Downward continuation of Mars SHARAD data

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ABSTRACT

Summary Shallow Subsurface Radar (SHARAD) data from the Mars Reconnaissance Orbiter are acquired approximately 300 kilometers above the Martian polar icecap. In this report we detail how to adapt seismic 3D poststack downward continuation to allow construction of the data that would have been recorded a short distance above the Martian surface, thereby saving significant computational time and storage in subsequent imaging and analysis of the shallow polar subsurface.

INTRODUCTION

At the 2013 ProMAX/SeisSpace User's Group in Highlands Ranch, coauthor Fritz Foss introduced the audience to a Mars radar dataset that he intended to image using seismic processing and imaging tools. One of the questions he raised was whether the SeisSpace/ProMAX software package provided him the ability to redatum those data from orbital heights around 300 km to near-surface altitudes around 1 km. Dr. Levin thought that there was already such an option in the 3D FK migration package, but if there wasn't, he'd cobble together a quick one. Well, there wasn't, so he did, though not so quickly.

THEORY AND METHODS

Because the speed of propagation of radar signals is basically constant due to the thin Martian atmosphere, a simple constant velocity method was appropriate. This could be done by either constructing an appropriate constant velocity Green's function in the time-space (Etgen, 1998) domain and then applying it in the $\omega - k$ domain or by applying an analytic phase shift directly in the $\omega - k$ domain (Gazdag, 1978). We chose the latter, primarily because the out-of-core F-K framework already available produced constant slices as the basic unit to process. In this approach, the phase shift is given by

$$\exp\left(-2\pi i \tau_0 \operatorname{sgn}\omega \sqrt{\omega^2 - v^2|k|^2/4}\right) \quad .$$

where τ_0 is the downward continuation time, v is the downward continuation velocity, and ω and k are frequency (Hz) and (vector) wavenumber (cycles per unit distance) respectively. In the radar application, where the input data are zero before time τ_0, it was computationally and memory advantageous to delete these zeroes before processing and absorb them into a static shift (retarded frame) and the definitions of t and τ. Specifically, if the data shift is t_0 (set equal to τ_0 in our implementation), the phase shift becomes

$$\exp\left(-2\pi i\tau_0 \operatorname{sgn}\omega\sqrt{\omega^2 - v^2|k|^2/4} + 2\pi i t_0\omega\right) \quad .$$

The reader should keep in mind that downward continuation is not the same as migration. Dipping events do not change their dip (or azimuth) during phase-shift downward continuation, unlike in phase-shift migration. Instead their dip controls the extent of the temporal shift upwards that is applied to the event. In particular, for constant velocity, if the downward continuation time is τ, the upward shift is $\tau\cos\theta$, where θ is the dip angle. In the retarded frame where the initial t_0 zeroed data are removed, additional zeros must be added below the remaining data to prevent, or at least limit, more steeply dipping energy from wrapping around into the top of the image. In the actual application we hardwired this padding to a factor of two, corresponding to a 60° maximum propagation angle.

To implement the phase-shift with few artifacts, we used the operator dip control of Levin (1983) to suppress wraparound. For constant velocity, the relevant limits for $p = |k|/\omega$ and aperture radius r are

$$p_{\max} = \frac{2}{v}\left(1 - \frac{\tau_0^2}{t_{\max}^2}\right) \text{ and} \tag{1}$$

$$r_{\max} = p_{\max}\, t_{\max}\frac{v^2}{4} \ , \tag{2}$$

where $t_{\max}$ is taken to be 1.25 times the trace length to allow dip tapering to complete in the padded zone.

In addition to wraparound suppression, we implemented an edge truncation suppression. By default, seismic data truncates abruptly at the extreme edges of the survey. Such truncations lead to "smile" artifacts that sweep back into the survey aperture. A common approach is to smoothly taper the data near the edges down towards zero so as to not create a sharp discontinuity. Rather than modifying the actual data in this way, we decided to use a variation of the method of Spitz (1991) to smoothly extrapolate the data off the edge into the padded zone required by 2.

