Modeling of the Sputtering Efficiency for Martian Atmosphere

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Abstract

The formation of a hot corona with the related escape rate of the oxygen atoms is an important issue affecting the evolution of the Marian atmosphere. While the dissociative recombination process appears to dominate the non-thermal escaping rate of the oxygen atoms, atmospheric sputtering by the re-impact of the pickup exospheric ions could have played a role in earlier epochs and at solar maximum in the present epoch. Due to the orientation of the interplanetary magnetic fields and the shielding of the crustal fields near Mar's surface, the pickup ions may re-impact the atmosphere with a variety of angles, energies, and spatial distributions. While night-side sputtering is suggested to occur based on modeling (L. Li et al., *JGR 116, A08204*, 2011), the sputter component due to pickup ion impacts on the oxygen corona can be distinguished from other ejection mechanisms, such as dissociative recombination. In preparation for the Maven mission, we performed a Monte Carlo model of the upper atmosphere coupled to a molecular dynamic calculation for the molecular collisions developed by F. Leblanc and R.E. Johnson (*JGR 107, 5010*, 2002) to study the cascade sputtering effects in the region of the Martian exobase. Different incident angle and energy spectrum of the impact ions were tested. Further calculations with more realistic pickup ion impact distributions will be performed based on the numerical results of a 3D Monte Carlo Pickup Ion Transport model, which includes the electromagnetic backgrounds from the 3D multi-species MHD simulations (Y. Ma et al., *JGR 109, A07211*, 2004; Y. Ma and A. F. Nagy, *GRL 34, L08201*, 2007).

1. Introduction

- The re-impact of the pick-up O^+ could have played a role in earlier epochs and at solar maximum in the present epoch (J.G. Luhmann et al., *GRL 19, 2151-2154*, 1992).
- The night-side sputtering can contribute hot corona at anti-sunward hemisphere (L. Li et al., *JGR 116, A08204*, 2011).

2. Atmospheric Sputtering Model

- A Monte Carlo model of the upper atmosphere coupled to a molecular dynamic calculation (F. Leblanc and R.E. Johnson, *JGR 107, 5010*, 2002) is used to simulate the pick-up O^+ sputtering.
- The background atmospheres are shown in Figure 1 (Ma et al., *JGR 109, A07211*, 2004).
- Different incident zenith angles and energies of O^+ are tested with the sputtering model at fixed location and flux (3.12×10^{22} s^{-1}). The escaping yields are calculated as

$$Yield = \frac{Number\ of\ Escape\ Neutrals}{Number\ of\ Incident\ Ions\ (Glancing\ Ions\ included)}$$

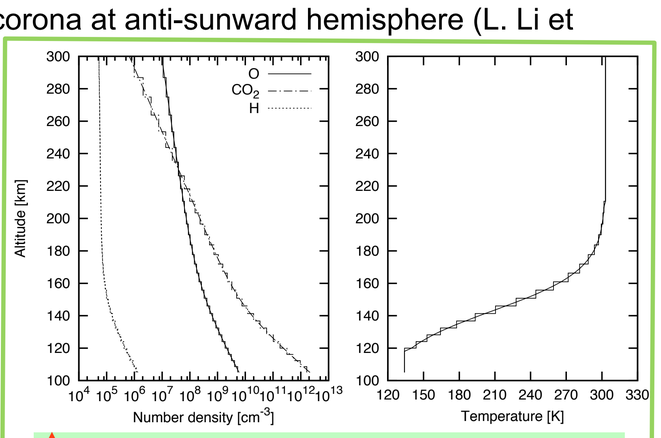


Figure 1. Uniform background atmospheric number densities and temperature distributions (Ma et al., 2004) used in the sputtering model.

