Updated algorithm to remove ionospheric distortion from MARSIS data. A. Ivanov[1], J. Plaut[2], Y. Gim[2], R. Orosei[3], A. Cicchetti[3], S. Giuppi[3], M. Cartacci[3], R. Noschese[3], G. Piccardi[4], [1]Planetary Science Institute, Tucson, AZ (anton@psi.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [3]Istituto di Astrofisica Spaziale e Fisica Cosmica, Istituto Nazionale di Astrofisica, 00133 Rome, Italy, [4]Infocom Department, "La Sapienza" University of Rome, 00184 Rome, Italy, [3]

Introduction.

MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) is a multi-frequency synthetic aperture orbital sounding radar on board of the Mars Express spacecraft. In its subsurface modes, MARSIS operates in four frequency bands between 1.3 and 5.5 MHz, with a 1 MHz instantaneous bandwidth that provides free- space range resolution of approximately 150 m. Lateral spatial resolution for the cross-track footprint is 10-30 km, and for the along-track footprint, narrowed by onboard synthetic aperture processing, 5-10 km (*1*).

Ionospheric compensation

The main source of noise in MARSIS subsurface data is ionospheric distortion, which is due to the fact that MARSIS frequencies are close to the ionospheric plasma frequency. One method to remove distortion is is a "contrast" method, which is a loop to estimate the value of the quadratic phase correction term of the signal Fourier spectrum. This algorithm optimizes the range compressed signal in terms of side lobes level, waveform shape, signal to noise ratio and range resolution, regardless any environmental behaviors. Another method is to modeling the total electron function (TEC) in the ionosphere. This method was described by (*2, 3*) and (*4*) and it is currently employed for MARSIS data processing. In this paper we present an improvement to modeling TEC function. Current compensation scheme only uses Mars DEM (*5*) to compute distance between spacecraft and sub-spacecraft point, but it is not used as a constraint to compute TEC. In this work, we introduce a clutter model of Mars surface to be used as a constraint for TEC evaluation. Clutter model used in this work was developed by A. Safaeinili (*6*). Similar models were developed by (*7*), (*8*). The clutter model simulates surface returns based on spacecraft geometry, radar parameter, and Mars DEM. For a given location, we compute the spectral response of each surface area element (facet) whose size is about 1/10th of wavelength after oversampling Mars MOLA data. We assume the facet is flat and that the frequency response is only dependent on the range between S/C and facet location. The number of facets are big enough to cover a large extend in the cross-track direction, about 400 km. The along-track is relatively short, about 25 km, after taking into account MARSIS's on-board Doppler bean-forming process

Implementation

Here we describe an overview of updated MARSIS processing pipeline, which now utilizes full clutter model. Overview is shown in Figure 1. First pass of ionospheric compensation assumes a fixed value for the Chapman parameter N_0. The initial value is based on all previous observations (*3*), however, this technique has shown to be quite robust to variation of this parameters. We have used values of N_0 to range from 1.7×10^{-5} to 2.2×10^{-5} and the final estimation of TEC was the same. Currently, this initial value of is set to $N_0 = 2.0 \times 10^{-5}$. Alternatively, N_0 can be estimated using contrast method (*9*).

The result is a first order estimate of MARSIS echo, which is still distorted by ionosphere because we used an assumed shape of the TEC function. The next step used this product and MARSIS clutter model to estimate corrections to TEC function, such that MARSIS first echo return is positioned (in time or range domain) exactly where it is predicted by the clutter model. We find offset between the delay of the first MARSIS echo (by using Fourier image correlation and Sobel filtering) and delay as it is predicted by the clutter model. We assume that this offset is due to variations in the total electron content and calculate corresponding offset to the TEC function.

The final ionospheric compensation is now using updated TEC values to prepare final radargram. As a side product we also estimate average value for the whole track. It is possible to re-run the whole process with this new value for Chapman function, but we have found it unnecessary.

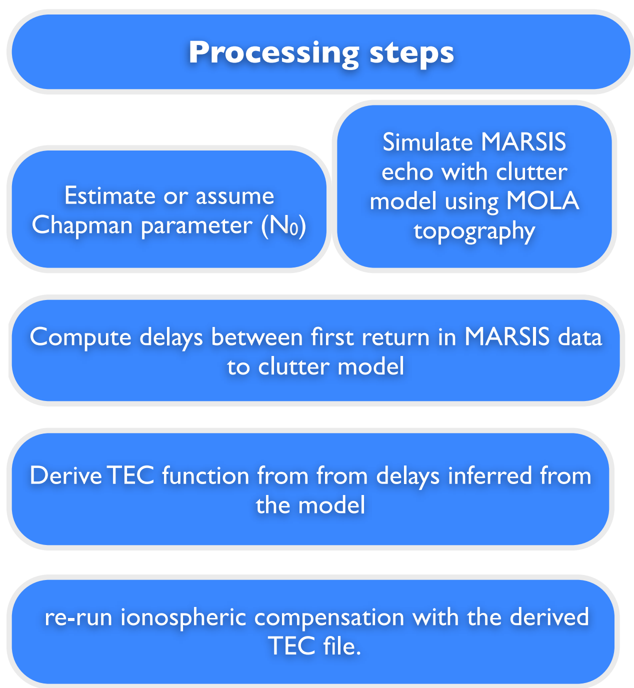

Figure 1. Updated data processing pipeline for MARSIS. This version generates ionospheric compensation using clutter model constrained

Results.