In principle, this should be done as a two-dimensional extrapolation filter (Spitz, 1990), but we implemented it as a cascade two orthogonal 1-D extrapolators. In order to more effectively use just a few traces near each edge (hardwired at 5 in the application), we chose to use Burg filter design (Claerbout, 1976, §7–2) rather than the more traditional Wiener-Levinson approach.

EXAMPLES

Figure 1 shows a synthetic 2-D section with a simple dipping event. Positing that 1 second of zero data had been removed from above the section, downward continuing

1 second with a 3000 m/s velocity produces the result in Figure 2. Note that, as predicted, the event has shifted downward. The $f-x$ lateral data extrapolation has left only very faint residual edge smile, unlike in Figure 3 where edge extrapolation was disabled.

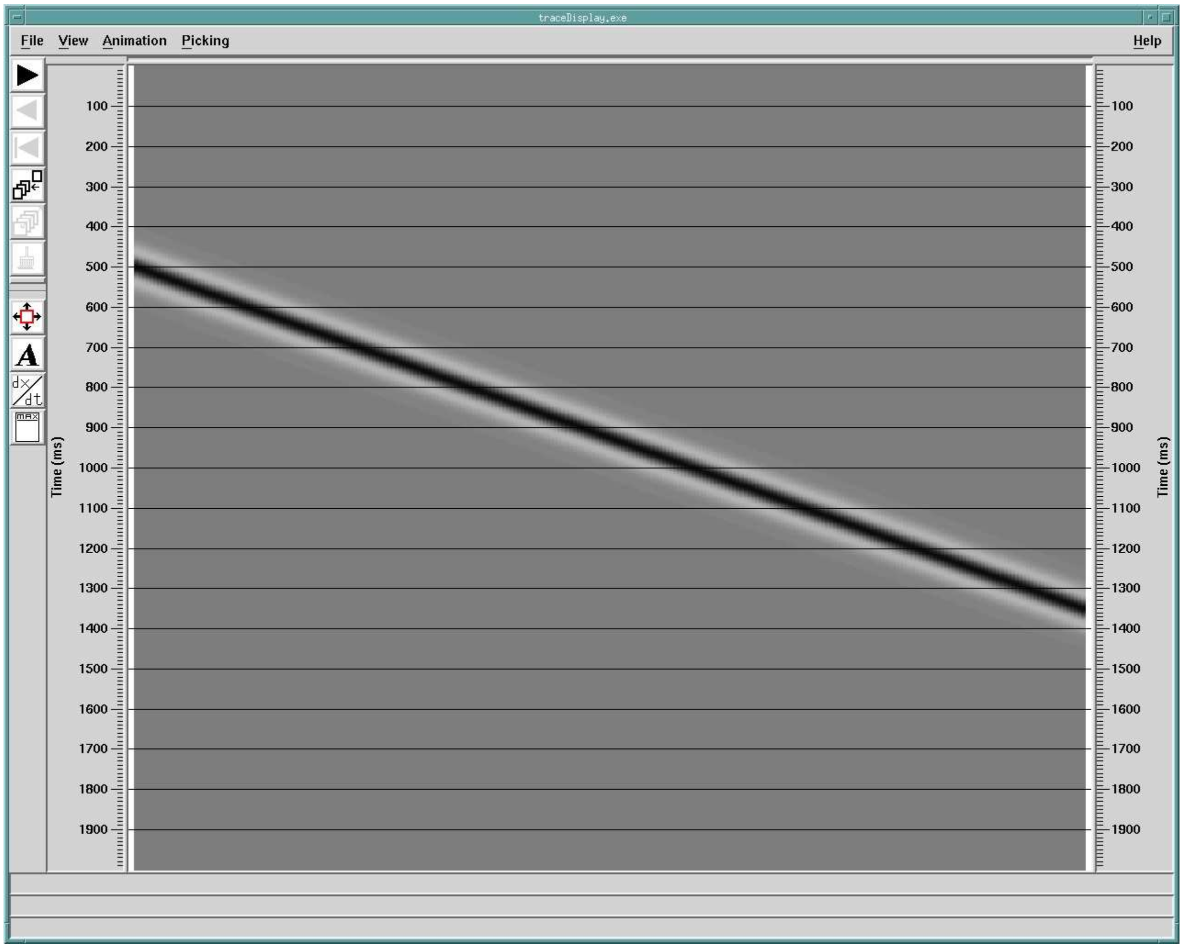

Figure 1: Dipping synthetic shifted by -1 s. Trace spacing is 10 m. Sample interval is 2 msec. [**CR**]

