MODELING THE MARTIAN IONOSPHERE USING THE TOTAL ELECTRON CONTENT MEASUREMENT BY THE NEIGE/NETLANDER EXPERIMENT

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ABSTRACT

With the NEtlander Ionosphere and Geodesy Experiment (NEIGE) of the Netlander mission to Mars, the total electron content (TEC) of the Martian ionosphere will be derived from the combination of the Doppler shifts which affect radio links between the Netlanders and the orbiter. Simulations have been performed to evaluate the resulting precision of the TEC determination using a coupled kinetic, fluid and MHD ionospheric model. We show that with TEC measurements made by NEIGE, one may diagnostic the penetration into the ionosphere of an induced magnetic field and give some constraints about other parameters such as neutral atmosphere and horizontal transport.

INTRODUCTION

The Martian ionosphere remains quite unknown, especially when we compare it with the Earth and the other terrestrial planets. The only in-situ measurements come from the retarding potential analyzers on the two Viking landers [4] but other data are coming from the radio occultation and spectro UV experiments (soviet Mars mission, US Mariner, Viking and Mars Global Surveyor). The next five years will probably lead a large amount of data with the ESA Mars Express, the Japanese probe Nozomi and the Netlander mission.

Nevertheless, by assimilating these past observations with the plasma physics theory of Mars or simply by comparing them to the results of pure theoritical models, elementary knowledge of the ionosphere and its interaction with the interplanetary medium have been established. The main layer of the dayside Martian ionosphere is quite well identified but it is not the case of the topside ionosphere where many unknowns subsist such as its precise composition, its dynamics, the penetration of the induced magnetic field, and the effect of the crustal magnetic field.

One of the goals of the NEIGE experiment in the Netlander mission is to study the ionosphere of the planet by measuring the Total Electron Content (TEC). In this paper, we will describe the production of simulated data and our data processing method. We also produce some results in order to have a discussion concerning the precision of our TEC determination and its utility to constrain some parameters of the current ionospheric models as the magnetic field at the top of the ionosphere.

IONOSPHERIC PART OF NEIGE

The measurement of Doppler shifts by the NEtlander Ionosphere and Geodesy Experiment (NEIGE) of the Netlander mission to Mars fulfills two scientific objectives : the monitoring of the structure and dynamics of the ionosphere of Mars and the precise determination of Mars orientation parameters in order to obtain information on the internal structure of Mars and on the seasonal mass exchange between the atmosphere and the ice caps [1]. The total electron content (TEC) of the Martian ionosphere will be derived from the so-called "geometric-free" combination of the Doppler shifts which affect radio links in the UHF and S bands between the Netlander micro-stations on the Mars surface and the relay orbiter. The ionospheric plasma introduces a frequency-dependent phase delay which is a disturbance to be removed for geodesy purposes, but which contains useful information on the TEC and its variation. The Doppler shift in both frequency bands is expected to be measured with an accuracy of 0.1 mm/s.

Simulation

Fig. 1 presents all the modules that we have implemented in order to simulate and process Doppler data.

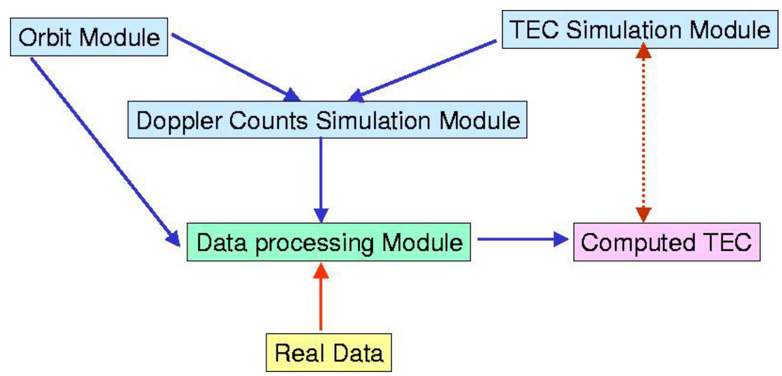

Fig. 1. Synopsis of the procedure for the ionospheric part of NEIGE

Doppler observations are simulated in order to evaluate the precision we can reach in the TEC reconstruction using our processing technique.
For this purpose, radial velocities between t_{i+1} and t_i are provided by using the following relation :

$$V_i(f) = \frac{c}{f} \frac{(\varphi_{i+1}(f) - \varphi_i(f))}{DT}$$

where φ is the beat phase between the signal emitted by the orbiter and the phase of the echo resent by the lander to the orbiter, *f* the signal frequency and DT the integration time.
At time t_i,

$$\varphi_i(f) = \varphi(f,t_i) = \frac{f}{c}\left[D(t_i) - \frac{K}{f^2 \cos\theta_i} TEC_i \right]$$

K is a constant, D, the geometric distance between the satellite and the Netlander, and θ, the angle between the vertical and the line of sight Netlander-orbiter at the ionospheric point (the intersection between the line of sight and the ionosphere when assuming that the ionosphere is concentrated in a spherical shell of infinitesimal thickness located at a mean ionospheric height) are obtained from the orbit module which is a Keplerian model.

