Parallel Global Three-Dimensional Electro-Magnetic Particle Model Simulation and its Application to Space Weather Problems

Graduate School of Systems and Information Engineering

University of Tsukuba

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XiaoYang Yan

Abstract

Parallel Computing involves all of the challenges of serial programming, such as data partitioning, task partitioning, task scheduling, parallel debugging, and synchronization. The field of parallel computing is growing and becoming synonymous to mainline computing topics, such as parallel performance and architecture, theory and complexity analysis of parallel algorithms, design and scheduling of parallel tasks, and programming languages and systems for writing parallel programs on data parallel, control parallel, and parallel programming.

Besides emitting a continuous stream of plasma called the solar wind, the sun periodically releases billions of tons of matter that are called coronal mass ejections (CME). These immense clouds of material, when directed towards the earth, can cause large magnetic storms in the magnetosphere and the upper atmosphere. Magnetic storms produce many noticeable effects on and near the earth. They are often referred as the space weather problems. Energetic particle entry into cusp and inner magnetosphere and its kinetic characteristics are also very important in space weather problems. In order to predict the space weather of the earth, many observation satellites, such as, cluster II, IMP 8, etc., are launched and numerous computer simulations are performed. Although global three-dimensional magnetohydrodynamic (3DMHD) simulations provide a quantitative picture, it can't include kinetic effects. Hybrid simulation also only processes ion as particle and electron as fluid. In order to include the full self-consistent kinetic characteristics, our global three-dimensional electro-magnetic particle model (3DEMPM) simulations become an important tool to reveal the phenomena in space weather problems.

In this thesis, based on SPMD (Single Program Multiple Data) Model, we construct a global three-dimensional electro-magnetic particle model (3DEMPM) using HPF (High Performance Fortran) that is an extended version of Fortran 90 for parallel systems and has become a standard parallel programming language in scientific calculation fields. Adapting the 3DEMPM model to the earth-magnetosphere system, we challenge to simulate one of important space physics problems, i.e. the space weather problem. The key issue of the space weather problems is the interaction between solar wind and the magnetosphere. We have been challenging to simulate the interaction between the solar wind and the earth magnetic field using our parallel global 3DEMPM simulation. These applications to space weather problems include (1) magnetic field reconnection at the magnetopause and magneto-tail; (2) "sash" and "Cross-tail S" that were recently observed by satellites and confirmed by 3D MHD simulations with dawn ward and dusk ward Interplanetary Magnetic Field (IMFs), and (3) magnetic field topology with time varying IMFs etc. The results of these simulations show that the particles directly enter into the cusp, the inner magnetosphere, the plasma sheet, and the magnetic field

reconnection takes place in the magnetopause and the near magneto-tail when the southward IMF arrives; the weak magnetic field regions at the magnetopause connect and rotate to the cross-tail neutral sheet from the dayside cusps when dusk-ward and dawn-ward IMF arrival, and through the "sash" and the "Cross-Tail S", the particles enter into the inner magnetosphere, the current sheet and the plasma sheet, and heat their temperature; In the topology visualization simulation with time-varying southward IMFs, when the southward IMF Bz is smaller, local reconnections take place at the magnetopause. Global reconnections take place when the southward IMF Bz is stronger enough. When the southward IMF Bz decreases, local reconnection will changes into global reconnection. When the southward IMF Bz increases back, global reconnection will not changes into local reconnection immediately. The magnetopause topology is bifurcated during this process. This symmetry-breaking and dissipative structure may be the reason for the burst of magnetic storms and sub-storms.

This thesis contains five chapters. Chapter 1 is the introduction. In Chapter 2, the numerical algorithms used in the global 3DEMPM simulations are explained in great details. Chapter 3 introduces the work of parallelizing global 3DEMPM code with High Performance Fortran (HPF). Chapter 4 introduces the space weather problems and the applications of 3DEMPM simulations. Chapter 5 gives the conclusions and recommendations. In the end, there are nomenclature, bibliography and appendix that include source codes of our global HPF 3DEMPM simulation code, data post-processing programs and topology visualization programs.