Figure 4 shows a single track from the SHARAD field data. Here, units were appropriately scaled to fit within the constraints of the seismic processing software. Figure 5 was obtained with a downward continuation velocity of 29979.2 (speed of light divided by 10,000) and the amount of time stripped off the top of the data being 20056.5 msec (equivalent to about 300 km elevation).

CONCLUSIONS

While time will tell whether full 3D migration of interpolated Mars SHARAD data will provide significant uplift in S/N and resolution over single track imaging, timing

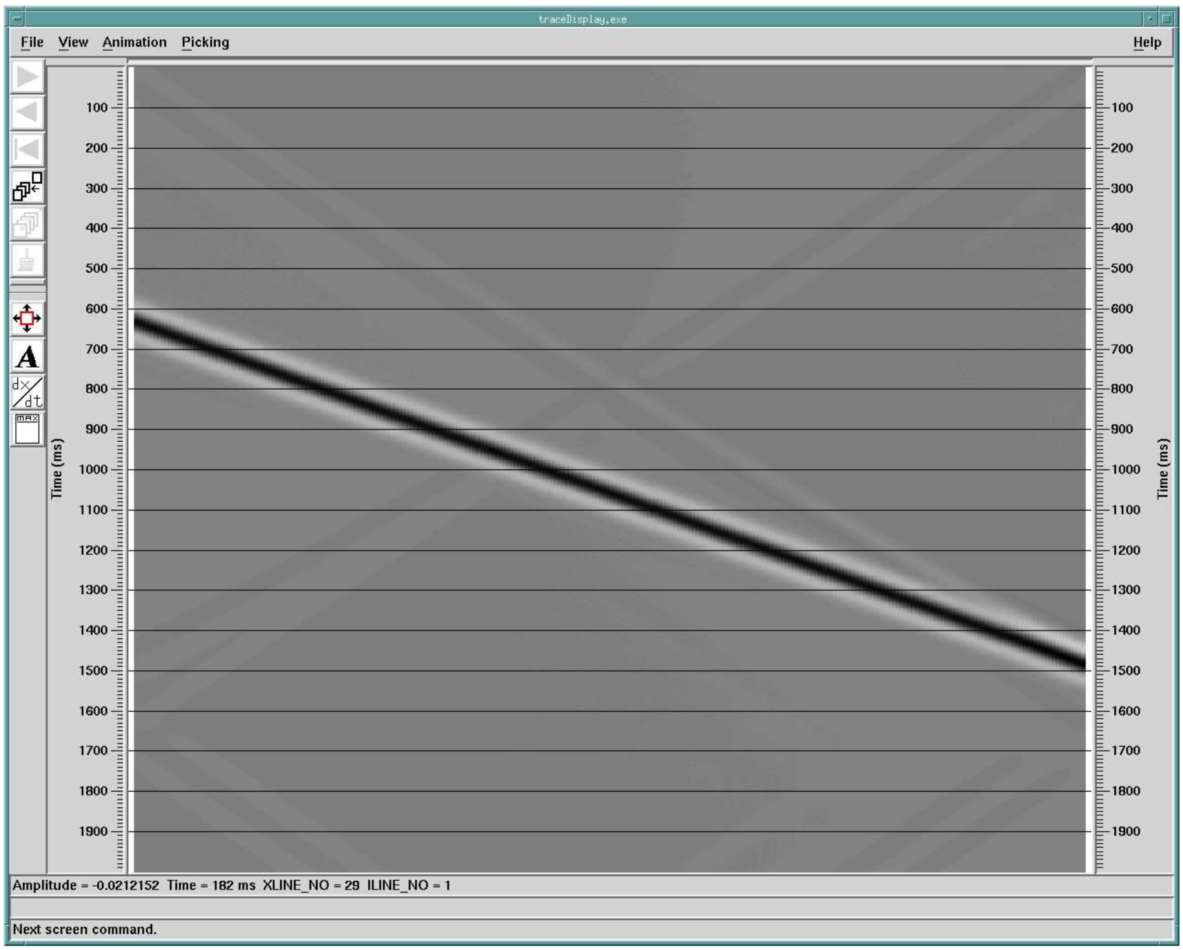

Figure 2: Dipping synthetic downward continued 1 second at 3000 m/s. The faint linear artifacts arise from the $f - k$ aperture limit. [**CR**]