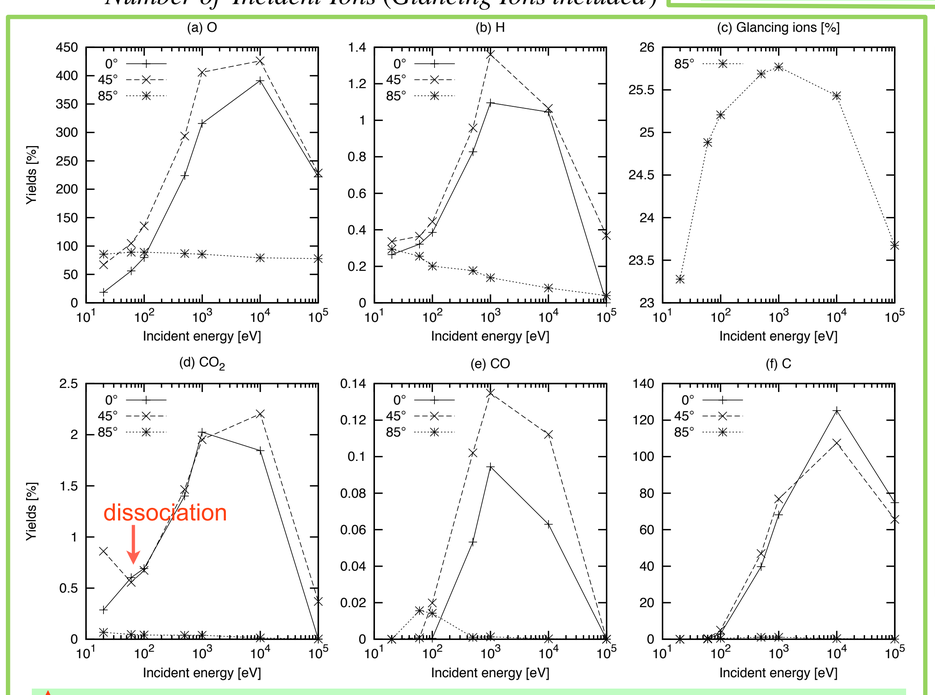


Figure 2. Escaping yields for different incident ion zenith angles and energies.

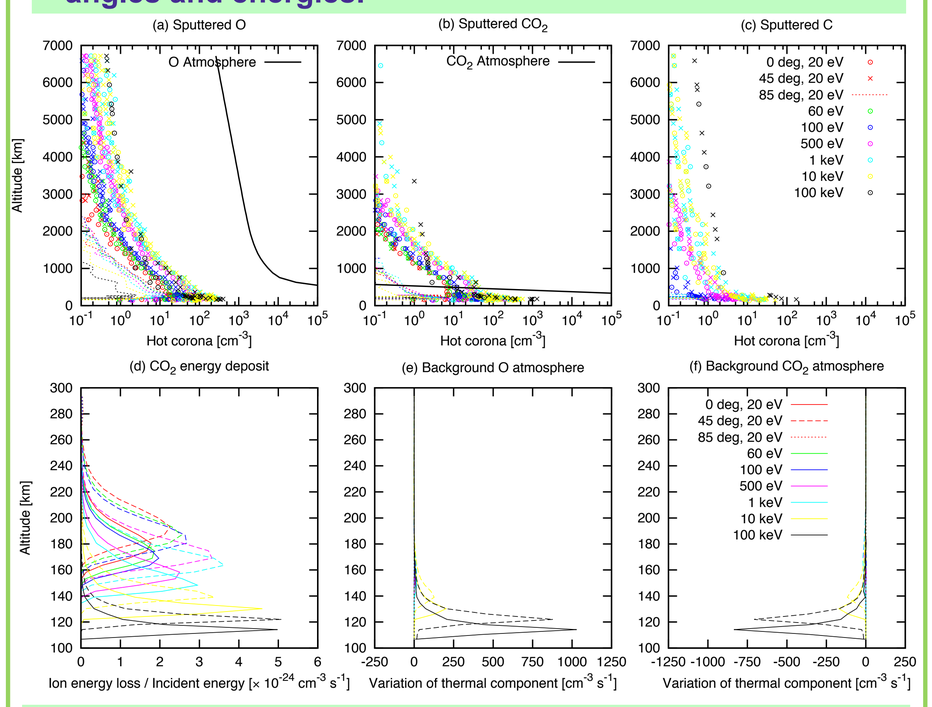


Figure 3. (a)-(c) The sputtered hot corona, (d) ion energy deposit, and (e)-(f) number density variation of the thermal atmospheres for different incident zenith angles and energies.

3. Responses to realistic O^+ sputtering

- The electromagnetic fields for three different solar activities are simulated with MHD model (Y. Ma et al., *JGR 109, A07211*, 2004; Y. Ma and A. F. Nagy, *GRL 34, L08201*, 2007). The resultant pick-up O+ recycling is calculated with Monte Carlo method based on the MHD results (Table 1).

