The Solar Wind Coupling and Geomagnetic Activity Group

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Introduction

The solar wind coupling and geomagnetic activity group headed by Professor R.L. McPherron is concerned with phenomena arising from the interaction of the solar wind with the earth's magnetic field. These include ultra low frequency (ULF) waves, magnetospheric substorms and magnetic storms. The group utilizes data acquired by past and present space missions as well as ground observatories to establish the morphology of these phenomena and to identify the physical processes that cause them. The group is also concerned with practical applications of these studies to the fields of scientific data management, geophysical exploration, and space weather forecasting. The group shares personnel with the Planetary Plasma Physics Group and interacts closely with them.

Solar Wind Coupling

Solar wind coupling is the name applied to empirical studies of the relation between phenomena on the Sun and in the solar wind to various measures of geomagnetic activity. This field of research often treats the earth's magnetosphere as a black box whose properties can be ascertained from records of its past behavior. These properties are then used in conjunction with measurements of the Sun and solar wind to predict future geomagnetic activity. Such predictions are frequently used in empirical methods of space weather forecasting. Measures of geomagnetic activity are called magnetic indices. The most popular indices include the planetary range index, Kp, the polar cap index, PC, the auroral electrojet index, AE, and the ring current index, Dst. Many important phenomena have been correlated with these indices and if the values of the indices are know, the correlations can be used to estimate or predict their development. For example, the electric potential applied to the polar cap by the solar wind is linearly related to the Kp index. Magnetic indices have been related to the solar wind dynamic pressure and electric field by a variety of methods that include linear regression, cross correlation functions, linear prediction filters, neural networks, and local linear prediction filters.

Prof. McPherron's group was one of the first to recognize that techniques such as linear prediction filtering could be used to encapsulate the behavior of the magnetosphere for prediction of activity measures, and that these encapsulations could be used to study the physical properties of the solar wind-magnetosphere system. A major contribution to this field was the work of Bargatze et al. [button to IGPP List] which established that the response of the westward auroral electrojet (substorm associated ionospheric current) to the solar wind was bimodal within certain ranges of geomagnetic activity. This then led to the modern idea that the magnetosphere is a nonlinear dynamic system driven by the solar wind. Current research in this field is focused on the idea that the properties of the magnetosphere are locally linear in time, but that as the internal state of the system changes, the transfer function between the solar wind and the magnetosphere changes. Past records of activity are used in real time to update the system transfer function. Recent contributions by McPherron's group include a review paper [button to IGPP List] summarizing the results of linear prediction filtering studies, and a paper with one of Prof. McPherron's principle collaborators, Dr. Dan Baker of the Laboratory for Atmospheric and Space Physics of the Univ. of Colorado on the factors controlling the intensity of magnetospheric substorms [button to IGPP List]. A graduate student in Prof. McPherron's group, Mr. Gerard Blanchard, has investigated how well a bimodal model of the system transfer function represents individual substorms and finds it is a remarkably good representation [button to IGPP List]. This result suggest that the magnetosphere behaves as a low dimensional system and that its behavior should be predictable if the proper differential equations can be found. Prof. Gene Stringer of Southern Oregon State College, a NASA JOVE (Joint Venture) scholar working with Prof. McPherron, is completing a manuscript describing the use of neural networks to predict the flux of relativistic electrons at synchronous orbit from the Kp index. These electrons are a major cause of failure in electronic systems within synchronous satellites.

Magnetospheric Substorms

explains

A magnetospheric substorms consists of an ordered sequence of physical processes that take place when the interplanetary magnetic field carried past the earth by the solar wind turns southward relative to the earth's magnetic field. A process called magnetic reconnection begins at the subsolar magnetopause allowing the two magnetic fields to interconnect. The earth's magnetic field is stripped from the day side and transported by the solar wind over the polar caps and drawn out into a long magnetic tail. These stretched field lines eventually reconnect and snap back towards the earth. Particles injected by these collapsing field lines both precipitate into the atmosphere creating aurora and ionospheric electrical currents, and enter closed drift paths around the earth forming the radiation belts.

Professor McPherron and his group have been pioneers in the development of a model of this process called the near-earth neutral line model of substorms [button to IGPP List]. For nearly twenty years this model has been the standard paradigm explaining substorm phenomena. Recently the model has come under attack because several sets of new observations do not appear to be easily incorporated in the model. As a consequence, intense controversy exists at the present time about whether magnetic reconnection is the fundamental process responsible for the collapse of the tail field, or whether another process called current disruption is more important.

