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# A new empirical model for Mars ionosphere to correct radio signal experiments.

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## Abstract

A new empirical model of the Mars' ionosphere called MoMo was developed. It is based on the large database of Total Electron Content (TEC) derived from the subsurface mode of the Mars Express MARSIS radar. The model provides the vertical TEC as a function of solar zenith angle, solar activity, solar longitude and the location. For the validation, the model is compared with Mars Express radio occultation data as well as with the numerical model IPIM (IRAP Plasmasphere-Ionosphere Model).

The model output is discussed in terms of climatologic behavior of the Mars' ionosphere. We also used the output of MoMo to quantify the impact of the Martian ionosphere on radio-science experiments. From our results, the effect is of the order of $10^{-3}$mm.s$^{-1}$ in Doppler observables especially around sunrise and sunset. Consequently, this new model could be used to support the data analysis of any radio-science experiment and especially for present InSight RISE and future ExoMars LARA instruments aiming at a better understand of the deep-interior of Mars.

## Results

In this paper, MoMo is used to estimate the impact of the ionosphere on radio-science experiments between Mars surface assets (e.g. lander, rover…) and Mars orbiters or Earth antennas. For that purpose, we produce vTEC maps for Mars with MoMo (Figure 1). We then use these maps to estimate the slant TEC in the line of sight of an external object, and we quantified the impact on different wave propagation parameters: phase delay, and Doppler shift from UHF to X-band.

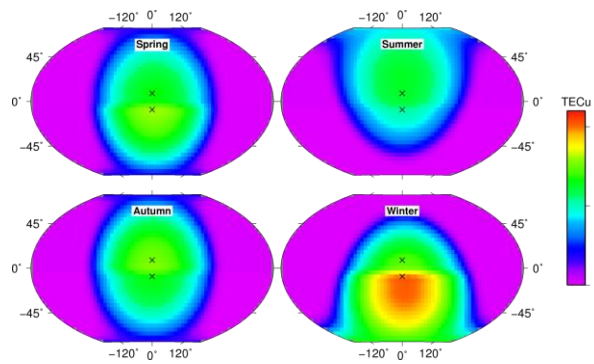


Figure 1: Global maps of Mars vTEC in TECu (1 TECu = $10^{16}$ $e^{-}.m^{-2}$. The different maps correspond to the different outputs of the MoMo model for different seasons (in the North hemisphere) at local noon at the meridian origin for a high solar activity level. The black crosses are the location of two assets on the Mars surface (N10° and S10° in latitude; 0° in longitude) used in Figure 2.

We consider two hypothetical surface assets positioned at S10° and N10° in latitudes and 0° in longitude (see crosses in Figure 1). The transmitting/receiving antennas on Earth (or on-board a Mars orbiting spacecraft) are assumed to be at different elevation angles seen from the asset: 20° and 55° which correspond to the typical elevation range for present and future radio-science operation of RISE [1] and LaRa [2]. We also consider an elevation angle of 90° (i.e. at the zenith of the asset). We estimate the phase delay (i.e. time delay of the phase) as well as the instant Doppler shift due to the Mars' ionosphere TEC change. Finally, the velocity change due to the Mars' Ionosphere is obtained assuming a two-way radio-link. These different quantities are given with respect to the Solar Local Time (SLT) at the asset location.

As shown in Figure 2, the maximum phase delay is obtained at 12:20 SLT with a stronger effect at lower elevation and for an asset situated in the Southern hemisphere. In that case, the values in phase delay reach more than 8 m in UHF, 32 cm in S-band and 2 cm in X-band. The effect on the Doppler measurements is maximum during local sunrise and sunset (around 06:00 and 18:45 SLT). The maximum shift is of the order of ± 1 mHz (± 3.6 x $10^{-1}$ mm.$s^{-1}$ in velocity change) in UHF, ± 2 x $10^{-1}$ mHz (± 1.5 x $10^{-2}$ mm.$s^{-1}$) in S-band and ± 5 x $10^{-2}$ mHz (± 1.0 x $10^{-3}$ mm.$s^{-1}$) in X-band when considering 20° elevation with respect to the asset.

This is about one order of magnitude below the estimated noise of RISE and LaRa instruments, but is of same order of magnitude as the contribution of the liquid core in the Doppler (~$10^{-3}$-$10^{-2}$mm.$s^{-1}$, [3]). Consequently, the predictions made with MoMo suggests that radio-science teams will have to either correct their data using our model for instance or adapt the mission to avoid operating during sunrise and sunset when TEC rapidly varies.

# Conclusion

A new empirical model of the Mars Total Electron Content (TEC) called MoMo (Model of Mars Ionosphere) was developed. The model provides values of vertical TEC (vTEC) for a given solar zenith angle, solar activity, solar longitude Ls in the two Mars hemispheres. One of the main motivations of this paper was to provide Mars ionospheric corrections for radio-science experiments. It was showed that, even if the expected noise of the radio-science instruments is large compared to the Mars ionospheric contribution, it is necessary to correct for this contribution, as its seasonal variations have the same periodicity as the geophysical parameters investigated in the experiments. It is advised to apply ionospheric corrections even during moderate solar activity level, in particular for studies based on long term data (i.e. more than 1 Mars sidereal year), such as the recent InSight RISE and future ExoMars LaRa experiments.

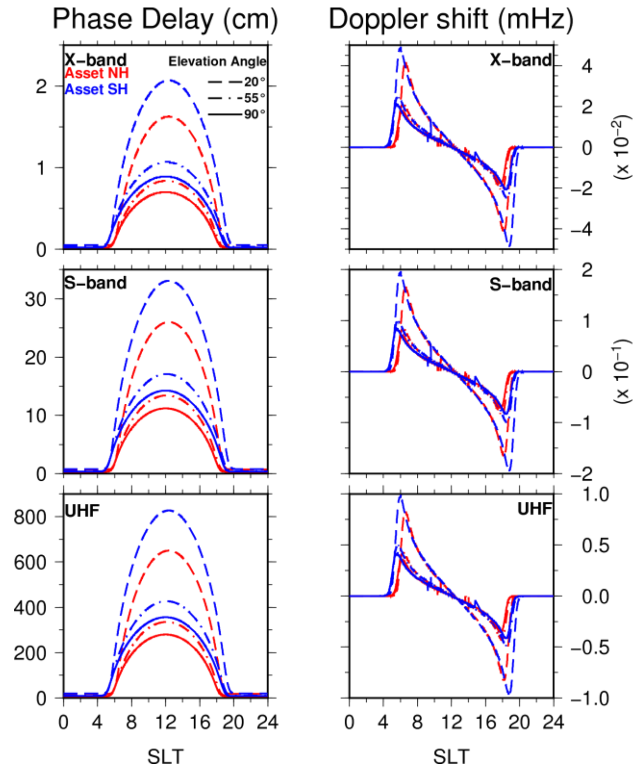


Figure 2: Effect of the Mars' ionosphere on radio wave propagation. Effect on UHF (0.4 GHz, bottom), S-band (2GHz, middle) and X-band (8GHz, top) radio signals. Left: effect on phase delay in centimeters; Right: impact on instant Doppler shift in mHz. The red curves correspond to an asset situated in the Northern Hemisphere (E0°, N10°) while the blue curves correspond to the one situated in the Southern Hemisphere (E0°, S10°). The bold, dashed-dots and dashed lines correspond to an elevation of 90°, 55° and 20° respectively. The solar activity level is fixed at as moderate.

# References


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