Solar activities	n_{sw}	V_{sw}	IMF
Nominal Quiet	4 cm^{-3}	400 km/s	3 nT (56° in XY-plane)
Nominal Active	4 cm^{-3}	1200 km/s	3 nT (y-component)
Extreme	20 cm^{-3}	1000 km/s	20 nT (y-component)

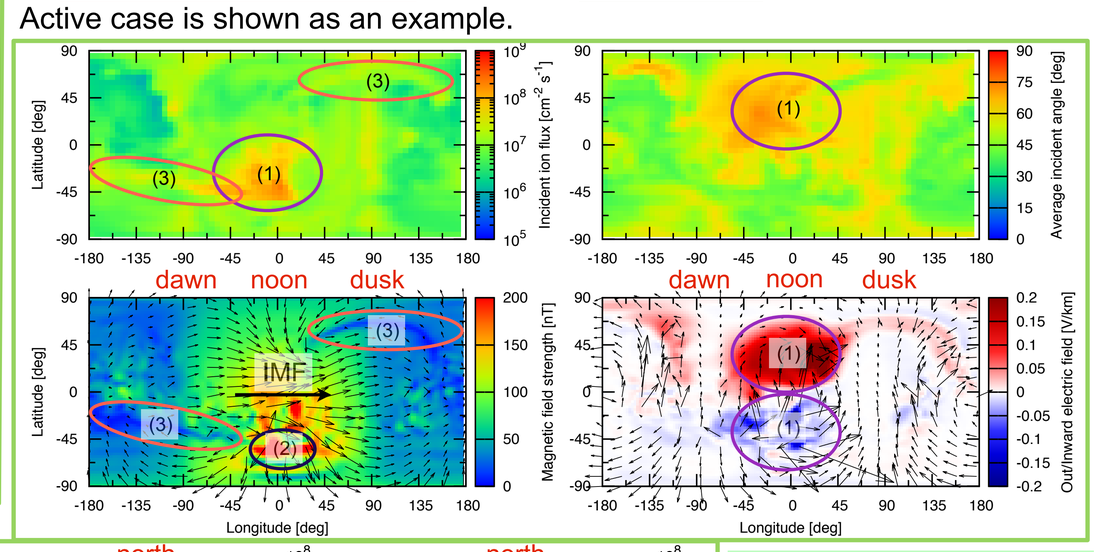
Table 1. Three solar activity parameters.

- **Pick-up O^+ impact flux**

There are four major factors which will influence the incident flux, zenith angles and energies.

(1) Electric field acceleration/reflection (2) Crustal magnetic field shielding
(3) Low magnetic field region (4) Tail recycling

Active case is shown as an example.



