

GENERATION OF ANOMALOUS FLOWS NEAR THE BOW SHOCK BY ITS INTERACTION WITH INTERPLANETARY DISCONTINUITIES

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LONG-TERM GOAL

To understand the generation of various waves and associated pressure pulses in the magnetosphere by the interaction of interplanetary discontinuities with the earth's bow shock, to understand the coupling among the solar wind, magnetosphere, and ionosphere, and to improve our knowledge of the ambient and disturbed space environment, which has been emphasized by the Office of Naval Research.

SCIENTIFIC OBJECTIVES

Physical processes that occur at the dayside magnetopause, such as pressure pulses and magnetic reconnection, may lead to a variety of physical phenomena in the Earth's ionosphere that can adversely effect satellite operations and observations and that can interfere with long-distance communications. These transient phenomena are usually related to perturbations in the solar wind and interplanetary magnetic field (IMF). Some phenomena, such as the magnetic impulse events (MIEs) observed in the high latitude ionosphere, the slow mode and mirror mode structure in the magnetosheath, and the anomalous flow events are found to be closely related to variations in the IMF direction. On the other hand, magnetohydrodynamic (MHD) discontinuities and shock waves, including tangential discontinuities, rotational discontinuities or Alfvén waves, and forward and reverse fast shocks and slow shocks, have been frequently observed in the solar wind. More complicated structures such as magnetic flux ropes, magnetic holes, and diamagnetic cavities are also observed. Since the bow shock is the frontier of the plasma environment of the Earth, any interplanetary discontinuities and shock waves that propagate to the Earth would first encounter the bow shock. This interaction may result in the generation of complicated wave structures and pressure pulses even though no pressure pulses are present in the incoming interplanetary discontinuities. The main objective of our study is to carry out a systematic study for the interaction of various interplanetary discontinuities and shock waves with the Earth's bow shock and then the magnetosphere. The effects of the incoming waves on the ionosphere will also be investigated. In particular, our objectives are investigate the generation of various waves and pressure pulses at the bow shock, in the magnetosheath, and at the dayside magnetopause by the interaction of interplanetary discontinuities, shock waves, and more complicated structures with the bow shock;

study the impacts of these waves, discontinuities, and associated pressure pulses on the earth's magnetopause and magnetosphere, as well as determine the influence of these impacts on the

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ionosphere; determine the local-time dependence of the magnetosphere and ionosphere on interplanetary disturbances under various conditions.

APPROACH

Our primary research tools are one-dimensional (1-D) and two-dimensional (2-D) hybrid simulations for a global system of the bow shock, magnetosheath, and magnetopause, guided by MHD theories and simulations of the shock/discontinuity (shock) interaction. In the hybrid simulations, ions are treated as individual particles, electrons are treated as a massless fluid, and the plasma moves self-consistently in the electromagnetic field. A curvilinear coordinate system that is suitable to the global system of the bow shock and magnetosphere is adopted. The simulation code was developed by Professor Dan Swift at the University of Alaska Fairbanks, who has also participated in the 2-D simulation study in this project. In addition, a Postdoctoral Fellow, Dr. Sam Cable has also joined the study to extend the simulation to three-dimensions (3-D). A 3-D global MHD simulation code has been developed and the simulation work is progressing.

WORK COMPLETED

In the past years we carried out the first 2-D hybrid simulations using a curvilinear coordinate system to study the generation of various waves and associated pressure pulses upstream and downstream of the bow shock by variations in the interplanetary magnetic field direction. The results were compared with satellite observations at the bow shock and in the magnetosheath. Two papers (Lin, et al., 1996a, b) have been published in the *Journal of Geophysics Research*. In the year of 1997, we carried out the first global 2-D hybrid simulation to study the generation of anomalous flows at the bow shock by its interaction with an interplanetary tangential discontinuity and rotational discontinuity.

RESULTS

A class of events, which are characterized by a hot subsonic plasma embedded in the upstream solar wind and a large sunward deflection in plasma flow velocity, has been observed by satellites near the Earth's bow shock. The majority of the events are found to be associated with a gross rotation in the IMF. It has been suggested that the formation of these events is due to the interaction of the bow shock with an interplanetary tangential discontinuity or rotational discontinuity.

