On the Horizontal Currents over the Martian Magnetic Cusp

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Abstract

A complex magnetic topology at Mars gives rise to diverging magnetic field cusps and closed magnetic loops with local magnetic conditions similar to those found above Earth’s polar region. One of such cusps is located at 82°S and 180°E where the crustal magnetic field is nearly vertical and open to the access of solar wind plasma through magnetic reconnection with the interplanetary magnetic field. This reconnection can allow solar wind electrons to penetrate into the Martian upper atmosphere, causing ionization and heating, which leads to the collapse of the topside plasma distribution to high altitude and excite the topside electron density scale height. These characteristics of the Martian upper atmosphere at this southern location are confirmed from the Mars Express electron density profile. We use our 1-D chemical diffusion model from an altitude of 100 km to 400 km to interpret the measured electron density profile with the vertical plasma transport simulated by vertical ion velocities and by imposing an outward flow boundary condition. The output of this model and available crustal magnetic field information at Mars are used to estimate the vertical distribution of ionospheric conductivities. We find that the ionosphere is highly conductive in the Martian dynamo region between 100 and 250 km altitude where plasma-neutral collisions permit electric currents to flow perpendicular to the magnetic field. The magnitudes of Pedersen and Hall conductivities are estimated to be -0.01 – 0.075 S/m, respectively, near the Martian ionospheric peak. We also estimated the magnitude of horizontal ionospheric currents driven by ion and electron motions in the Martian dynamo region. The model results will be presented in comparison with existing estimates of the Martian conductivities and ionospheric currents. The research reported in this poster is supported by Mohammed Bin Rashid Space Centre (MBRSC), Dubai, UAE, under Grant ID number 201604.MA.AUS.

Background

➢ The ionosphere of Mars (the region of the upper atmosphere with a high concentration of plasma) exhibits compelling atmospheric dynamics. The solar wind and interplanetary magnetic field (IMF) induce electrical currents in the atmosphere. These currents generate an induced magnetosphere.

➢ The flow of atmospheric electric currents can couple the planet to the external plasma, leading to atmospheric loss.

➢ In order to study the flow of electric currents, we examine the ability of the ionosphere to allow the flow of currents – the electrical conductivity.

➢ We calculate ionospheric conductivity and currents at the southern coordinate (82°S; 180°E) where the crustal magnetic field is nearly vertical.

➢ Crustal magnetization acts like buried dipoles, inducing a strong magnetic field and an Earth-like conductivity profile.

➢ We use neutral model atmosphere at this location from [Bougher et al., 2016] and the best model fit to the Mars Express electron density profile [Dudalld et al., 2016] from Majeed et al. (Session C3.2; poster number WT-128)

Electrical Conductivity Model

➢ We use ion and neutral composition (Figure 1) to study the conductive properties of the Martian upper atmosphere.

➢ Next, we perform calculations for the gyrofrequency (Ω), the rate at which charged particles gyrate when exposed to a magnetic field and the collision frequency (ν), the rate at which ionospheric particles interact and crash into one another (Schunk and Nigg, 2009).

➢ Ionospheric and neutral densities allow for computations of the electrical conductivity in its three forms:

➢ Parallel Conductivity, across the magnetic field [Maus, 2006]:

\[ \sigma_1 = \frac{e^2}{m_i} \left( \frac{1}{n_i + n_e} \right) \]

➢ Pedersen Conductivity, perpendicular to the magnetic field, but across the electric field:

\[ \sigma_2 = \frac{e^2}{m_i} \left( \frac{1}{n_i + n_e} \right) \]

➢ Hall Conductivity, across both, the electric and magnetic fields [Maus, 2006]:

\[ \sigma_3 = \frac{e^2}{m_i} \left( \frac{V_x}{n_i + n_e} \right) \]

We also estimate horizontal ionospheric conductivities due to a uniform meridional wind (u) in the upper ionosphere of Mars following the equation:

\[ \sigma = \mu_0 (\nabla \times V) \cdot V \]

Where \( n \) is the number density, \( (\nabla \times V) \) is the magnetic field, and \( V \) is the ion and electron velocities, respectively. The magnetic field is in the equatorial plane and varies with latitude. The ion and electron velocities are from the model output.

With the assumption of magnetic field to be vertical, we calculate the ion and electron velocities in the meridional (x) and zonal (g) directions as follows (Fillingim et al., 2012):

\[ V_x = \frac{\mu_0 \sigma}{\mu_0 \sigma} \left( \frac{1}{n_i + n_e} \right) \]

\[ V_g = \frac{\mu_0 \sigma}{\mu_0 \sigma} \left( \frac{V_x}{n_i + n_e} \right) \]

Results

Figure 1: Here, we present some of the results produced by our model.

Figure 2: The calculated meridional (solid curve) and zonal (dotted curve) currents are shown for different magnetic field orientations at the northern and southern locations. The ionospheric conductivities of 0.01 and 0.075 S/m, respectively, at SZA of 82° are shown. Pedersen currents (parallel to the direction of the applied force) flow in the perpendicular direction while Hall currents (perpendicular to both the applied force and the magnetic field) flow in the same radial direction. In the dynamics region, ions collide with neutrals more frequently than they get about magnetic field lines (ξ < ν, solid lines). Electrons, with their much higher gyrofrequency, gyrate more often than they collide with neutrals (ξ > ν, dashed lines). When an external force is applied to the plasma, the collision rates move in the direction of the force. The magnetic field is strong enough to flow in the equatorward direction, in the other hand, fluid in electric perpendicular to both applied force and magnetic field. We also estimate horizontal ionospheric conductivities due to a uniform meridional wind (υ) in the upper ionosphere of Mars following the equation:

\[ \sigma = \mu_0 (\nabla \times V) \cdot V \]

Where \( n \) is the number density, \( (\nabla \times V) \) is the magnetic field, and \( V \) is the ion and electron velocities, respectively. The magnetic field is in the equatorial plane and varies with latitude. The ion and electron velocities are from the model output.

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Conclusions

➢ The ionosphere is highly conductive in the Martian dynamo region with peak Pedersen and Hall conductivities of 0.01 and 0.075 S/m, respectively, at SZA of 82° in the high southern latitude region where the crustal magnetic field is strong. These results are similar to those obtained by Oppenheim et al. [2012].

➢ A strong equatorward current of magnitude ~1 A/m² is calculated near the ionospheric peak similar to that simulated by Fillingim et al. [2012].

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