METHODS FOR MAGNETOSPHERE AND NEAR-SPACE PROBLEMS

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Summary

Mathematical models are discussed for the two central problems, which are of great importance for the understanding of the solar wind interaction with the Earth's magnetosphere: solar wind flow around magnetosphere and magnetic field reconnection. There are two approaches, which complement each other. The first is global MHD models, which can predict large-scale features. The second type is a boundary layer model or magnetic flux tube model, which are designed to describe physical effects in relatively small-scale regions, such as the magnetic barrier or magnetic reconnection.

Recent attempts to combine the MHD model with kinetic elements have very good perspectives. Successful examples are plasma instability criteria used as closure relations for anisotropic MHD model. Another important example is that of magnetic reconnection problem. The latter can not be solved completely within the MHD model because the behavior of resistivity can be obtained only from plasma kinetic theory.

The interplanetary magnetic field (IMF) is a key parameter, which controls the solar wind interaction with the Earth's ionosphere. A very important structure directly related with IMF is the magnetic barrier, which indicates a way of energy transport into the magnetosphere. The IMF is the magnetic barrier, which indicates a way of energy transport into the magnetosphere. The IMF is relatively weak in the solar wind but it is compressed substantially inside the magnetic barrier, where the magnetic field eventually starts to influence the flow.

The magnetospheric boundary is a thin current layer, which might be unstable at some points where the effective conductivity of plasma might decrease considerably. The latter will initiate the magnetic reconnection process, which converts the magnetic energy accumulated in the magnetic barrier into energy of accelerated particles and MHD waves propagating towards the ionosphere of the Earth.

1. Introduction

The structure of the space environment near the Earth is determined by the interaction of the solar wind with the geomagnetic field. This interaction results in the formation of the magnetosphere separating the magnetic field of the Earth from that of the interplanetary medium. The general pattern of the magnetosphere (M) is shown in Figure 1. The magnetosphere is the blunt obstacle around which the solar wind flows. There exists a detached bow shock (S) separating the supersonic solar wind from the magnetosheath region in front of the magnetosphere.

