putzig,[1] Frederick J. Foss II,[2] Bruce A. Campbell,[3] and Roger J. Phillips[1]

[1] Southwest Research Institute, Boulder, CO (contact: nathaniel@putzig.com); [2] Freestyle Analytical & Quantitative Services, LLC, Longmont, CO; [3] Smithsonian Institution, National Air and Space Museum, Washington, DC

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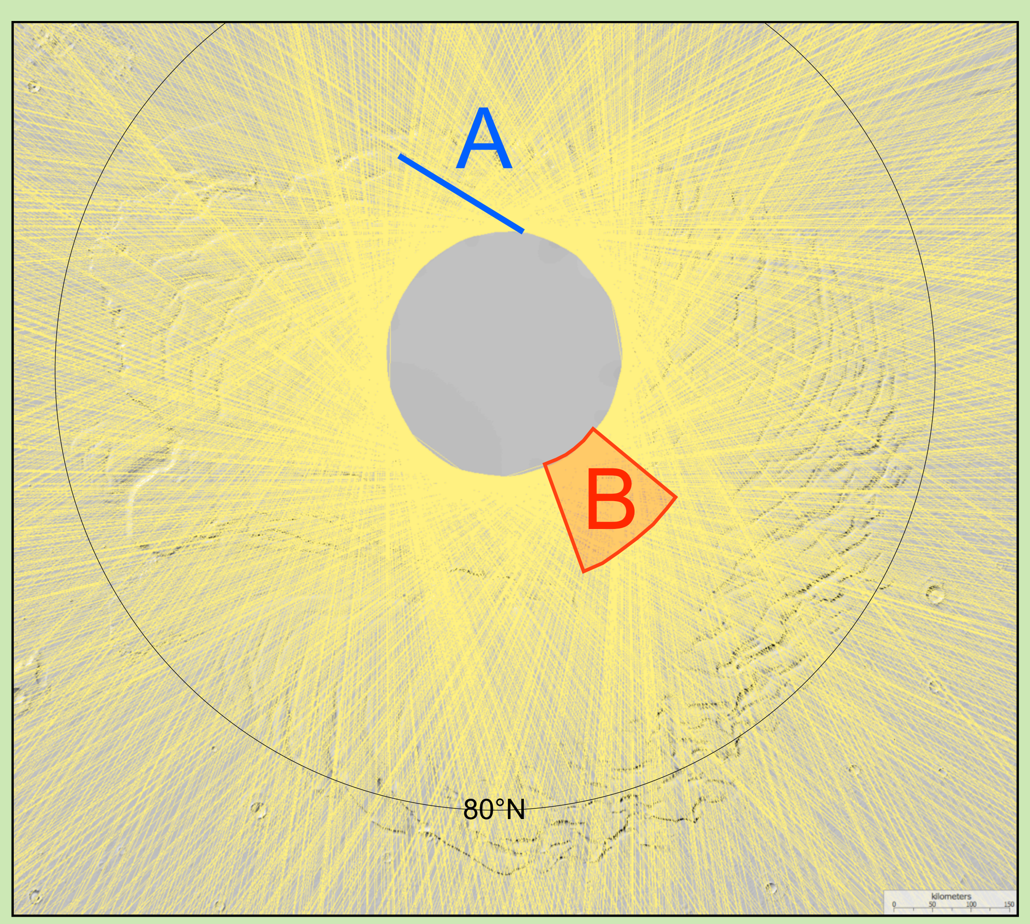
Summary

