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Hybrid simulation of the Solar wind interaction with the Martian ionosphere and magnetic field

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Abstract

In the frame of the HELIOSARES project (PI F. Leblanc) dedicated to the modeling of Mars environment (neutral and charged species) from the lower atmosphere to the solar wind, a modeling effort has been conducted to parallelize a multi-species hybrid simulation code. This code now provides a kinetic description of the ions with a rather improved spatial resolution (smaller than the ion inertial length). The latest progresses are reported and simulations results with a uniform spatial resolution of 80 km are presented. This fully parallelized code describes both the dynamics and physical and chemical processes involved in the interaction. Photoproduction, charge exchange and electron impact ionization are computed dynamically through the simulation domain. The Martian ionosphere can be described either by external profile – e.g. by coupling with the result of ionosphere-exosphere simulations – or internally computed profiles obtained by assuming an equilibrium between several chemical processes (in which case transport is neglected). Moreover, the Martian crustal field can be integrated in our model to study its influence on the interaction dynamic and the ionosphere escape rate. We hereby show the results of these simulations and discussed their impact on the understanding of the Martian environment.

1. Introduction

Due to the absence of strong intrinsic magnetic field, the Martian atmosphere/exosphere is directly in contact with the Solar Wind (SW), exchanging part of its momentum and energy. This coupling occurs via ionization processes and contributes to the erosion of the neutral environment of the planet. Several space missions (past, active and future), such

as Phobos-2, MGS, Mars-Express and soon MAVEN, are dedicated to reveal the Martian neutral and ionized environment properties. Many in situ observations are available and characterize the plasma (and neutral) environment in the near vicinity of the spacecraft but these observations are highly localized in space and time. With a single spacecraft it is difficult to separate spatial from temporal structures and we often resort to global simulation to set back the observation in a global context.

2. Hybrid code

In this scope, and in the frame of the HELIOSARES project granted by the French National Research Agency, we have parallelized our previous hybrid model [1]. In the hybrid frame, only kinetic effects related to ions are taken into account. Ions are considered as macro-particles and electrons are treated as an inertia-less fluid ensuring the neutrality of the plasma and contribute to the total current and electronic pressure. The model solves the Maxwell equations to provide the temporal evolution of the electromagnetic field.

The numerical code we developed simulates several physical and chemical processes. This capability can be used to compute ionosphere profiles for each species from specified chemical processes. Alternatively, simulation results from different codes [5, 6] can be used to specify the ionosphere and exosphere profiles.

3. Simulations

This study presents simulation results with a 80km spatial resolution from a 3-dimensional parallel

multi-species (H, He, O⁺, O₂⁺, CO₂⁺) hybrid model of the Martian interaction with the SW. Physical and chemical processes (photoproduction, electron impact ionization and charge exchange) modifying the concentration of these species are dynamically computed by the model. Their effect on the Martian interaction are identified and discussed.

Our code also permits us to model the effect of the crustal field on the interaction between Mars and the solar wind. As the Mars crustal field presents fine structures and varies a lot depending on the Sun sub-longitude (SSL), we perform several runs with different SSLs. The results are discussed and compared with previous studies [1, 2, 3, 4].

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