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Correction of the ionospheric distortion of MARSIS signals: Ionospheric properties from the contrast method

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Abstract

Echoes obtained by the MARSIS radar in subsurface sounding mode are distorted by the dispersive Martian ionosphere. A method for the correction of such distortion yields estimates of the total electron content as a by-product. These estimates are shown to be consistent with first-order models of the Martian ionosphere, and can thus be used to study higher-order ionospheric properties.

1. Introduction

The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) [1], carried by ESA's Mars Express spacecraft, is both a synthetic-aperture, orbital sounding radar and a topside ionospheric sounder. In its subsurface sounding mode, it works by transmitting a low-frequency radar pulse that is capable of penetrating below the surface, and is reflected by any dielectric discontinuity present in the subsurface. MARSIS is optimized for deep penetration, having detected echoes down to a depth of 3.7 km over the South Polar Layered Deposits [2], and is capable of transmitting at four different bands between 1.3 MHz and 5.5 MHz, with a 1 MHz bandwidth.

2. The contrast method

As penetration of the radar signal is approximately proportional to wavelength, MARSIS operates at the lowest possible frequencies capable of propagating through the Martian ionosphere, just above the maximum plasma frequency. At those wavevelengths, the Martian ionosphere behaves as a dispersive medium and, as a consequence, different frequencies within the radar signal suffer different delays. This results in a distortion of the received signal, which can severely degrade data quality. Different methods have been proposed to correct this distortion, such as [3], [4], [5] and [6].

Ionospheric distortion produces two different effects, namely an added delay in signal travel time, and a phase distortion of the signal causing loss of signal-to-noise ratio and range resolution. The so-called "contrast method" [5] was developed to correct phase distortion, and it is implemented in MARSIS on-board software as well as in the ground processing software.

At its core, the contrast method works by determining the value of the quadratic phase correction term of the signal Fourier spectrum that maximizes a function of the signal itself (contrast). It can be shown [5] that the quadratic phase correction term (called *a2*) is tied to the total electron content (TEC) along the path between spacecraft and the Martian surface.

3. Results

The processing of the whole MARSIS dataset has produced hundreds of thousands of values of *a2*, and thus of TEC estimates, for different conditions of solar zenith angle, latitude and longitude. Our first step in the analysis of such large dataset was to test it for consistency. We have thus estimated the average value of *a2* as a function of the Sun elevation angle, using more than 3500 orbits and each band (1.8 MHz, 3 MHz, 4 MHz and 5 MHz) available to MARSIS. The bands at 4 and 5 MHz provide the largest dataset, as they are routinely employed during both day-side and night-side observations.

In Fig. 1, the derived value of the TEC as a function of the Sun elevation angle is shown for these two different frequencies. It can be seen that the curves are very similar, and that they are consistent with a Chapman model of the Martian ionosphere.

4. Discussion and future work

The TEC of the Martian ionosphere was already derived from MARSIS subsurface sounding data by [7], using a different algorithm for the correction of ionospheric distortion. In this preliminary work we have

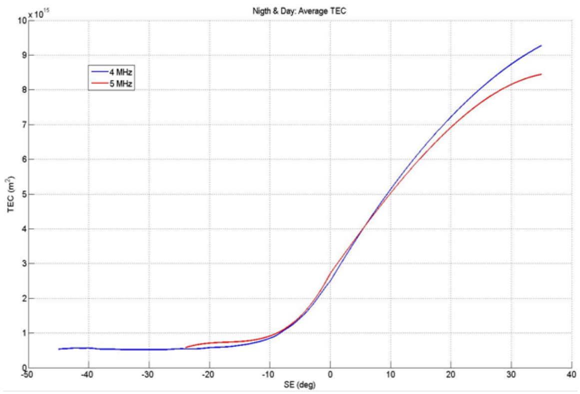

Figure 1: Average total electron content of the Martian ionosphere as a function of Sun elevation, derived from the value of the *a2* parameter produced by the contrast method. Curves have been obtained for two MARSIS operation frequencies, 4 MHz and 5 MHz.

shown that the contrast method is producing estimates of the TEC that are consistent with current models of the Martian ionosphere. The next step will be the detailed analysis of the properties of the dataset thus obtained, to study higher-order effects such as the influence of local magnetic anomalies.

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