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Three dimensional exosphere model : multispecies thermal and non-thermal model

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Abstract

3-D Mars' exosphere models of four seasons are developed in this study. Thermal exosphere of oxygen, CO_2, and CO is derived from 3-D Chamberlain model based on the Martian Global Circulation Model (GCM). Non-thermal atomic oxygen exosphere is obtained by 3-D Monte-Carlo simulation. Production of hot oxygen is due to Dissociative Recombination (DR) of O_2^+, and sputtering is neglected in this study. The profiles of O_2^+ and background atmosphere are also given by MGCM model. Thermal components of exosphere show the strong asymmetry of dayside-nightside, and complicated structures, which depend largely on the seasons. On the other hand, non-thermal profiles depend only on the solar zenith angle(SZA) though there are also strong asymmetry between day and nightside. From the comparison between thermal and non-thermal oxygen, the thermal oxygen is the main component below ~700km.

1. Introduction

The aim of this study is to describe the atmospheric evolution of Mars. Mars' atmospheric escape is thought to be one of the channel that constrains the past evolution of Mars' atmosphere. Thermal escape is essentially important for light species such as hydrogen. Non-thermal escape is the main channel for heavy species and is produced by ion sputtering, or photo-chemical processes. In this study, we developed exosphere model of the thermal component of O, CO_2, and CO by coupling Mars GCM model with exospheric model, that is, modified 3D Chamberlain model with rotation [Kim and Son, 2000]. We discuss the altitude profiles with respect to local time, seasonal variations, and composition. We also compare these results with a simplified modeling of non-thermal oxygen component to highlight where thermal and non-thermal components can be distinguished.

2. Simulation Model

3D Chamberlain approach is used to develop the thermal exosphere. Although the altitude of the exobase depends on the season and local time, we fixed it at 200km for simplicity. We discuss thermal O, CO_2 and CO species for four equinox of Ls=0-30, 90-120, 180-210, 270-300 where Ls indicate the solar longitude. The density and temperature conditions of exobase are given by LMD Martian GCM[Gonzalez-Galindo et al., 2009].

3. Results

Throughout the seasons, strong asymmetry between dayside and nightside can be found on all species. The structure of the profiles is complex, and is largely dependent on the seasons. For oxygen, the structure of the density at low altitude reflects the density profiles at exobase, At higher altitude, the exobase temperature shapes the density structure. For CO_2, at 300km in altitude, the densty profiles display stronger asymmetry than the oxygen between dayside and nightside. In all seasons, dayside density is 10^5~10^6 cm^{-3} while the average density is less than 10 cm^{-3} at nightside. The structure of the profiles at 300km is strongly affected by both density and temperature profiles at exobase. For altitude above 500km, the average CO_2 density on the dayside is less than 10 cm^{-3} whereas the oxygen density is ~10^5 cm^{-3}. At the exobase, the densities of O, CO_2, and CO are almost of the same order of magnitude whereas CO_2 and CO densities decrease much faster than the O because of their small scale height.

For comparison, we also examined the non-thermal oxygen using a Monte-Carlo simulation [Leblanc and Johnson, 2001] in which the atmospheric background is deduced from the MGCM, as in our calculation of the thermal exosphere. We calculate only dissociative recombination(DR) of O_2^+, since sputtering is negligible at low solar activity [Chaufray et al., 2007] . The characteristics of the density at a given altitude are simpler than the density of the thermal component. Indeed, DR depends only on the solar zenith angle. The dayside density remains over 1000cm^{-3} at 1000km on the dayside, while it is almost negligible at 300km compared to the thermal oxygen. Ratio between thermal and non-thermal oxygen densities shows that the thermal component is dominant below 600km.

4. Conclusion

3-D Mars' exosphere models at solar minimum condition are developed in this study. 3-D Chamberlain approach is used to calculate the thermal exosphere model of O, CO_2, and CO. The LMD Martian Global Circulation Model (MGCM) is used to estimate the exobase conditions. We examined four seasons of Ls=0-30, Ls=90-120, Ls=180-210, and Ls=270-300. Below 500km, the oxygen density profiles are strongly influenced by the density profiles at exobase. Above 500km, it is the exobase temperature which constrains the exospheric oxygen density. We also compared the thermal and non-thermal oxygen components in the exosphere. The scale height of the non-thermal component is extremely large, and the number density at 300km is almost negligible compared to the thermal component. The altitude where the ratio of the thermal to the non-thermal densities is equal to one is between 600km to 800km.

Acknowledgements

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