One recent group contribution to the subject of magnetospheric substorms includes the work of Professor Jeff Sanney of Loyola Marymount University, a NASA JOVE (Joint Venture) Scholar mentored by Prof. McPherron, and Dr. Tuija Pulkkinen of the Finnish Meteorological Observatory in Helsinki, Finland, a scientific collaborator. Sanny's paper [button to IGPP List] uses ISEE magnetometer data in the tail to show that current sheet thinning is a precursor to the onset of the collapse phase of a substorm. Pulkkinen's paper establishes this result in a different way using global magnetic models. Another contribution is work by Prof. McPherron with Dr. Ed Hones of the Los Alamos National Laboratory. This paper [button to IGPP List] uses ground magnetometer data to establish that past reports of near- earth reconnection occur at the center of the region of tail collapse, not outside as claimed by proponents of current disruption. Mr. Tung-Shin Hsu, a new student working with Prof. McPherron has begun a statistical study of the relation of substorm phenomena in the tail to a variety of indicators of tail collapse in an attempt to better understand which processes are important in its initiation.

Magnetic Storms

Magnetic storms occur when the radiation belts become filled with energetic ions and electrons. The drift of these particles produces a doughnut shaped ring of electrical current around the earth. The magnetic perturbations of this current are measured on the ground as a decrease in the magnitude of the horizontal component of the earth's magnetic field.. Magnetic storms are often initiated by the sudden arrival of a high speed stream of solar wind carrying high particle density and high magnetic field. If the solar wind field is southward prior to the arrival of the high pressure solar wind the earth's magnetotail may be loaded with magnetic energy and a violent magnetospheric substorm is immediately triggered. Such substorms often trigger transients on electrical power lines, telephone lines and north-south pipelines, and cause failures in these systems.

Nearly twenty years ago, Prof. McPherron and Prof. Russell collaborated in an important study that demonstrated that the Dst index which measures the strength of the storm time ring current could be predicted by the solar wind electric field and dynamic pressure [button to IGPP List]. This result was originally summarized in the form of a differential equation, but has since been recast in the form of linear filters and neural networks. Only now are civilian and military agencies beginning steps to incorporate this important prediction technique into space weather forecasting. As a preliminary step both the Space Environment Laboratory of NOAA in Boulder, and the Air Force Space Weather Forecast Center in Colorado Springs are planning to calculate the Dst index in real time and predict it an hour ahead using upstream solar wind measurements. Prof. McPherron is collaborating with Professors R. Schunk and J. Sojka of the University of Utah in Logan, and Mr. Tom Detteman of NOAA to evaluate algorithms that calculate the Kp and Dst indices created with real time data. As part of this project Prof. McPherron is also evaluating techniques for generating quiet day traces (needed to obtain the disturbance variations). Prof. Gene Stringer of Southern Oregon State College, and Prof. Vince Wickwar of University of Utah are installing UCLA magnetometers provided by Prof. McPherron's group to measure midlatitude magnetic variations during magnetic storms.

ULF Waves

Ultra low frequency waves (period 1-1000 sec) are a common occurrence during all forms of magnetic activity. These waves provide a means for the magnetospheric plasma to release energy stored in the particle populations (instabilities) and are also the normal modes of oscillation of various cavities within the magnetospheric system. ULF waves are useful as probes of the magnetospheric environment because they carry information about their source regions and the plasma through which they propagate. Prof. McPherron's group was among the first to study the properties of these waves with spacecraft measurements and has developed a number of techniques for such studies. One example of such studies is the proof that a class of ULF waves characterized by azimuthal linear polarization that is observed on the dayside of the magnetosphere at synchronous orbit is produced by harmonic oscillation of magnetic field lines [button to IGPP List]. The period of oscillation is characteristic of individual field lines and depends on both the length of a field line and the distribution of plasma along it. Up to seven or more harmonics of the fundamental may be observed at any one point, but the period of oscillation changes continuously as one moves through the magnetosphere. The magnetosphere is thus divided into regions dominated by waves of different period [button to IGPP List]. The source of the energy for these waves appears to be waves generated in the solar wind upstream of the bow shock.

In contrast to the above, another class of waves is characterized by constant frequency as a function of position within the magnetosphere. These waves tend to have a strong compressional component and are thought to be produced by oscillation of the resonant cavity formed by the volume of space between the magnetopause and the plasmapause. A study of a rare event exhibiting these properties was described in the Ph. D. dissertation of Dr. Ming Cao. A paper describing this event is under review [button to IGPP List]. Again, the solar wind is thought to be the cause of these waves, but by processes such as buffeting of the magnetopause.

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Last Updated: November 21, 1994