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Precipitation of energetic neutral atoms on the Martian upper atmosphere: hybrid simulation

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Abstract

We explore the precipitation of energetic neutral atoms (ENAs) on the Martian upper atmosphere using a hybrid plasma model and a spherically symmetric exosphere model. ENAs are generated via charge-exchange reaction between the ions in the Martian plasma environment and the neutrals in the exosphere. ENAs do not feel the electromagnetic field, and their birth places are collisionless. Therefore ENAs moving towards the planet can precipitate to the exobase. We study the spatial distribution and spectral characteristics of these precipitating ENAs, and investigate the consequences caused to the upper atmosphere of Mars.

1. Introduction

Martian space environment is an active ENA source. Most of the ENAs are generated in the dayside hemisphere of Mars, via the charge exchange reaction between the solar wind protons (both upstream and shocked) with the highly extended Martian exosphere. These ENAs are not affected by the electromagnetic field in the interplanetary space, in the magnetosheath, or in the induced magnetosphere. In these regions, the particle mean free path is comparable to the altitude to the exobase, therefore ENAs can directly reach the exobase and precipitate to the upper atmosphere. The ENA precipitation can cause several consequences: 1) it is a source of hydrogen in the Martian atmosphere, 2) it transfer momentum from the super- and sub-sonic solar wind to the Martian atmosphere, and 3) it is an extra heating source for the Martian upper atmosphere.

In this work we focus on the spatial and energy distribution of ENAs that precipitate to the exobase, using a well-established hybrid plasma model and a well-received exosphere model.

2. Models

We use the HYB_MARS hybrid model [5] to get a self-consistent description of the fields and particles in the solar wind interaction with Mars. The model treats ions as particles and electrons as massless neutralizing fluid, and includes the electron pressure term, a fluid background ionosphere, and charge exchange processes. The latter allows for tracking of ENAs. The model was launched with the nominal solar wind parameters at Mars. The coordinate system is set such that the interplanetary magnetic field is in the xy plane, and the convective electric field (Ec) is in the xz plane, x being the vector from the center of Mars to the Sun.

The exosphere model was adopted from a community-wide model challenge project [1]. It includes both cold and hot components for hydrogen and oxygen exospheres, respectively. In the production of ENAs, the hydrogen exosphere is dominant due to its large scale height and the relatively large resonant charge exchange cross section with protons. The model is spherically symmetric, for the nightside of Mars is not within the scope of this study.

3. ENA precipitation map

We collect the birthplaces and velocity vectors for all ENAs produced in the model. Then we only select those penetrating the exobase, a spherical surface at 200 km altitude above the surface of Mars. We calculate the penetration position of each ENA particle on the exobase, expressed in longitude and latitude in the Mars-centered spherical coordinate system. The resultant precipitation map is achieved by binning the precipitating ENAs according to the penetration location into 6°×6° grid. **Figure 1** is such a map for the ENAs generated in the dayside magnetosheath. We will also plot a similar precipitation map for the ENAs generated upstream of the bow shock.

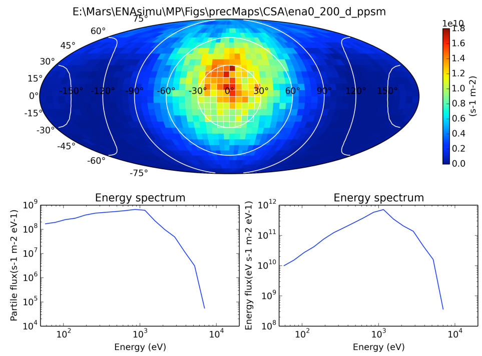

Figure 1: (Top) Particle precipitation map on the exobase of ENAs produced in the magnetosheath. Black numbers are the longitude (horizontally distributed in the middle) and latitude (on the left of the map). White curves are the iso-SZA (solar zenith angle) lines on the exobase. (Bottom) Energy spectrum of (left) precipitating ENAs and (right) precipitating energy within the SZA<30° region (white gridded region in the top panel).

Following aspects will be explored:

1. The role of magnetosheath ENAs. In previous models [3, 4], the ENAs from upstream solar wind is dominant. This is because the plasma model used in these studies did not account for the spread of proton velocity direction in the subsolar point, which was important for the production of ENAs in the magnetosheath. In our model the precipitating flux and energy due to magnetosheath ENAs are comparable to that of the upstream ENAs. Moreover, as shown in **Figure 1**, the precipitation pattern of magnetosheath ENAs is deviated to the +Ec direction

2. The variability of energy deposition rate due to the variability of the hydrogen exosphere. The exobase temperature for atomic hydrogen is the most important controlling factor of the ENA production rate [3]. The exobase temperature affects the scale height and eventually the column density of the hydrogen, and it is highly variable [2]. Particularly, a ~50% difference in the Sun-Mars distance can cause a factor of ~8 difference in the exospheric density of hydrogen. Therefore one may expect that ENA precipitation during the perihelion period would be of more importance compared to the total energy deposition due to solar EUV radiation, which scales with the square of Sun-Mars distance.

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