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Statistical properties of planetary heavy ion precipitations toward the Martian ionosphere based on Mars Express observations

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Abstract

Picked-up ion precipitations are a potential mechanism to increase an atmospheric escape from the unmagnetized planet of Mars. The interplanetary magnetic field (IMF) embedded in the supersonic solar wind is one of the crucial parameters to control the behavior of the Martian planetary heavy ions. We statistically investigated the effects of the IMF orientation on planetary heavy ions precipitating toward the Martian ionosphere by using data obtained from the Ion Mass Analyzer (IMA) onboard the Mars Express (MEX). To compensate for the absence of a magnetometer onboard MEX, we estimated the IMF orientation from the velocity distribution function of exospheric protons observed in the solar wind. The statistical analysis shows that the precipitations of planetary heavy ions tend to be observed in the direction or the anti-parallel direction of the solar wind electric field inferred from the estimated IMF orientation. We defined the IMF polarity for one event via comparisons of the ion velocity distribution function obtained from MEX/IMA observations and a statistical trajectory tracing of test particles. The estimated polarity corresponds to the anti-parallel direction to the solar wind electric field and is consistent with the asymmetrical distribution of planetary heavy ion precipitation in terms of the solar wind electric field derived from the previous numerical simulations. The observed precipitating planetary heavy ions are accelerated only up to a few keV. This feature may reflect the short distance from the picked-up region in the magnetosheath.

1. Introduction

Mars does not possess a global intrinsic magnetic field except for the localized crustal magnetic fields mainly located in the southern hemisphere [1]. The supersonic solar wind can thus directly interact with the Martian upper atmosphere and ionosphere. As a result, atmospheric escape phenomena induced by the solar wind have been observed by several spacecraft missions (Phobos-2 and MEX) [6, 2]. Previous spacecraft measurements indicate that the ion escape rate is highly variable depending on the solar activity and the solar wind conditions [2].

One key parameter relevant for understanding atmospheric escape is the convective electric field. Picked-up planetary heavy ions are asymmetrically distributed with respect to the convective electric field [2]. In addition, a part of picked-up ions precipitates onto the Martian upper atmosphere. It should contribute to the atmospheric escape via sputtering process of the neutral atmosphere [5]. Precipitating ions is also asymmetric with respect to the convective electric field in the solar wind [3, 5]. Recent MEX/IMA observations reveal that the precipitation of planetary heavy ions during passages of the compressed IMF region in front of corotating interaction regions [4]. However, the lack of magnetic field observations prevents a direct assessment of the effects of the solar wind electric field direction based on MEX measurements.

In this study, we estimated the IMF orientation from the velocity distribution function of picked-up protons (ring ions) owing to compensate for the lack of magnetic field observations by MEX. We statistically investigated the effects of the IMF orientation on planetary heavy ion precipitations toward the Martian ionosphere based on MEX/IMA observations.

2. Statistical Analysis

We surveyed the MEX/IMA data acquired between July, 2007 and September, 2009. The time interval is approximately 1 Martian year. To ensure to select the events, we excluded low quality data using the criteria of minimal UV interference (low background) and no obvious interference from other instruments (e.g., MARSIS) onboard MEX. We then selected planetary heavy ion precipitation events when the precipitating flux integrated over > 100 eV is larger than 10^5 cm^{-2} s^{-1} so as to ensure to identify clear precipitation events. We could thus identify 59 precipitating planetary heavy ion events.

Precipitating planetary heavy ions are observed both northern and southern hemispheres. Although a part of the events are observed in the vicinity of the crustal magnetic field, precipitating heavy ion precipitation events are not frequently observed in the southern hemisphere, where the crustal magnetic fields are primarily concentrated. Planetary heavy ion precipitations are more frequently observed in the low solar zenith angle (SZA) region rather than in the high SZA region. In addition, those events are mostly observed in the region where the modelled crustal magnetic field magnitude is small (< 25 nT at 400 km) in all SZA.

Among the 59 precipitation events, we then selected the events in which the ring ion population to estimate the IMF orientation is observed within the same MEX orbit. We can thus estimate the IMF orientation for 10 events. MEX observation indicates that planetary heavy ion precipitation events are more frequently observed around the solar wind electric field inferred from the estimated IMF orientations.

3. Discussions and Summary

The statistical analysis shows that the precipitations of planetary heavy ions tend to be observed along the parallel or the anti-parallel direction of the solar wind electric field. The tendency is consistent with the results of previous simulation studies [3, 5], in which the ion precipitations tend to be concentrated in the anti-electric field hemisphere rather than in the IMF orientation.

We could determine the IMF polarity for one event via comparison of the ion velocity distribution functions obtained from the MEX/IMA observation and a statistical trajectory tracing of test particles. The result suggests that the planetary heavy ion precipitation was observed along the anti-parallel direction to the solar wind electric field and it further supports the numerical simulation results [3, 5]. The planetary heavy ion precipitation events onto the Martian upper atmosphere are distributed rather randomly and appear to be independent of the location of the crustal magnetic field.

The energy of planetary heavy ion precipitations provides a clue of their origin. The observed energy of the precipitating planetary heavy ions is rather low (up to a few keV), compared to the energy of picked-up O^+ ions accelerated up to the typical solar wind velocity. The picked-up planetary heavy ions beyond the Martian bow shock should be precipitating with energies of up to several tens of keV, corresponding to the maximum energy of the picked-up ions. This therefore indicates that the observed precipitating planetary heavy ions should be picked up from a region not too far from the observation point to be accelerated only up to a few keV by the solar wind electric field. These results might indicate that precipitating planetary heavy ions have been picked up in the magnetosheath rather than in the upstream solar wind outside the bow shock.

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