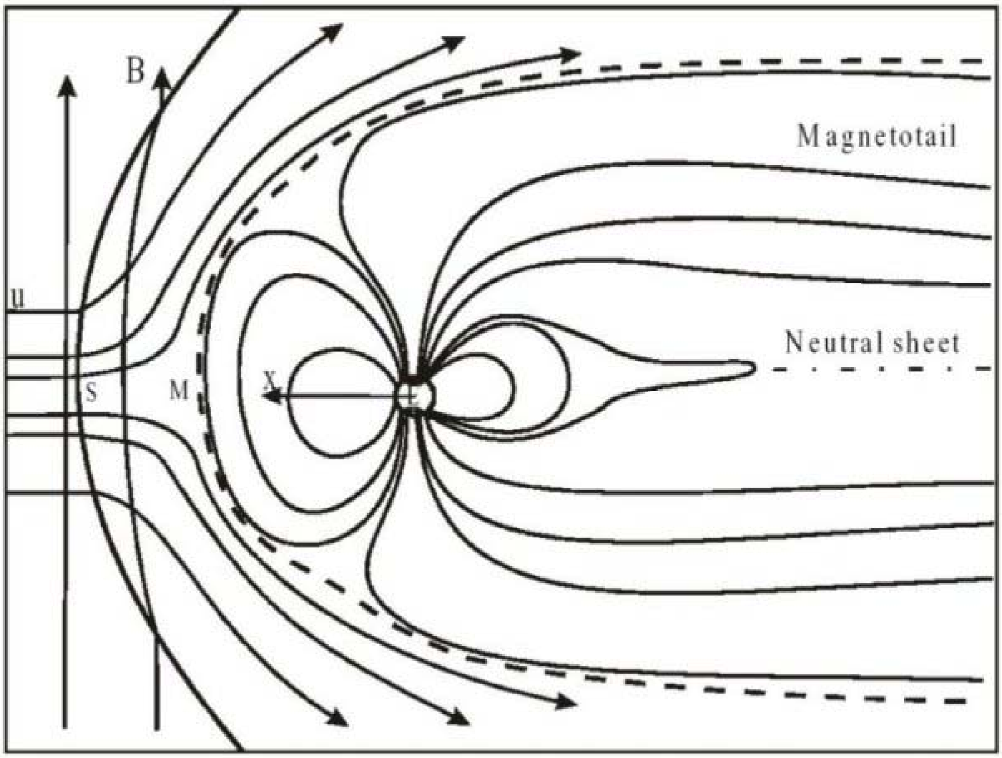

Figure 1: Structure of the Magnetosphere.

Physical conditions of the near-Earth space environment (plasma parameters, electromagnetic fields) are responsible for space weather and as such are very important for space and terrestrial systems. During high solar activity, there exist large disturbances in space propagating from the Sun towards the Earth. In particular, interplanetary magnetic clouds and coronal mass ejections released from the Sun produce strong disturbances in the Earth's magnetosphere. Magnetic storms are associated with the Earth passage of magnetic clouds. Large magnetic storms are prevalent near the maximum of solar activity. Within the main storm, the activity peaks in episodic events called substorms. In a substorm energetic particles are injected at low and high latitudes, energizing the ring current and producing auroras.

Large magnetic storms might cause disruptions of communication and navigation systems, power surges in ground transmission lines, failures of communication from geosynchronous satellites and other problems. During the magnetic storms, strong variations of magnetic field induce currents that might overload power grids, damage transformers, and increase corrosion in long pipelines. Ionospheric heating, caused by the energetic particles precipitating from the magnetosphere, changes the scale height of the neutral atmosphere. This increases the drag on satellites at low orbits. Also, there is a very real hazard to astronauts and pilots flying regularly along routes over the poles because of the dose of radiation they might get. In the medical aspect, there exist statistical studies indicating that people with chronic illnesses are sensitive to the magnetic field activity.

Magnetic storms and magnetospheric activity are controlled by the solar activity that has an 11-year cycle. These cycle variation effects are well pronounced in the climate of the Earth.

Mathematical models based on observations are important tools for studying and forecasting the dynamics of near-Earth environment. In general, the problem of solar wind interaction with Earth is very complicated and consists of a number of subproblems: the shape of the magnetosphere, solar wind flow around the magnetosphere, the dissipative processes at the magnetospheric boundary, transfer processes of momentum and energy through the magnetospheric boundary, plasma convection inside the magnetosphere, penetration of electric fields and magnetic field-aligned currents into the ionosphere, and acceleration of particles precipitation in the ionosphere.

Mathematical models developed for the magnetosphere and the near-space medium can be classified as follows: (1) global magnetohydrodynamics (MHD) models, (2) boundary layer MHD models, (3) hybrid simulation models, and (4) kinetic models of collisionless plasma.

Global MHD models are successfully used for prediction of large scale features. In addition to the global models, there exist MHD models suitable for thin boundary layers that significantly affect the solar wind – magnetosphere interaction. The first example is the magnetic barrier or plasma depletion layer (PDL) near the magnetospheric boundary. The second is the so-called reconnection layer, which can exist at the magnetospheric boundary and in the neutral sheet of the magnetotail (see Figure 1). More detailed descriptions of plasma processes are provided by the hybrid simulation and kinetic models. Good perspectives are expected with the recent attempts to combine MHD models with kinetic models. In MHD models, empirical relations are also used in combination with the MHD equations.

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Biographical Sketches

Nikolai V. Erkaev was born in Ufa, Russia. He completed his Diploma in Physics and Applied mathematics at the Novosibirsk State University, Novosibirsk, Russia in 1974. In 1979 he obtained the Russian degree of candidate in Physics and Mathematics at the Institute of Hydrodynamics of the Russian Academy of Sciences, Novosibirsk. In 1992, N.V. Erkaev was awarded the Russian degree of Doctor in Physics and Mathematics from St Petersburg University (Russia) with the thesis “Solar wind flow around the magnetosphere and the theory of magnetic barrier”.