The TEC is obtained from the TEC simulation module using the Mars ionospheric code TRANSCAR ([2] et [9]). The code provides the electron density as a function of the altitude, for different values of the Solar Zenith Angle (SZA) and of the induced magnetic field at the top of the ionosphere.
In order to remove the geometric terms and the clock errors, we construct the geometric free combination of velocity measurement, $v_{rad,f1} - v_{rad,f2}$, at two frequencies f_1 and f_2 (UHF and S bands) :

$$v_{rad,f_1} - v_{rad,f_2} = \frac{-40.3}{DT}\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)\left(\frac{TEC_{i+1}}{\cos\theta_{i+1}} - \frac{TEC_i}{\cos\theta_i}\right)$$

Using the above equation, we are able to simulate the pseudo-observation $v_{rad,f1} - v_{rad,f2}$ using our orbit and TEC simulation modules.

Processing Method

The geometry-free combination of velocity measurements at two frequencies allows to eliminate the geometric term D and the equation below is obtained :

$$\frac{TEC_{i+1}}{\cos\theta_{i+1}} - \frac{TEC_i}{\cos\theta_i} = -\frac{v_{rad,f_1} - v_{rad,f_2}}{c\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)} DT$$

Doppler measurements performed along a pass at DT intervals lead to an undetermined system of N equations with N+1 unknowns. It is possible to solve this system by giving constraints on the TEC behaviour. Using these constraints, it is possible to reconstruct the absolute TEC ([3] et [7]).

RESULTS

Fig. 2 shows both the simulated TEC and the TEC computed along a pass (SZA variations range from 10° to 21°) for two ionospheric models, with a magnetic field at the top of the ionosphere of 30 nT and 0 nT.

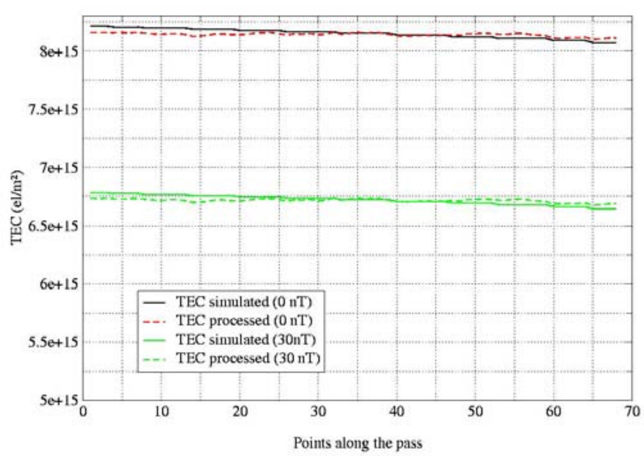

Fig. 2. Simulated and computed TEC along a pass coming from two ionospheric models, with or without a magnetic field at the top of the ionosphere.

The differences between simulated and computed TEC illustrate the precision of our TEC determination method. In a recent study [3], we have shown that the absolute TEC of the Martian atmosphere can be determined with a typical standard deviation of 5.10^{13} m^{-2} which was shown to be satisfactory for the daytime ionosphere. As expected, the differences between the simulated TEC and the computed TEC are of this order which is much smaller than the TEC difference coming from two ionospheric models with a magnetic field at 500 km of 0 nT and 30 nT respectively. Thus, the figure shows that the difference between a magnetized and a non magnetized topside ionosphere can be easily observed by the NEIGE experiment.
Recent studies include the numerical simulations of the dayside ionosphere in 2 dimensions in order to take into account the horizontal processes and the influence of other parameters as the neutral atmosphere and particle precipitations. With this complementary study, we should be able to give valuable constraints on the magnetic field value in the upper part of the ionosphere.

CONCLUSION

The NEIGE ionospheric experiment will allow to map the ionospheric TEC along the orbiter pass with a precision of 5.10^{13} m^{-2}. We have showed that our TEC reconstruction method allows to "detect" if there is a magnetic field at the top of the ionosphere. As we have also considered other parameters which can influence the TEC (neutral atmosphere, horizontal transport and particle precipitations), our results can lead valid constraints on the main parameters of the Martian ionospheric model.

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