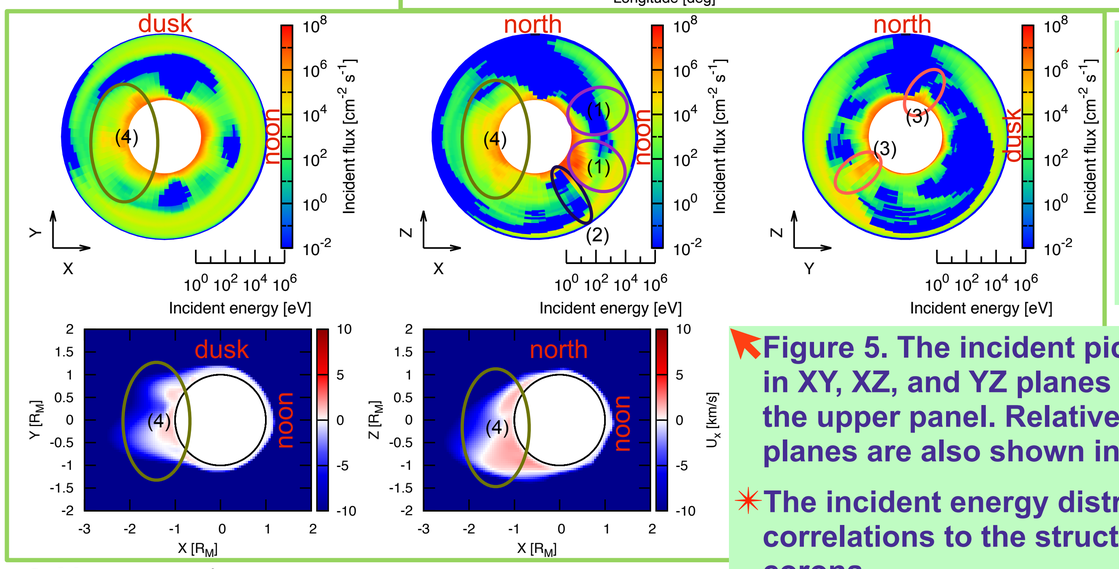


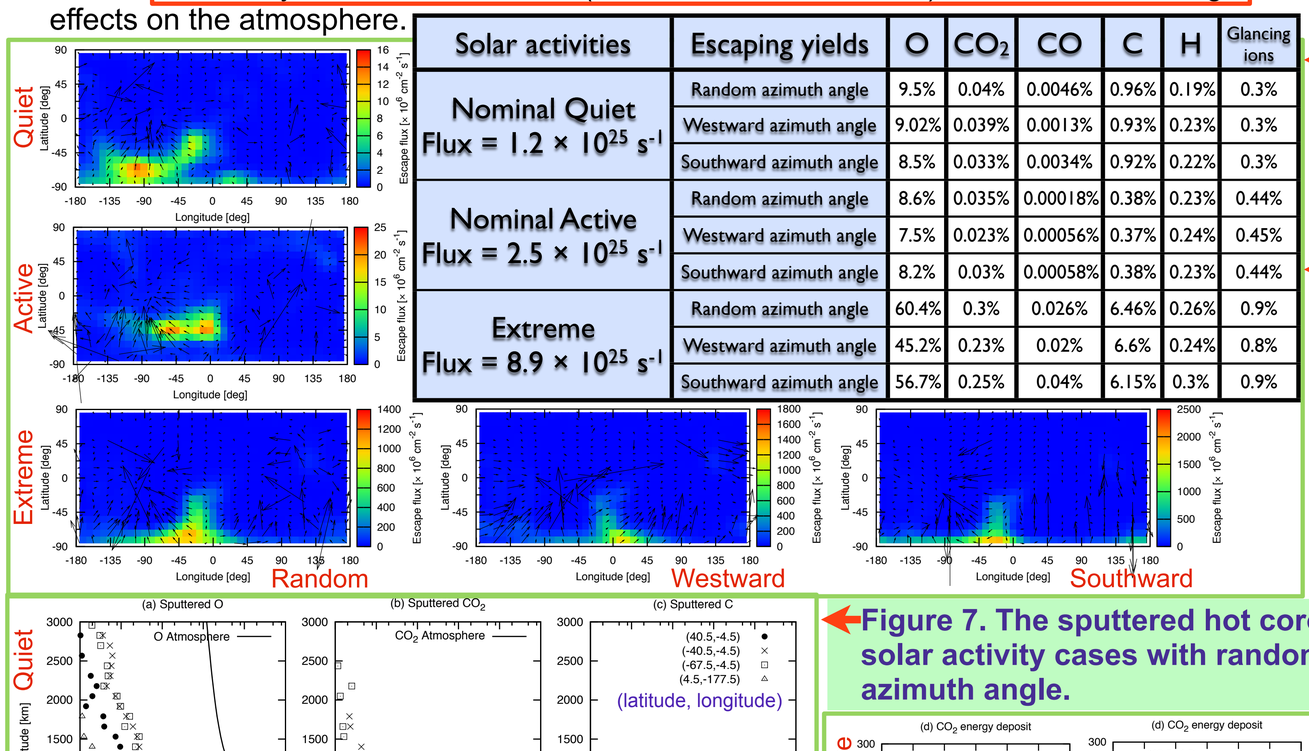
Figure 4. The incident pick-up O^+ flux and averaged zenith angle distribution for active case are compared with the magnetic and electric field at altitude = 300 km.

Figure 5. The incident pick-up O^+ energy distribution in XY, XZ, and YZ planes for active case are show in the upper panel. Relative plasma flow in XY and XZ planes are also shown in the lower panel.

The incident energy distribution will have direct correlations to the structure of the sputtered hot corona.

- **Atmospheric responses**

The sputtering yields, hot corona distribution, and influences to the background atmosphere are shown as follows. Randomly distributed and fixed (westward and southward) incident azimuth angle are tested to see their effects on the atmosphere.



Solar activities	Escaping yields	O	CO_2	CO	C	H	Glancing ions
Nominal Quiet Flux = 1.2×10^{25} s^{-1}	Random azimuth angle	9.5%	0.04%	0.0046%	0.96%	0.19%	0.3%
	Westward azimuth angle	9.02%	0.039%	0.0013%	0.93%	0.23%	0.3%
	Southward azimuth angle	8.5%	0.033%	0.0034%	0.92%	0.22%	0.3%
Nominal Active Flux = 2.5×10^{25} s^{-1}	Random azimuth angle	8.6%	0.035%	0.00018%	0.38%	0.23%	0.44%
	Westward azimuth angle	7.5%	0.023%	0.00056%	0.37%	0.24%	0.45%
	Southward azimuth angle	8.2%	0.03%	0.00058%	0.38%	0.23%	0.44%
Extreme Flux = 8.9×10^{25} s^{-1}	Random azimuth angle	60.4%	0.3%	0.026%	6.46%	0.26%	0.9%
	Westward azimuth angle	45.2%	0.23%	0.02%	6.6%	0.24%	0.8%
	Southward azimuth angle	56.7%	0.25%	0.04%	6.15%	0.3%	0.9%

Table 2. Sputtering yields for different cases.