The updated has now been implemented we are evaluating it on large sets of data. We have found that it performs very well in places of interest. For example, echoes that come from polar layered deposits (PLD) terrains are now much better correlated with MOLA DEM. We also have a better results in other areas where observe subsurface signatures (e.g. Medussae Fossae Formation). Daytime observations, where signal-to-noise ratio is not big have improved considerably. There are, however, observations where this scheme does not perform well. For example, in place where MARSIS distortion is due to magnetic field effects. This violates our assumption that all distortion are to ionospheric effect and therefore our scheme predictably fails. Current pipeline produces two versions of compensated radargrams: using TEC and using Chapman function of the solar zenith angle, which is a fit to observed TEC. The first product allows to isolate local TEC variations, while the second one is consistent with Mars topography for a scale for one radargram.

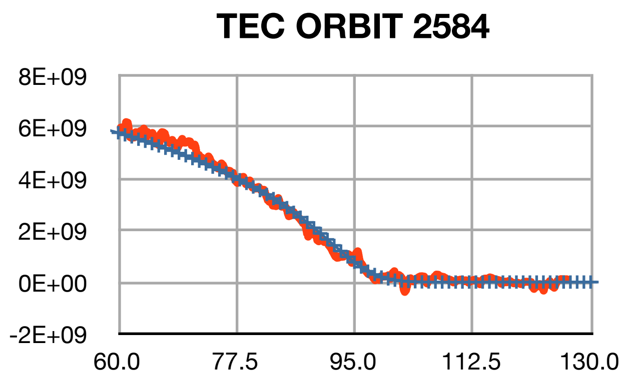

Figure 2. Total electron content (y-axis) as a function of the solar zenith angle (x-axis). Red - TEC estimate constrained by clutter model, blue - best fit Chapman function.

Summary.

In this work we have presented an update to level 2 processing of the MARSIS subsurface sounding data. The update is employing Mars surface clutter model as constraint to calculate total electron content function. Updated pipeline is using correct geometry for all orbits and generates models along with actual data. The algorithm performs very well in areas where subsurface echoes are observed.

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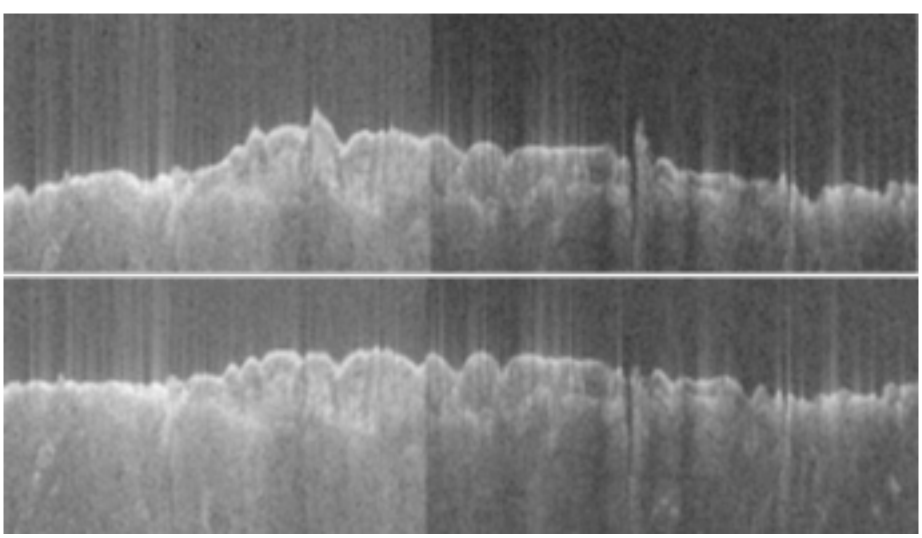

Figure 3. Comparing results of current pipeline (top radargram) and using MOLA clutter model as constraint (bottom radargram) for orbit 2584. X-axis is formed by stacking together individual echoes along the spacecraft path, Y-axis is time delay. Notice that the surface of the South Polar Layered deposits is consistent with MOLA topography. In low SNR situations, new approach produces dataset that is more consistent with MOLA DEM.