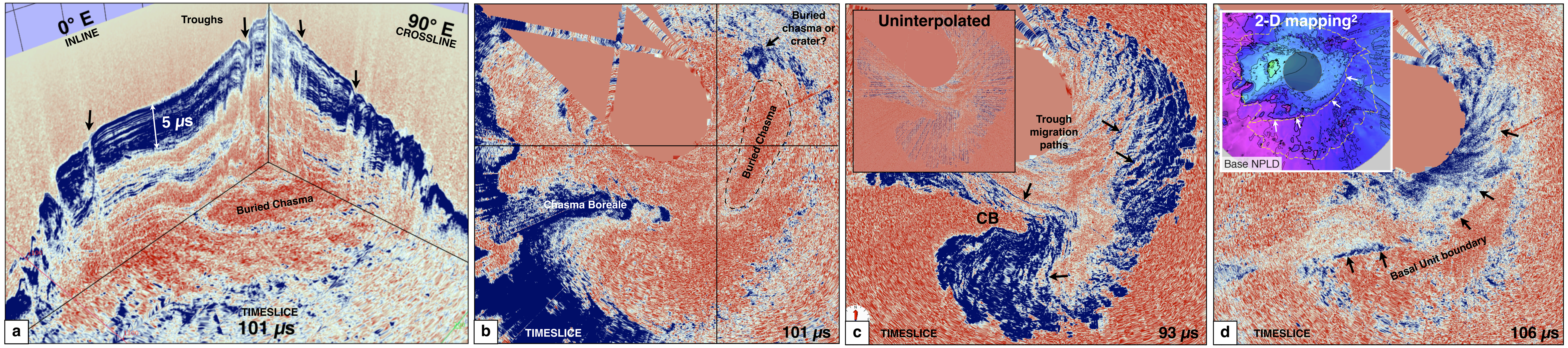
- ✦ Two-dimensional (2-D) radargrams from the Shallow Radar (SHARAD) instrument onboard the Mars Reconnaissance Orbiter (MRO) provide profile views into the interior of Planum Boreum[1,2,3,4] and Planum Australe.[5,6,7]
- ✦ Subsurface returns in 2-D radargrams are often obscured by returns from off-nadir topography and loss of signal due to unfavorably sloped nadir features.
- ✦ To alleviate these problems, we have developed a means to transform SHARAD data in areas of dense coverage into 3-D volumes.
- ✦ Further improvements in data quality from 3-D imaging will shed light on the nature and timing of the polar layered deposits at both poles, thereby helping to decode past climate.[8,9,10]

The CAT-Scan Analogy

- ✦ 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 thousands of 2-D radar images of Mars around its polar regions, and we have used a subset of those radargrams to generate a 3-D image of Planum Boreum's interior.



SHARAD groundtracks (yellow) over Planum Boreum as of August 2012 (1949 orbits). Blue line is segment of SHARAD observation 1233602 (Box A). Observations from 540 groundtrack segments crossing Region B are used in 3-D binning and migration tests (Box B). Basemap is MOLA shaded relief.



Interior views of Martian north polar cap from the first 3-D volume of SHARAD data

