On the Horizontal Currents over the Martian Magnetic Cusp

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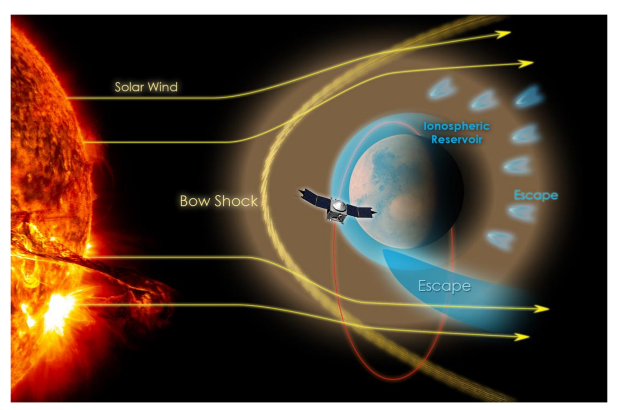
Abstract

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 82ºS and 180ºE 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 inflate the topside plasma distribution to high altitude and increase 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 diffusive 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 flux 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 perpendicular to the crustal 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 then generate an induced magnetosphere.
- The flow of atmospheric electric currents can couple the planet to 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 (82ºs; 180ºE) where the crustal magnetic field is nearly vertical.
- Crustal magnetization acts like buried dipoles, inducing a strong magnetic fields and an Earth-like conductivity profile.
- We use neutral model atmosphere at this location from *Bougher et al.* [2017] and the best model fit to the Mars Express electron density profile [*Padzold et al.*, 2016] from *Majeed et al.* [Session C3.2; poster number WT-128]

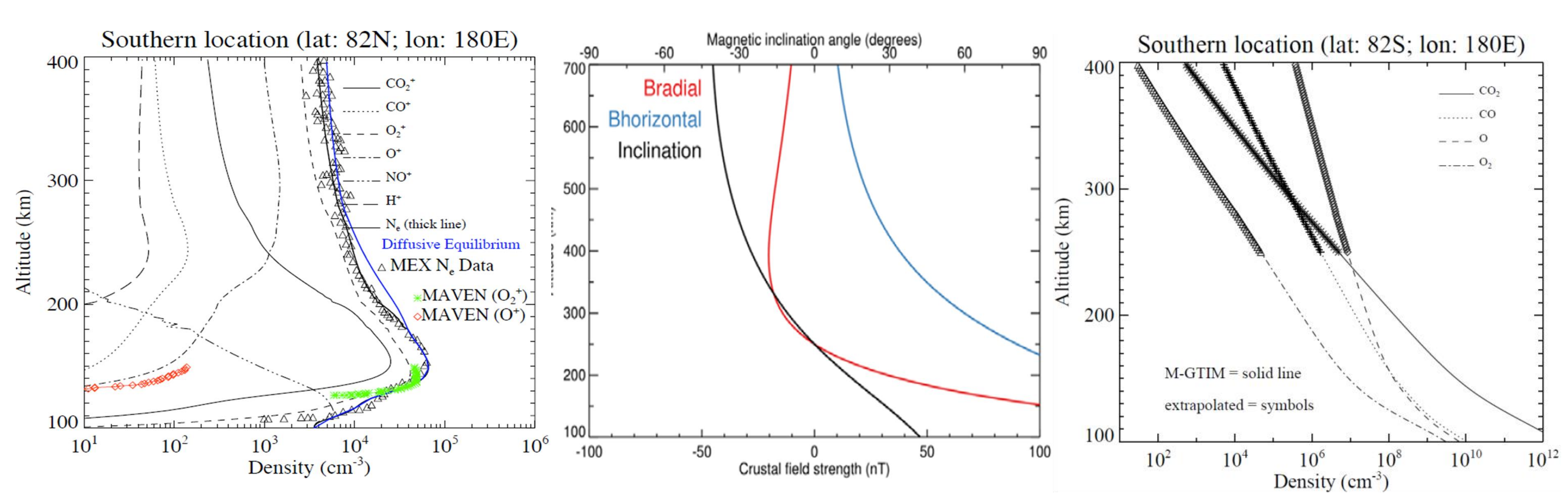


Figure 1: Model electron density fit to the Mars Express electron density profile in comparison with MGS and MAVEN/NGIMS data (left panel). Crustal magnetic field components at coordinates 80ºS and 180ºE [*Morschhauser et al.*, 2014] [middle panel). Neutral model densities from MGITM [*Bougher et al.*, 2017].