Two-dimensional hybrid simulations using a curvilinear coordinate system are carried out to study the interaction of the Earth's bow shock (BS) with an interplanetary directional discontinuity. In particular, plasma flow patterns are examined. In the interaction of the bow shock with an interplanetary tangential discontinuity (TD), a bulge of magnetic field and plasma may be present near the intersection between the fronts of the BS and the TD. The bulge expands to the upstream and is embedded in the solar wind. High magnetic field and ion density are present in the boundary regions of the bulge, and the temperature in the bulge is significantly higher than that in the ambient solar wind. A core of low density and sometimes low field is present inside the bulge. The flow speed changes from supersonic in the solar wind to subsonic throughout the bulge. A strong sunward deflection in flow velocity is present both in the bulge and in the magnetosheath behind the bulge. The presence of such hot anomalous flows depends

on the direction and symmetry condition of the upstream motional electric field. The formation of the bulge and the associated anomalous flows is found to be mainly due to (1) the reflected ions which are focused to TD under the proper electric field conditions, (2) the unbalanced pressure associated with the geometry change and reformation of the BS which causes the expansion of downstream and the sunward motion of ions, or (3) the occurrence of magnetic reconnection in the current sheet. In the interaction of the BS with an interplanetary rotational discontinuity (RD), the flow may be deflected sunward by the magnetic tension force associated with the resulting rotational discontinuities and slow shocks in the magnetosheath. It is suggested that the observed anomalous flow events upstream of the bow shock may be due to the BS/TD interaction, and both BS/RD and BS/TD interactions may generate strong sunward flow deflections in the magnetosheath.

A paper (Lin, 1997) has been published in the *Journal of Geophysics Research*.

IMPACT/APPLICATION

Our simulation is the first systematic study for the reaction of the earth's plasma environment to the interaction between the bow shock and interplanetary discontinuities. It is shown that the resulting waves are usually complicated, and that anomalous flow reversals and pressure pulses may be generated in the upstream and downstream of the bow shock, while the incoming interplanetary discontinuity may simply be a directional discontinuity in which only the IMF direction changes. Since the impinging of these waves and pressure pulses on the earth's magnetopause may cause the irregular wavy motion of the magnetopause, field-aligned currents and associated perturbations may occur in the ionosphere. For example, magnetic impulse events have been frequently observed in the high latitude ionosphere, with a magnetic field perturbation of $\sim$ several 10's of nT and a duration of several minutes as observed by ground magnetometers. A recent statistical survey indicates that more than 50% of the MIE events are associated with IMF direction changes while only about 30% are associated with the solar wind dynamic pressure change. Our simulation study suggests that the interaction between the bow shock and an interplanetary RD, through which only the IMF direction changes, may provide a pressure pulse to the magnetosphere, cause the wavy motion of the magnetopause, and lead to the MIEs in the low altitude regions. In addition, our study of the BS/TD interaction indicates that a bulge of magnetic field and hot plasma may be generated at the bow shock, which is associated with a sunward flow deflection. This result provides a mechanism for the generation of the anomalous flow events observed by satellites. Further influence of such events on the earth's magnetopause may lead to some very important and interesting phenomena in the coupled system of the solar wind, magnetosphere, and ionosphere. Our study has received a wide response from the community of Magnetospheric Physics, especially from the researchers working on satellite and ground-based observations. Currently a few collaborations between our team and the researchers of observational data analysis are ongoing. The simulation results will be compared with the observations and be used to explain the observed correlated phenomena in the solar wind, magnetosheath, and inner magnetosphere.

TRANSITIONS

As described above, our 2-D hybrid simulations are the first to model the collisionless plasmas in the bow shock-magnetosheath-magnetosphere system using a curvilinear coordinate system. The

oblique BS/discontinuity interaction is simulated with high spatial and time resolution to catch the physics in the associated waves. The results from our study have provided a mechanism for the magnetic impulse events observed in the high latitude ionosphere. They have also been used to explain the hot anomalous flow events at the bow shock. Our study has received a wide response from the researchers working on satellite and ground-based observations. The simulation results will be compared with the observations and be used to explain the observed correlated phenomena in the solar wind, magnetosheath, and inner magnetosphere.

RELATED PROJECTS

Consider the following related projects:

1. To carry out 3-D MHD simulations of the bow shock/discontinuity interaction for the global system of the bow shock-magnetosheath-magnetosphere-and ionosphere, which will extend our previous simulations to 3-D and will include the ionosphere; and
2. To study magnetic reconnection at the dayside magnetopause associated with the variation in magnetic field direction and examine the roles of impinging dynamic pressure pulses and magnetic reconnection in the coupling between the solar wind and the magnetosphere.

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