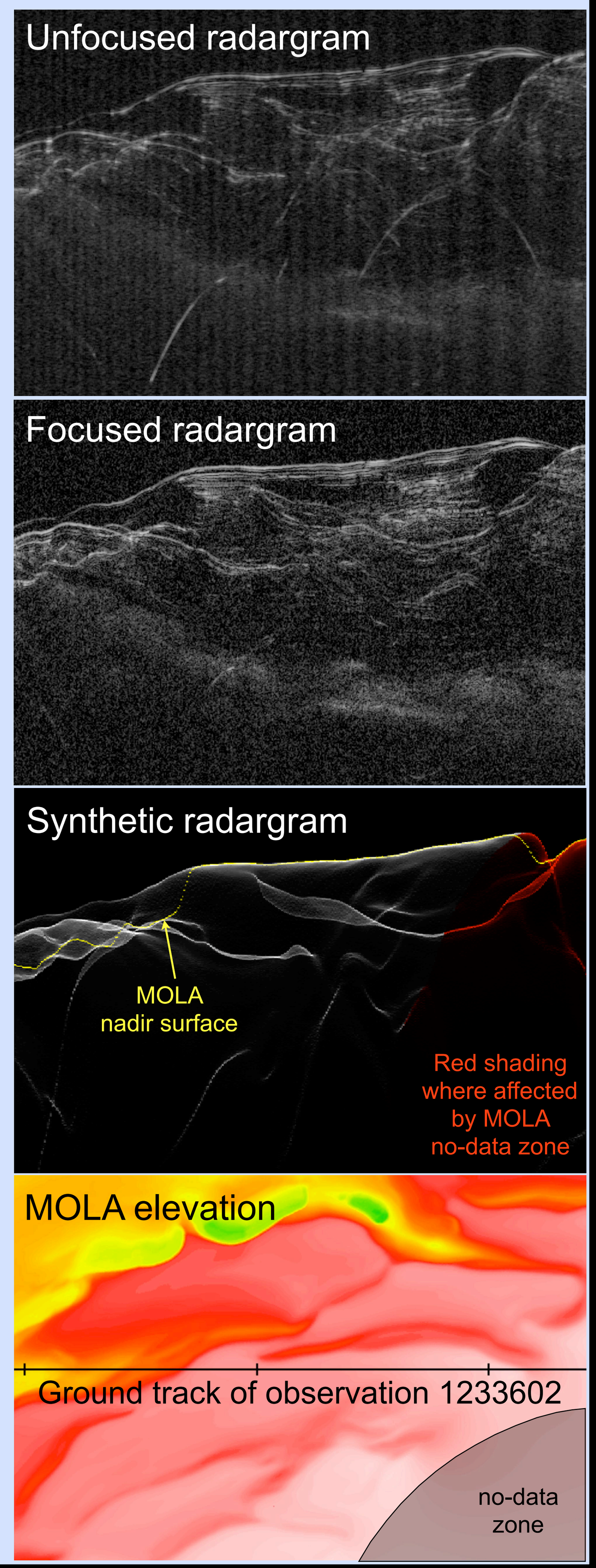
3-D movies: data.boulder.swri.edu/than/AGU2012

(a) Chair-cut and (b) timeslice views of the radar volume show internal structures, such as details of a buried chasma not seen in 2-D mapping[3]. Timeslices allow close tracking of (c) trough-migration paths and (d) major boundaries such as the periphery of the basal unit.

A Conventional Radar Analysis

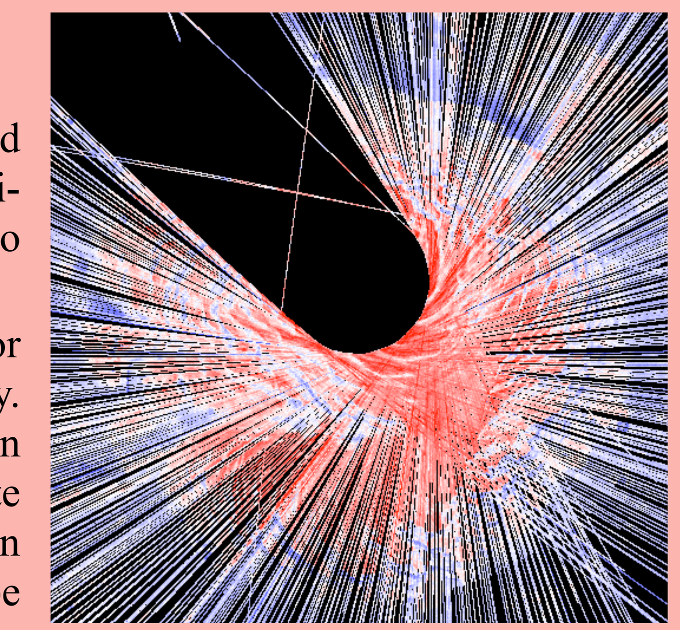
- ✦ Collections of radargrams (2-D power profiles) are used to map radar returns from the surface and subsurface.
- ✦ *Clutter* (returns from features outside of the spacecraft's nadir track) may interfere with or be mistaken for actual subsurface returns. Rarely, clutter may arise from subsurface interfaces.[11]
- ✦ No returns are seen from features at nadir that slope away from the radar.
- ✦ Synthetic radargrams generated from topographic models of the surface are used to identify surface clutter and locations with no nadir return. Radar signals with corresponding features in a synthetic are deemed clutter and dismissed as "noise".
- ✦ Subsurface clutter and off-nadir surface features not sampled in topographic models will not appear in synthetics.
- ✦ These issues show the limitations of attempting to produce a 2-D cross-section of a 3-D object from an inherently 3-D signal.