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 Nagy* [2009].
- Ionospheric and neutral densities allow for computations of the electrical conductivity in its three forms:
- Parallel Conductivity, across the magnetic field [*Maus*, 2006]:

$$\sigma_{||} = e^2 n_e \left[\frac{1}{m_i v_i} + \frac{1}{m_e v_e}\right]$$

- Pedersen Conductivity, perpendicular to the magnetic field, but across the electric [*Maus*, 2006]::

$$\sigma_P = \frac{en_e}{|\mathbf{B}|}\left[\frac{\Omega_e v_{en}}{\Omega_e^2 + ven^2} - \frac{\Omega_i v_{in}}{\Omega_i^2 + vin^2}\right]$$

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

$$\sigma_H = \frac{en_e}{|\mathbf{B}|}\left[\frac{\Omega_e}{\Omega_e^2 + ven^2} - \frac{\Omega_i}{\Omega_i^2 + vin^2}\right]$$

- We also estimate horizontal ionospheric currents due to a uniform meridional neutral wind (*u*x) in the upper ionosphere of Mars following the equation

$$\mathbf{j} = nq(\mathbf{V_i} - \mathbf{V_e})$$

Where subscripts *i* and *e* stand for ion and electron, respectively, *m* is the mass, *q* is the fundamental charge, *n* is the ion and electron density, Ω is the gyrofrequency, ν is the collision frequency. **j** is the current density, ***vi*** and ***ve*** are the ion and electron velocities, respectively. We assume that the magnetic field is pointing in the vertical direction only. This simplification makes the particle velocities and currents to enhance the physical understanding of the processes giving rise to the currents.

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

$$v_{ix} = m_i v_{in} u_x \frac{v_{in}}{m_i} \frac{1}{(\Omega_e^2 + vin^2)} = \frac{v_{in}^2}{(\Omega_i^2 + vin^2)} u_x$$

$$v_{iy} = -\frac{\Omega_i}{v_{in}^2} v_{ix}$$

$$v_{ex} = m_e v_{en} u_x \frac{v_{en}}{m_e} \frac{1}{(\Omega_e^2 + ven^2)} = \frac{v_{en}^2}{(\Omega_e^2 + ven^2)} u_x$$

