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Effect of Solar Wind Density and Velocity Variation on Martian Ionosphere and Plasma Transport

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Abstract: In this study, a 3D MHD model is established to investigate the influence of individual solar wind density and velocity to Martian ionosphere. Ion distributions of dayside and near nightside ionosphere under different N_{sw} and V_{sw} were analyzed, as well as the ion transport process. For same dynamic pressure condition, the ionosphere extends to higher altitudes under higher N_{sw}. A higher V_{sw} will result in stronger induced magnetic field, shielding Martian ionosphere, preventing the penetration of solar wind particles. For same dynamic pressure, increasing N_{sw} (decreasing V_{sw}) leads to a higher horizontal ion velocity, facilitating day-to-night plasma transport, as a result, the ion distribution in nightside ionosphere is more extended into the darkness.

Model description:

The equations used in the model is composed of Navier-Stokes equations :

$$\frac{\partial \rho_s}{\partial t} + \nabla \cdot (\rho_s \boldsymbol{u}_s) = \frac{\delta \rho_s}{\delta t}$$

$$\frac{\partial(\rho_s \boldsymbol{u}_s)}{\partial t} + \nabla \cdot (\rho_s \boldsymbol{u}_s \boldsymbol{u}_s + I p_s) = n_s q_s (\boldsymbol{u}_s - \boldsymbol{u}_+) \times \boldsymbol{B} + \frac{n_s q_s}{n_e e}(\boldsymbol{J} \times \boldsymbol{B} - \nabla p_e) + \frac{\delta M_s}{\delta t}$$

$$\frac{\partial e_s}{\partial t} + \nabla \cdot [(e_s + p_s)\boldsymbol{u}_s] = \boldsymbol{u}_s \cdot \left[\frac{n_s q_s}{n_e e}(\boldsymbol{J} \times \boldsymbol{B} - \nabla p_e) + n_s q_s (\boldsymbol{u}_s - \boldsymbol{u}_+) \times \boldsymbol{B}\right] + \frac{\delta E_s}{\delta t}$$

And the magnetic induction equation is expressed as:

$$\frac{\partial \boldsymbol{B}}{\partial t} - \nabla \times \left(\boldsymbol{u}_+ \times \boldsymbol{B} - \frac{\boldsymbol{J} \times \boldsymbol{B}}{e n_e} + \frac{\nabla p_e}{e n_e}\right) = 0$$

The solar wind conditions are set as follows:

	V_X (km/s)	n (cm^{-3})	P_{dyn} (nPa)	$\lvert B \rvert$ (nT)	T_p (K)
Case 1	566	2	1.07	3	3.5×10^5
Case 2	400	4	1.07	3	3.5×10^5
Case 3	283	8	1.07	3	3.5×10^5
Case 4	1131	2	4.28	3	3.5×10^5
Case 5	800	4	4.28	3	3.5×10^5
Case 6	566	8	4.28	3	3.5×10^5

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Dayside and near nightside ionosphere:

1. For the same P_{dyn}, the upper boundary of ionosphere extends to higher altitudes for high N_{sw} case .
2. The ionosphere on the dayside and near terminator region (SZA range $0° - 100°$) at southern hemisphere extends to higher altitudes as compared to the ionosphere at northern hemisphere.

