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高解像度磁気圏グローバルMHDシミュレーション

High-resolution global MHD simulation of the terrestrial magnetosphere

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Global MHD simulation of the terrestrial magnetosphere numerically solves an interaction of the magnetosphere with the supersonic solar wind plasma. The first attempt was conducted with the 2-D model by Leboeuf et al. [1978] more than 30 years ago. Bow shock formation and magnetic reconnection at the day side magnetopause and in the tail region were successfully shown for the first time in a time-dependent model. Rapid growth of computational capabilities in the last 30 years enables us to simulate more realistic situations such as interactions of Coronal Mass Ejections (CMEs) with the magnetosphere and resultant ionospheric responses as auroral brightenings. Nowadays, the global MHD simulation is a powerful tool for predicting the geospace environment in response to the solar activities, that is, the space weather forecast.

Despite the great progresses on the global MHD simulations, some important issues are remained to be solved for the future high-performance computing. While recent numerical simulations and in-situ observations have shown that eddy and magnetic turbulence are of particular importance in discussing plasma transport and acceleration in the magnetosphere, their generation mechanism and roles in the magnetosphere has not been understood by global MHD simulation models. In oder to show importance of turbulence in the context of plasma transport and acceleration, we have developed a new, high-resolution global MHD simulation model of the magnetosphere. The model implements the CIP algorithm [Yabe et al., 2001] which enables to solve the advection equation stably with a low numerical dissipation. By solving MHD equations based on Elsasser variables [Elsasser, 1950], the CIP scheme gives highly accurate solutions to Alfven wave propagations as well as advective (eddy) motions [Matsumoto and Seki, 2008]. With the newly developed model, we aim at reproducing eddy turbulence at the magnespheric boundary layer (magnetopause) as a first step. As a result, we successfully reproduced vortex formation at the magnetopause under typical solar wind conditions of $|V_x|$=400 km s^{-1}, N=4 cm^{-3}, B_z=-5 nT, and the plasma beta=1.0. The vortical motion starts at the dayside magnetopause and subsequently evolves to larger scale vortices. The unstable region extends in 3D space whose vertical scale ranges +- 5 R_E, which is consistent with the recent statistical study of the Kelvin-Helmholz vortex obseravations [Hasegawa et al., 2006]. In addition to the basic vortex formation, magnetic reconnection is triggered due to current sheet compression by the growth of the Kelvin-Helmholtz instability. The newly found picture of the solar wind-magnetosphere interaction at the flank magnetopause became possible by the high-resolution global MHD simulation model.

キーワード:地球磁気圏,グローバルMHDシミュレーション,乱流, MHD波動

Keywords: terrestrial magnetosphere, global MHD simulation, turbulence, MHD waves