Panels at right: **Portion of a SHARAD observation** of Planum Boreum. Unfocused radargram shows both along-track and cross-track clutter. 2-D focusing corrects along-track components, but retains cross-track ones. Synthetic radargram made from MOLA data show returns that are due exclusively to surface features.



B Three-dimensional Radar Analysis

- ✦ If data are treated collectively in a 3-D volume, the imaging process known as ***migration*** will reposition off-nadir signals to their source locations, promoting clutter from noise to signal and producing a geometrically corrected image (see Physical Model Example below).
- ✦ Migration algorithms require data to be referenced to a common datum (aligned in range delay) and to be ***binned*** (emplaced into a regular lateral grid)[14].
- ✦ We began our 3-D analysis in Planum Boreum, where subsurface returns are more consistent than those of Planum Australe.[1,7]
- ✦ The Planum Boreum subset chosen for binning and migration tests has a regular sequence of quasi-parallel layers as well as sufficient structure to evaluate the quality of migration results.
- ✦ Different migration algorithms can account for different types of subsurface geologic complexity. Seismic velocities in typical terrestrial studies can be highly variable, but radar signals propagate through the ice-rich polar layered deposits[1,12] at an essentially constant velocity. Thus, we expect to be able to employ fast and accurate imaging methods, such as 3-D frequency-wavenumber migration.[15]



SHARAD observations crossing Region B. Binning grid: 3000×3000 bins, each 500×500 m. Color is RMS of radar power between 80 and 120 μs delay time (blue=low, red=high).

Physical Model Example

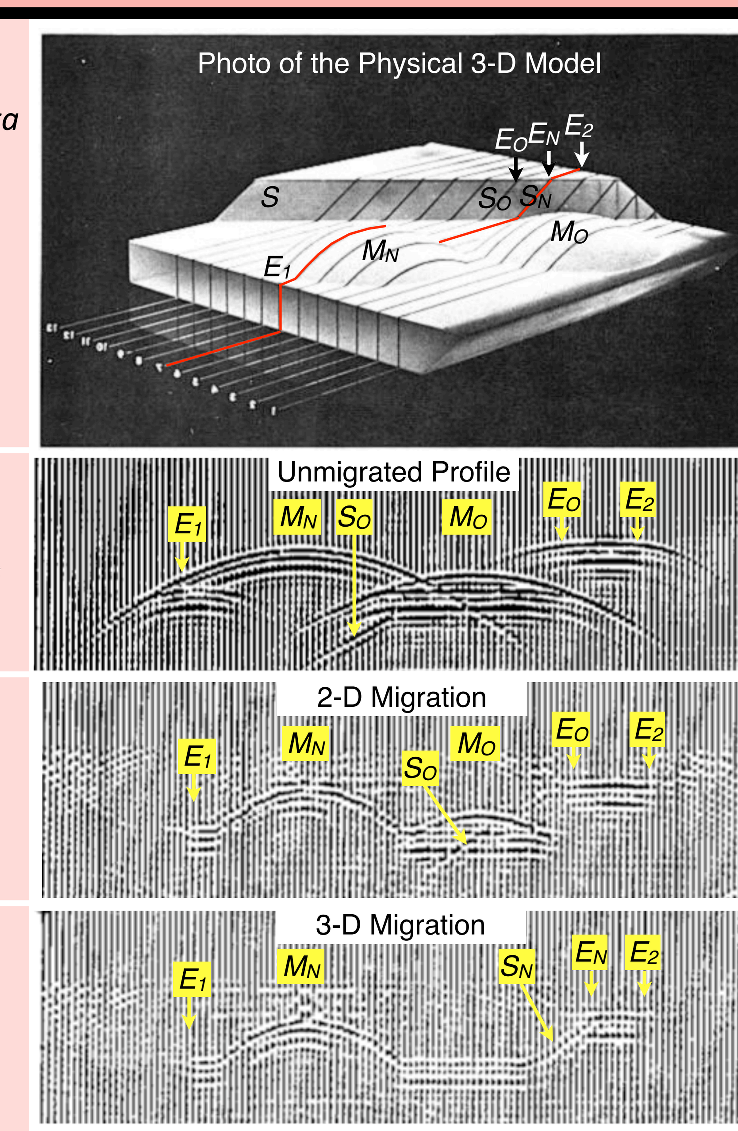
French (1974)[13] acquired ultrasonic seismic data over a 3-D physical model immersed in water.