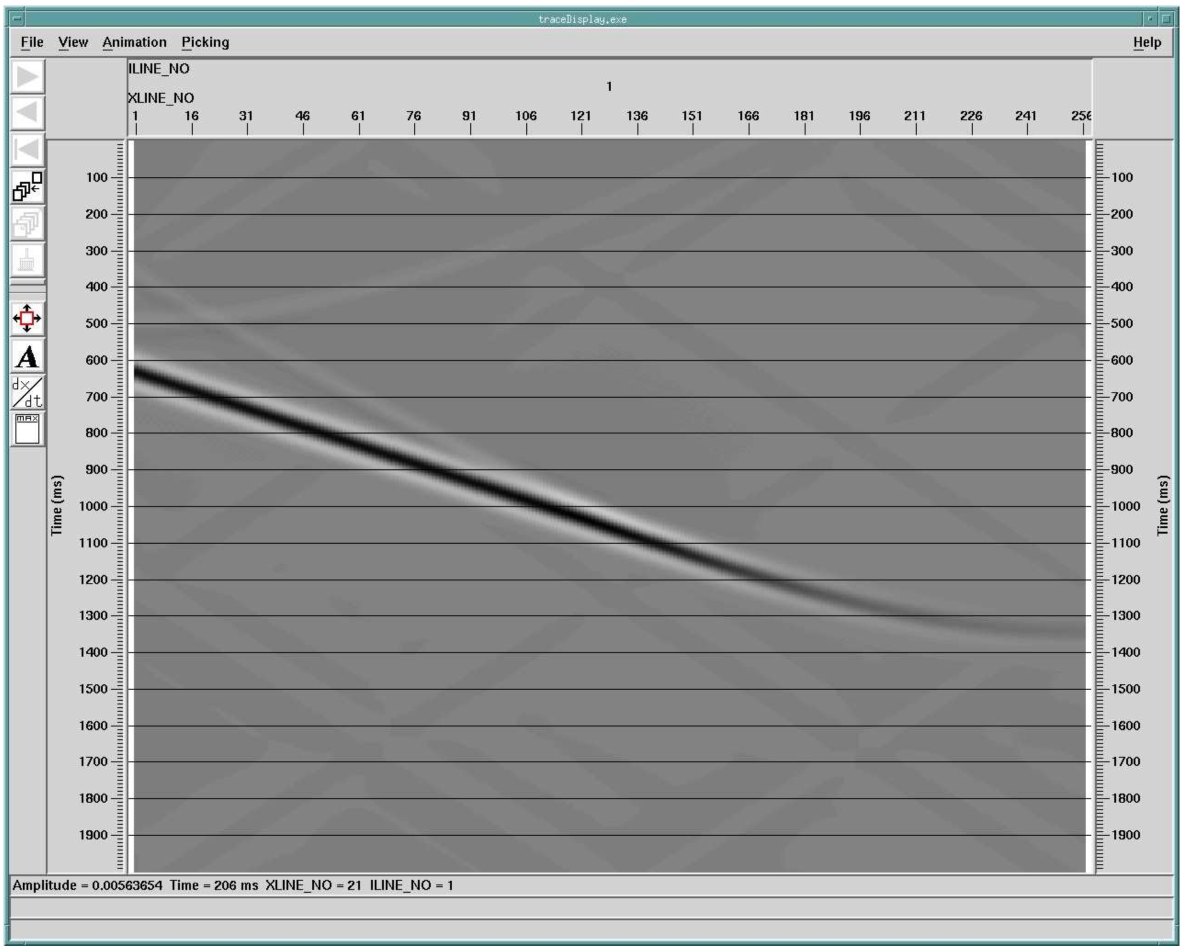

Figure 3: Dipping synthetic downward continued 1 second at 3000 m/s without off-end $f-x$ extrapolation. In addition to the $f-k$ aperture limit artifacts, there are half smiles originating from the edge locations of the original event and we lose downdip infill. [**CR**]

