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First Global Model of Meteoric Magnesium in the Martian Atmosphere

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Abstract

Meteoric ablation produces a layer of Mg^+ ions peaking around 90 km in the Martian atmosphere. The layer was recently recorded by NASA's MAVEN spacecraft, the first time that a meteoric metal layer has been observed directly in another planetary atmosphere. These metals are very useful tracers of chemistry and dynamics, as well as being significant components of the lower ionospheric plasma and forming nuclei for the condensation of mesospheric ice clouds. A module of Mg neutral and ion-molecules reactions, which have mostly been studied in the laboratory, were included in the Laboratoire de Météorologie Dynamique (LMD) Mars global circulation model to investigate the global Mg^+ and Mg layers. A simulation over a full Martian year reveals very surprising differences with the Mg^+/Mg layers in the terrestrial atmosphere, on diurnal, seasonal and latitudinal scales.

1. Introduction

The ablation of cosmic dust in planetary atmospheres produces a continuous injection of metallic vapours such as Mg, Fe and Na [1]. Although the metallic atoms and ions have been observed for four decades in the terrestrial atmosphere [8], it was only recently that meteoric metals have been observed directly in another planetary atmosphere. The Imaging Ultraviolet Spectrograph (IUVS) on NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) mission has observed the dayglow emission at 280 nm from Mg^+ ions. These ions occur as a layer in the Martian atmosphere between 70 and 130 km, peaking around 90 km with a peak density of ~350-400 cm^{-3} [2]. One surprising result is that a neutral Mg atom layer has not been detected by IUVS, despite a very good instrumental detection limit [2], in contrast to earlier model predictions [9]. We have recently used a 1-D model to show that the absence of Mg can be explained by the dissociative recombination of CO_2-clustered MgO^+ ions with electrons to form $MgCO_3$ directly, rather than Mg [7]. Figure 1 shows that satisfactory agreement with Mg^+ observations around midday at low latitudes was achieved. Furthermore, the Mg layer is just below the IUVS detection limit at 90 km. $MgCO_3$ has a very large electric dipole moment (11.6 Debye), and thus form clusters with up to 6 H_2O molecules at temperatures below 150 K. These clusters should then coagulate efficiently to form metal carbonate-rich ice particles which can act as nucleating particles for CO_2-ice clouds [7].

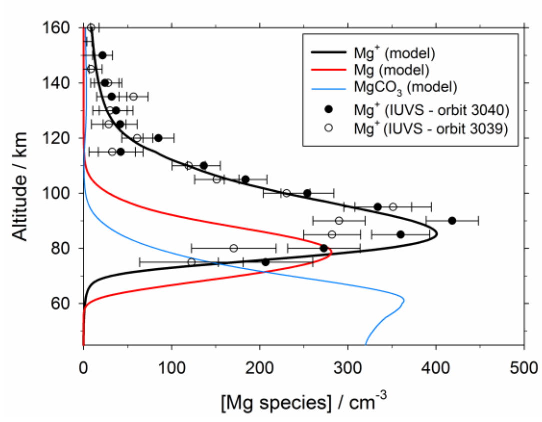

Figure 1: Vertical profiles of Mg^+, Mg and $MgCO_3$ predicted by the 1D model for local noon at the equator, L_s = 85°. The symbols show Mg^+ measurements by the IUVS instrument during two successive orbits (reproduced from ref. [7]).

MAVEN's Neutral Gas Ion Mass Spectrometer (NGIMS) has measured a range of ions, including Mg^+, Fe^+ and Na^+ during deep dip orbits, which extend periapse down to 130 km [4]. These measurements have revealed several surprises: ions of very different masses have the same scale heights above the homopause (i.e. there is limited gravitational separation), and often have the same scale height as the neutral atmosphere (i.e. ambipolar diffusion does not seem to dominate transport) [4].

2. The LMD-Mg model for Mars

The LMD Mars general circulation model extends from the surface to the exosphere, and has been developed for the self-consistent study of coupling between all layers of the atmosphere [3]. The version of the model used here includes an extension of the chemistry module to include nitrogen chemistry and ion-molecule chemistry relevant to the ionosphere, as well as improved treatments of the day-to-day variability of the UV solar flux and 15 μm CO_2 cooling under non-local thermodynamic equilibrium conditions [3].

A set of 22 Mg neutral and ion-molecule reactions, validated through the satisfactory fit to IUVS observations shown in Figure 1, were then added to the chemical model. The Meteoric Input Function (MIF) for Mg was calculated from the absolute fluxes of cosmic dust particles entering the Martian atmosphere from short-period Jupiter Family Comets, Long Period Comets and Asteroids [1]. The size and velocity distributions of dust from each source were determined from an astronomical model [6], and the height-dependent Mg ablation rate from individual particles was calculated using the Leeds Chemical Ablation Model (CABMOD) [1]. The total dust input rate is estimated to be 3.6 t sol^{-1}.

3. Results and Discussion

The LMD-Mg model has been run for a full Martian year. It should be noted that the Mg^+ and Mg layers in the terrestrial atmosphere have been observed near-globally between 70 and 140 km by the SCIAMACHY instrument onboard the Envisat satellite, and satisfactorily modelled using the Whole Atmosphere Community Climate (WACCM) model [5]. The terrestrial situation provides a useful contrast with Mars. Dynamics clearly controls the Martian Mg/Mg^+ layers much more strongly than in the Earth's atmosphere, producing quite unexpected diurnal, seasonal and latitudinal variations. These will be compared to IUVS observations.

Acknowledgements

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