$$v_{ey} = \frac{\Omega_e}{v_{en}^2} v_{ex}$$

Results

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

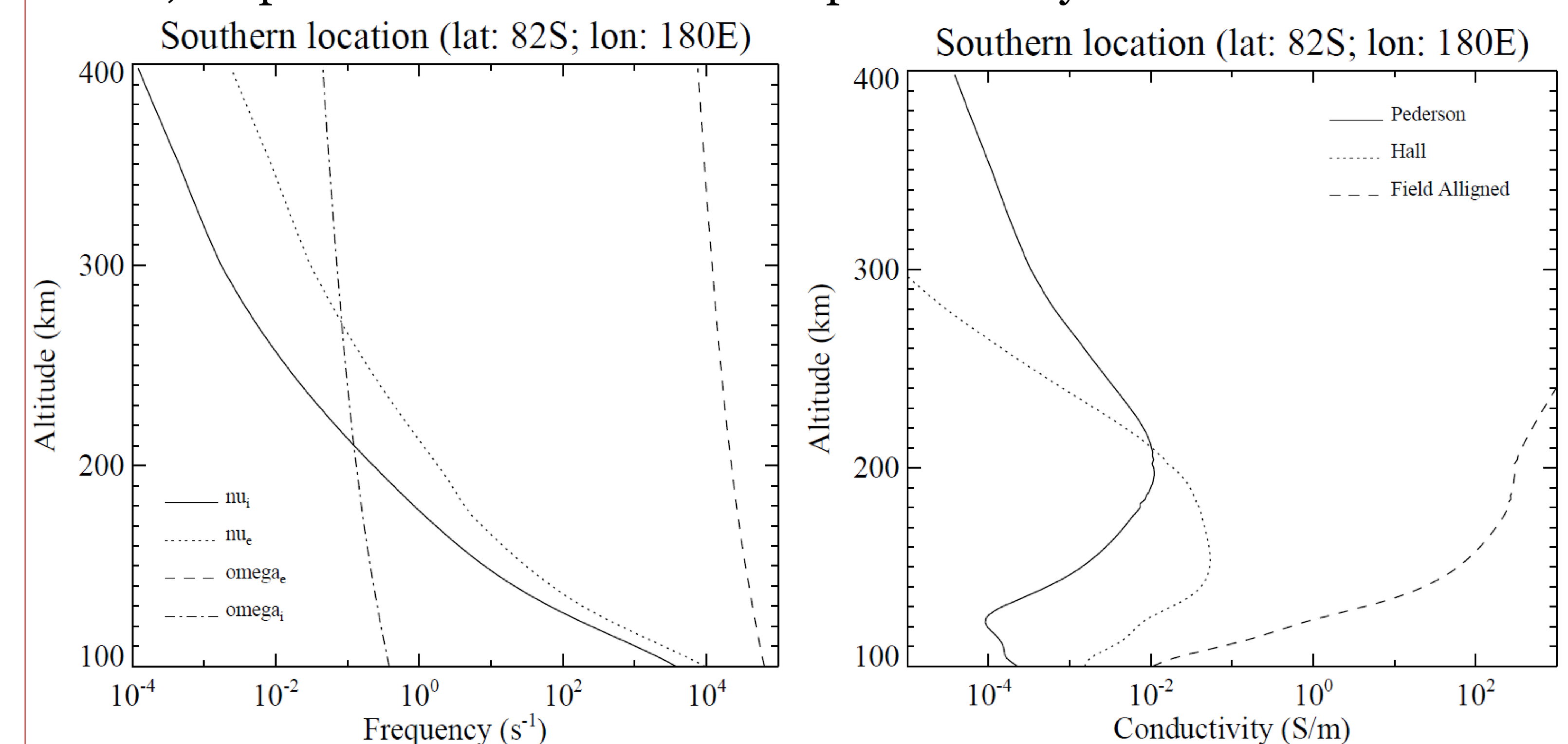


Figure 2: Left panel shows altitude profiles of collision (ν) and gyrofrequencies (Ω) at 82ºS and 180ºE using neutral atmosphere and crustal magnetic field information shown in Figure 1. The dynamo region at Mars is defined by the altitude region between the two crossing points where $\Omega_i = \nu_i$ (at ~280 km) and $\Omega_e = \nu_e$ (<100 km). The right panel shows the calculated ionospheric conductivities, Pedersen (solid curve), Hall (dotted curve), and field-aligned or parallel (dashed curve).

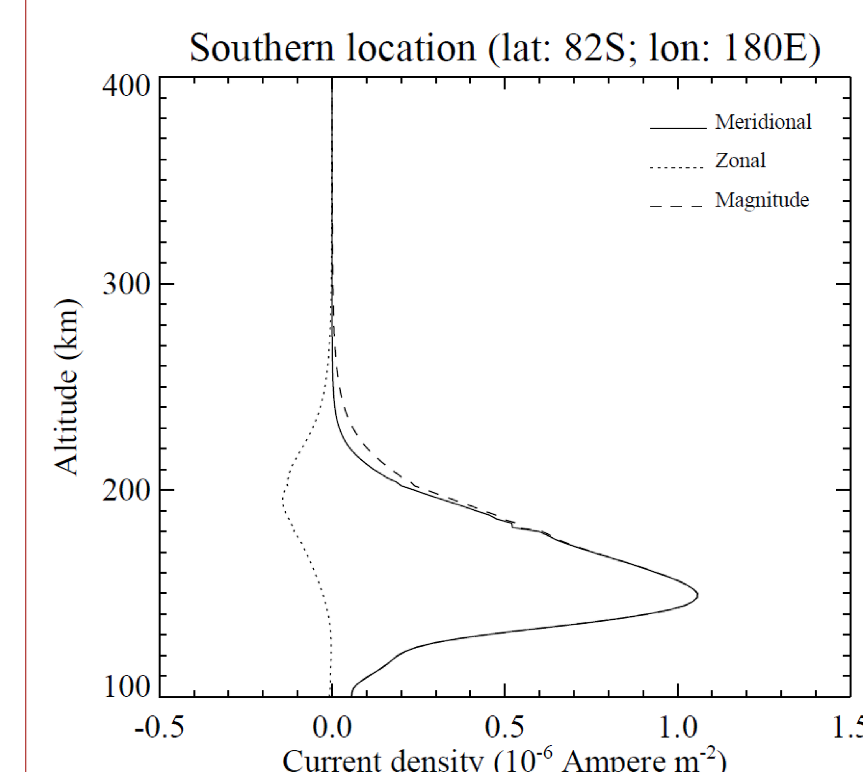


Figure 3: The calculated meridional (solid curve) and zonal (dotted curve) components of the current density due to a uniform meridional neutral wind of 100 m/s are shown. Pedersen currents (parallel to the direction of the applied force) flow in the meridional direction while Hall currents (perpendicular to both the applied force and the magnetic field) flow in the zonal direction. In the dynamo region, ions collide with neutrals more frequently than they grate about magnetic field lines ($\Omega_i << \nu_i$)while electrons, with their much higher gyrofrequency , gyrate more often than they collide with neutral ($\Omega_e >> \nu_e$). When an external force is applied to the plasma, the collisional ions move in the direction of the force. The magnetized electrons over strong crustal field, on the other hand, drift in a direction perpendicular to both the applied force and the ambient magnetic field. This differential velocity between ion and electron motion generate currents. This current is strongest at the ionospheric peak and flow equatorward (see Figure 3). A negligibly small westward current is also calculated as a result of changing magnetic field direction.

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 82º in the high southern latitude region where the crustal magnetic field is strong. These results are similar to those obtained by *Opgenoorth et al.* [2010].
- A strong equatorward current of magnitude ~1 μA/m² is calculated near the ionospheric peak similar to that simulated by *Fillingim et al*. [2012].

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