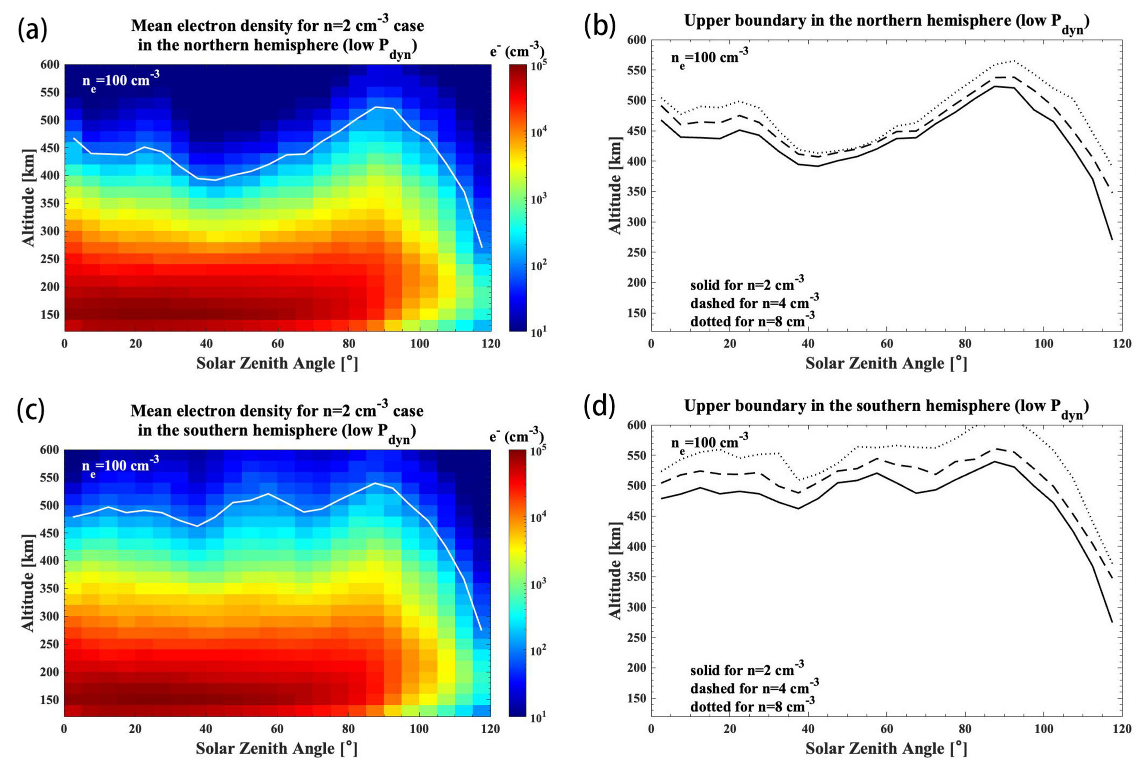

Figure 1. The mean electron density and the upper boundary profiles of Martian ionosphere for low P_{dyn} condition cases, divided into northern (panel a, b) and southern (panel c, d) hemisphere.

Nightside ionosphere:

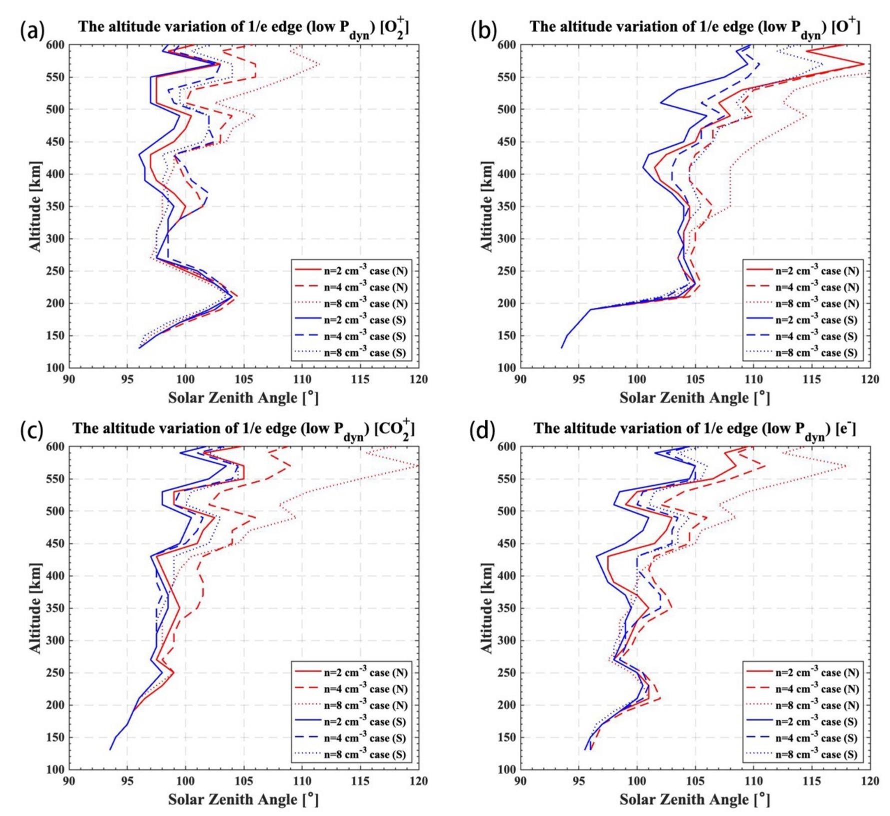

Figure 2. The 1/e edge profile of O_2^+ (panel a), O^+ (panel b), CO_2^+ (panel c) and e^- (panel d) density for low P_{dyn} condition.

1. With the increase of N_{sw} and the decrease of V_{sw}, the ion distribution on both northern and southern hemisphere extends into regions with higher SZA.
2. As compared to the southern hemisphere, the 1/e edges of northern hemisphere are more extended into nightside for all four ion species and cases.

Day to night ion transport:

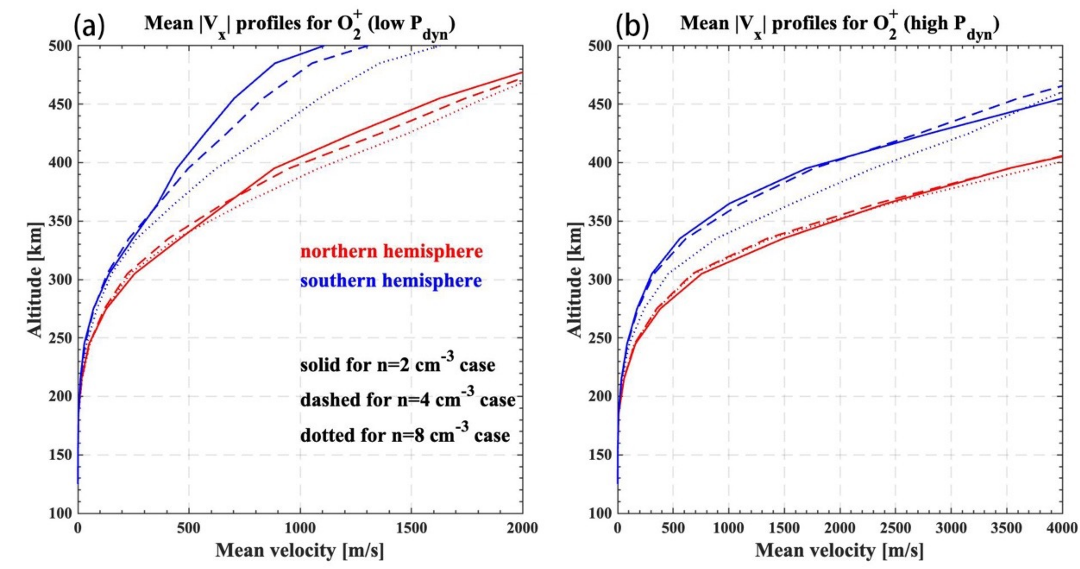

Figure 3. Mean velocity profiles along -X direction for O_2^+ with respect to altitude at XZ plane, divided into northern and southern hemisphere.

1. The magnitude of V_X is significantly larger for high N_{SW} case, indicating that higher solar wind density condition can facilitate day-to-night plasma transport.
2. the trans-terminator velocity at northern hemisphere is significantly higher as compared to southern hemisphere, showing that the suppression effect of dayside strong crustal field to plasma transport can influence the ion velocity at terminator region.

Conclusion:

1. The increase of solar wind velocity compresses Martian ionosphere more efficiently, for higher solar wind density can uplift ionosphere.
2. For same dynamic pressure, higher solar wind density leads to higher horizontal ion velocity, facilitating day-to-night transport.
3. Strong remnant field in southern hemisphere uplifts Martian ionosphere and hinders horizontal ion transport.

Reference

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