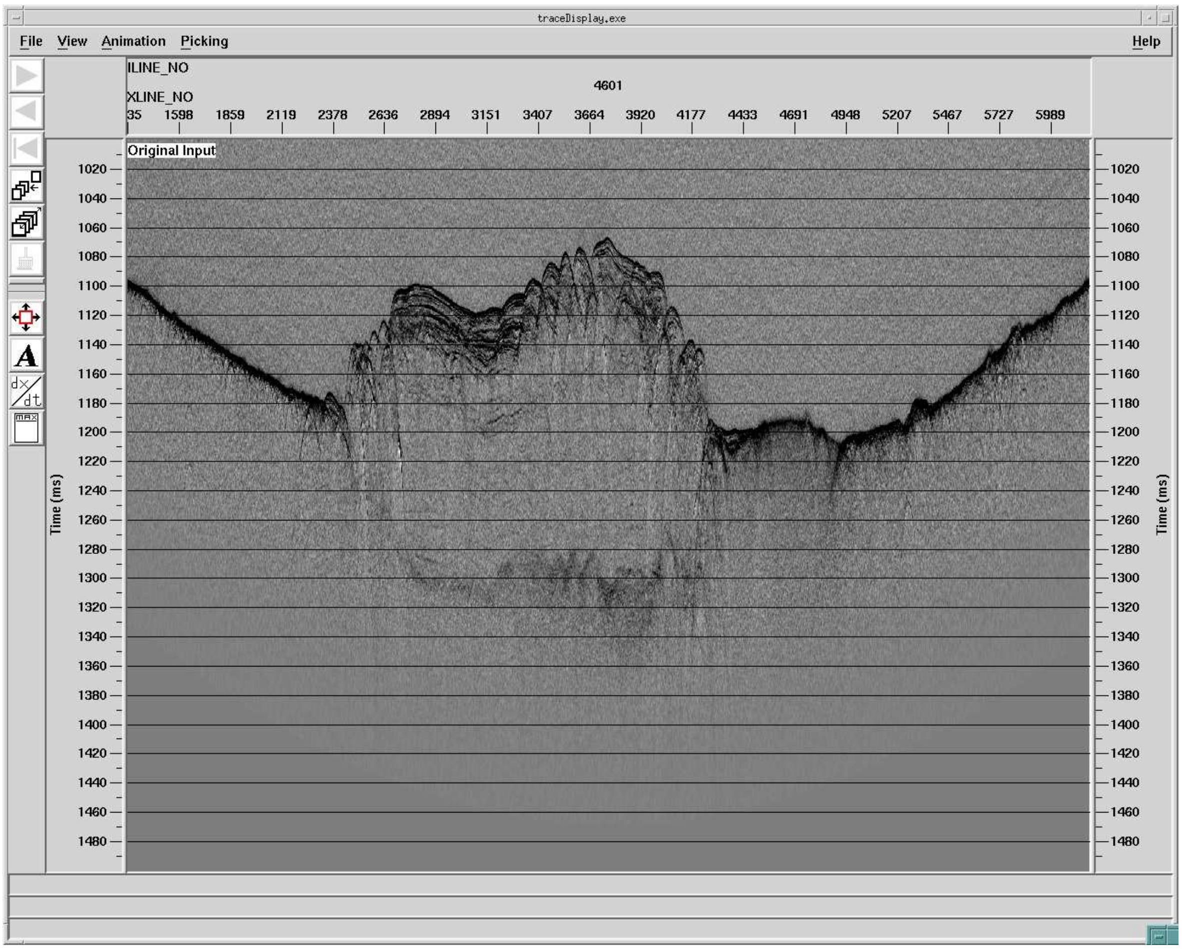

Figure 4: Mars radar track 32930200. The data have been bulk shifted upwards by about 20 (scaled) seconds. [**CR**]