Figure 6. Escape flux distributions for different solar activity cases and incident azimuth angle distributions.

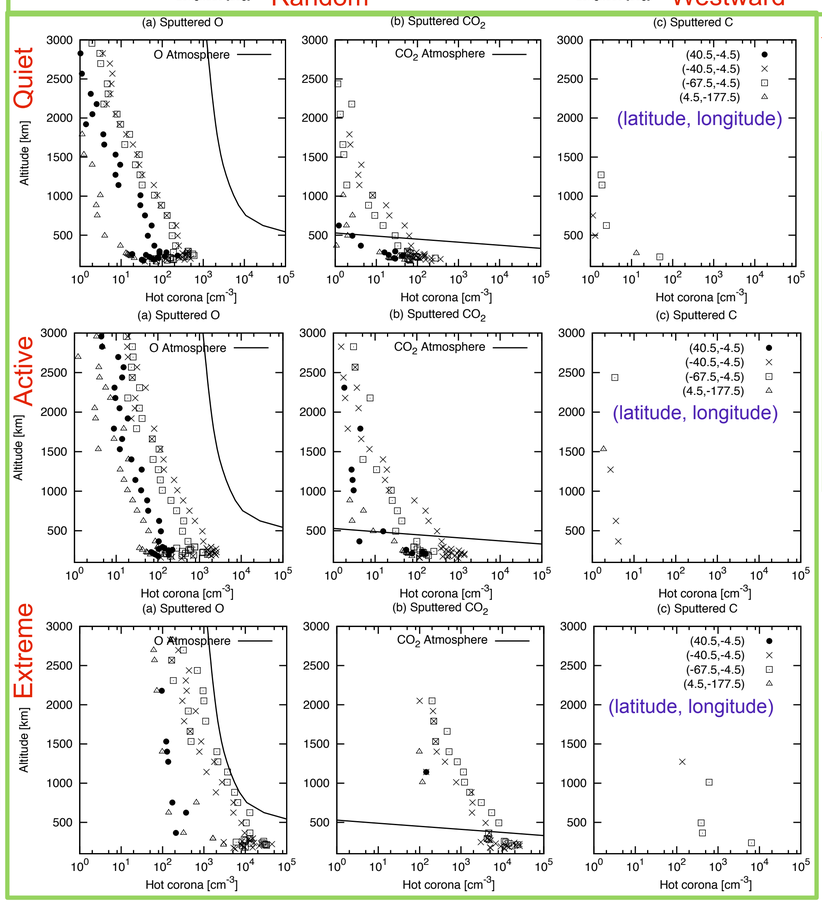


Figure 7. The sputtered hot corona for different solar activity cases with randomly distributed azimuth angle.

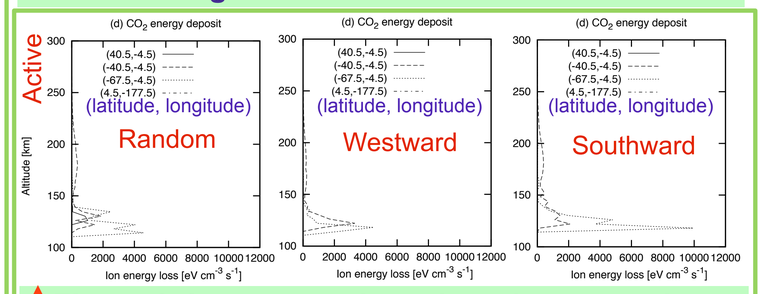


Figure 8. Ion energy deposit to the atmosphere for active case.

- Although the sputtered O component might be small compared to other sources, the sputtered CO_2 might be detectable as hot corona.
- For extreme solar activity case, the number density of sputtered O increased to the order of 10^3-10^4 cm^{-3}, which might be comparable to other sources. In addition, the dissociated C can be prominent.
- Although the azimuth angle distribution of the pick-up O^+ sputtering may have little effects on the hot corona distribution, the influence on the background upper atmosphere will be significant.

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