In 1994 N.V. Erkaev obtained the Diploma of Professor in the field of "Mathematical Modeling in Mechanics". From 1975 to 1981 he was Research scientist at the Computer Center of the Russian Academy of Sciences in Krasnoyarsk, Russia, and was promoted to Senior Scientist at the same Computer Center, a position he held from 1982 to 1992. Since 1992 N.V. Erkaev is Head-Scientist at the Computer Center of the Russian Academy of Sciences in Krasnoyarsk, Russia, which is now renamed the Institute of Computational Modeling of the Russian Academy of Sciences.

Special fields of research activity include MHD modelling, numerical computations, space plasma physics and data analysis. He wrote about 130 scientific papers including 3 monographs. He has contributed to MHD modelling of the solar wind flow around Earth and other planets as well as around interplanetary magnetic clouds. His current work centers around MHD modeling of flow structures in space plasma including fast reconnection of magnetic fields.

Helfried K. Biernat was born in Graz, Austria. He completed his studies with the Ph.D. in Physics and Mathematics at the University in Graz with a thesis on solid state physics in 1978. In the following years he complemented his studies with Teacher Diplomas in Physics, Mathematics and Chemistry as well at the University in Graz. After positions at the Graz University, finally as a Research and Teaching Assistant, H. Biernat changed in 1978 to the Space Research Institute of the Austrian Academy of Sciences in Graz as a Research Scientist. Parallel to this work, H. Biernat started in 1987 to give lectures in magnetohydrodynamics and plasma physics at the University in Graz and got his Habilitation in ``Theoretical Physics" in 1996 with the thesis “Magnetic Field Line Merging”. Thus H. Biernat is also Lecturer and University Dozent at the Institute for Meteorology and Geophysics and at the Institute for Theoretical Physics of the University in Graz. He is now University Professor at the University in Graz

Dr. H. Biernat got his professional experience during about 20 several—weeks visits to various institutions abroad, like the Universities in St. Petersburg, London, St. Andrews, Brighton, Buenos Aires, the NASA Goddard Space Flight Center in Maryland, University of New Hampshire, the Russian Academy of Sciences in Krasnoyarsk.

H. Biernat worked in the last years on various aspects of plasma physics, most of the work being devoted to space science, in particular in the solar wind--magnetosphere system. He wrote more than 140 scientific papers including review articles. H. Biernat organized about 10 international meetings in Austria and Russia, he edited 9 books in his working field. In addition, he acts as a Referee for various scientific journals and academic institutions all over the world.

Charles J. Farrugia, a permanent US resident, was born in Malta.He completed his BS in physics and mathematics at the University of Malta. On being awarded a Swiss Government Fellowship, he obtained a Masters' degree at the University of Bern (theoretical physics, specializing in General Relativity) and a Doctorate in space physics (Plasmaspheric Physics). He also holds a Diploma in Education from the University of London, England. From 1984 to 1986 he was European Space Agency Fellow at the Space and Atmospheric Physics Group of Imperial College, England, and Research Associate up to 1990. From 1990 to 1993 he was Research Scientist at NASA's Goddard Space Flight Center. After being Senior Lecturer at the Department of Science and Technical Education of the University of Malta (1993-1996), he has been Research Scientist at the Space Science Center of the University of New Hampshire since April 1996. He has many ongoing scientific collaborations with international space physics research groups, and was twice Visiting Professor at Institute for Plasma Physics of the University of Buenos Aires, Argentina.

Dr Farrugia has worked on various aspects of space physics in data analysis, theory, and numerical computation. He wrote more than 140 scientific papers including various review articles in monographs. He has contributed to interplanetary physics, particularly in modelling the non-linear evolution of magnetic clouds. He has worked extensively in the field of solar wind-magnetosphere interactions, on which he co-edited a book. His current work centers around multi-spacecraft and ground observations of the effects of interplanetary structures on the Earth's geophysical environment.