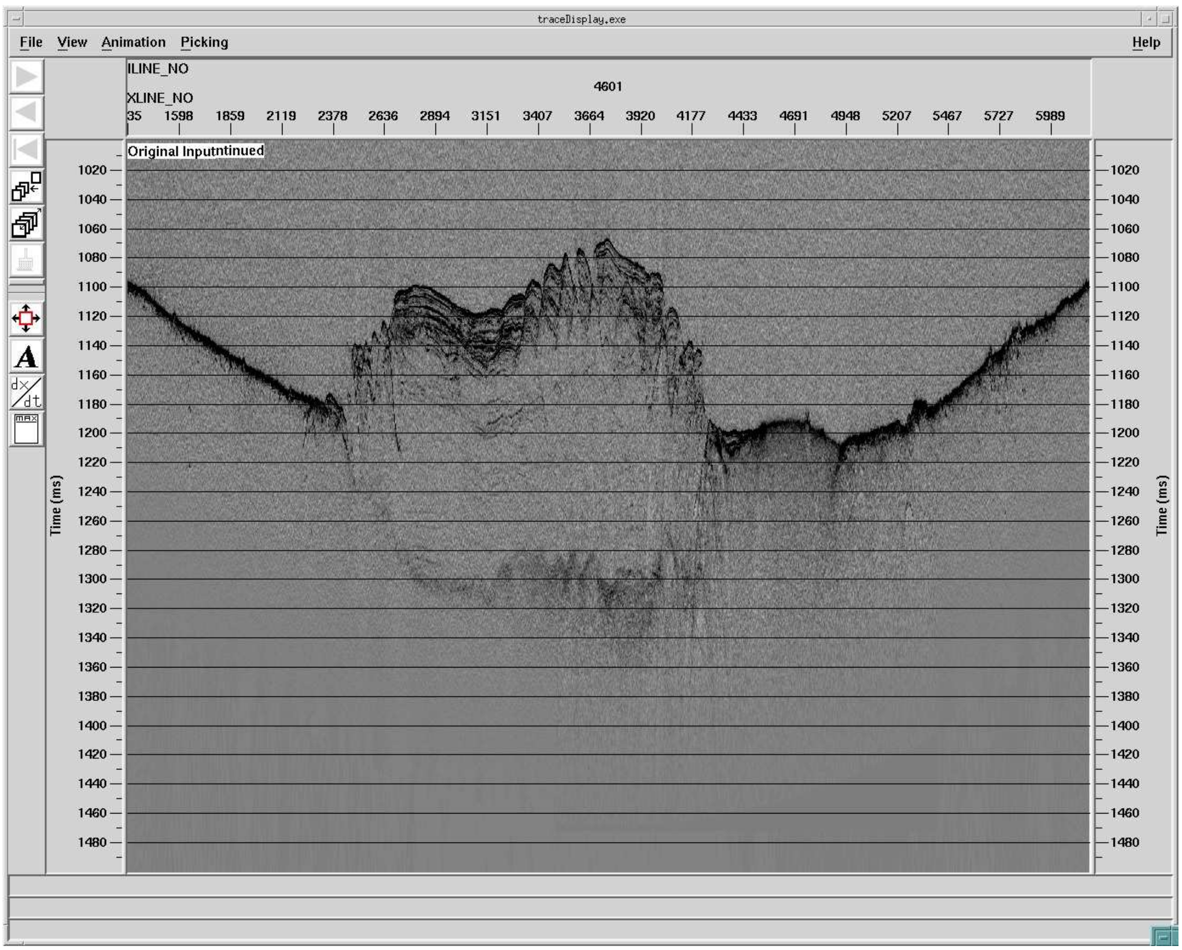

Figure 5: Mars radar track 32930200 after downward continuation at (scaled) light speed. [**CR**]

tests indicate that the downward continuation is expected to knock over 100 days from the cost of 3D F-K migration of those data.

Of the two modifications to traditional downward continuation, using a retarded frame to suppress processing of data before the very late first arrivals and f-x off-end extrapolation to reduce edge truncation sweep noise, the latter is helpful but not perfect, sometimes creating fictitious low amplitude events adjacent to the zero padding zone.

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