Numbered lines show the location of 2-D profiles acquired. Model features include Mounds M_N and M_O and Slope S, crossed at an oblique angle by the profiles. Profile 7 (red line) is displayed below.

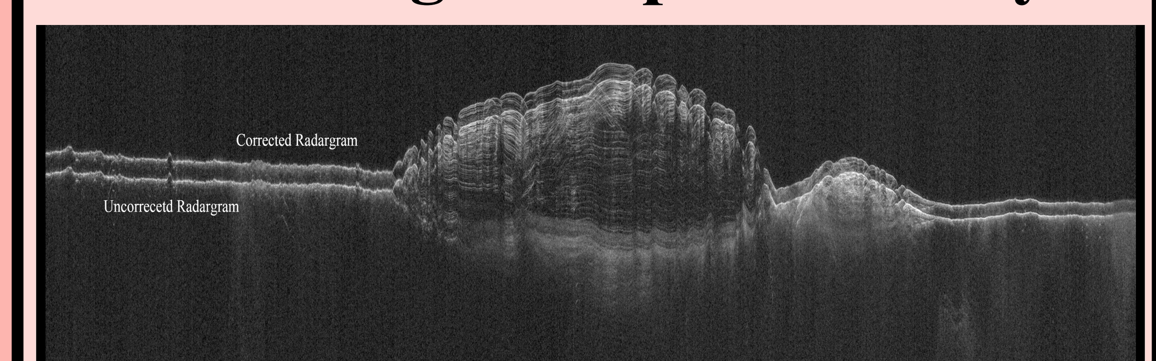
Unmigrated profile is obscured by returns diffracted from the edges of structures (E_x) and by returns from features out of the plane of the profile (M_O, S_O).

2-D migration collapses diffractions and fully images in-plane features (M_N), but out-of-plane returns remain (M_O,S_O). Returns from features oriented obliquely (S_O, E_O) to the profile may interfere.

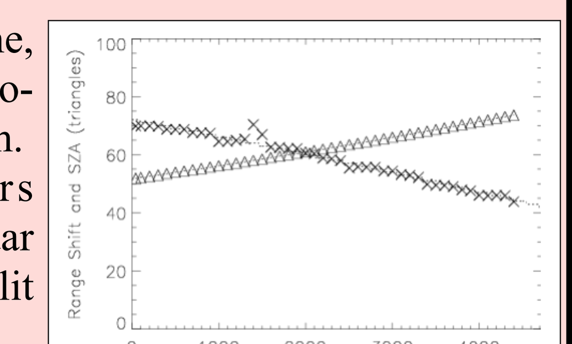
3-D migration collapses diffractions and repositions out-of-plane returns to their source locations. Energy from adjacent profiles is thereby restored to image obliquely oriented nadir features (S_N, E_N).



Correcting Ionospheric Delays



- ✦ When creating a 3-D volume, SHARAD data must be co-registered to a common datum.
- ✦ The ionosphere of Mars distorts and delays the radar signals, especially on the sunlit side of the planet.
- ✦ We derive phase corrections and estimate the time delays using an autofocus method[16] that optimizes image quality in 100-km segments of each radargram. The correction typically varies inversely with the solar zenith angle.



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