MAGNETOSPHERE AND ITS COUPLING TO LOWER LAYERS

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Summary

The near-Earth space, the magnetosphere, has recently become of interest to people outside the space physics community. As humans are gaining presence in space (for example, at the International Space Station), it is necessary to understand the dynamic behavior of the hostile space environment to protect humans and their equipment. Furthermore, our everyday lives are increasingly dependent on technology in space: telecommunication satellites relay telephone calls and television programs, weather forecasts utilize satellite imagery, and natural resources are being mapped using remote-sensing instruments onboard low Earth orbiting spacecraft.

The magnetosphere is a highly dynamic region, where solar wind energy input causes periodic strong variations in the local magnetic field, and accelerates particles to very high energies. These high-energy particles are the most hazardous to the electronic components in space. These processes are governed by electromagnetic forces within the fully ionized plasma in the magnetosphere. At Earth's surface, these space storms are recorded as variations in the compass needle and as beautiful auroral displays. Space weather is an applied field of space physics, which aims at predicting these hazardous events in advance.

Magnetospheric substorms are processes during which solar wind energy is stored in the magnetosphere, and later explosively released and dissipated in the inner magnetosphere and in the high-latitude ionosphere. A key process during substorms is magnetic reconnection, which allows for large-scale reconfiguration of the magnetospheric magnetic field, and provides a means to transfer magnetic field energy to plasma energy. Substorms typically last a few hours, and occur at a rate of a few substorms per day. Geomagnetic storms are larger disturbances that typically last over a day, and are associated with high fluxes of energetic particles in the inner

magnetosphere, and strong disturbances of the geomagnetic field. Storm occurrence is highly correlated with the level of solar activity.

1. Introduction

The magnetosphere is the region of near-Earth space where dynamical processes are governed by the internal geomagnetic field. It is often defined to begin above the ionosphere (the ionized part of the upper atmosphere) from about 1000 km upward, but there is no strict inner boundary to the magnetosphere. On the other hand, the outer boundary of the magnetosphere is a well-defined current layer. In the sunward direction, it is located at about 60 000 km from Earth, and on the nightside of Earth it extends to over several million kilometers, giving the magnetosphere a comet-like shape with an elongated tail in the direction away from the Sun. Matter in the magnetosphere is almost entirely in the plasma state. Hence, the processes are governed primarily by electromagnetic forces. The gravitational forces are important only in the lower magnetosphere below a few thousand kilometers altitude.

2. An Introduction to the Magnetosphere

2.1 Historical Observations

There are two manifestations of the existence and dynamics of the magnetosphere that can be observed from Earth's surface: auroras and the variations in the geomagnetic field. The temporal coincidence between compass needle variations and bright auroral displays was first reported by Swedish scientists Anders Celcius and Olav Hiorter in 1747. Furthermore, Celcius found the large-scale nature of the geomagnetic field variations in his experiments of comparing simultaneous compass needle variations in London and in Uppsala.

In the mid-nineteenth century, the correlations between solar flares, auroras, and geomagnetic disturbances were established. In 1860, an Englishman, Richard Carrington, correlated observations of a solar flare with the following geomagnetic disturbance and auroral display. Long-term observations of sunspot numbers were found to show an 11-year variability, which was correlated with the occurrence frequency of magnetic disturbances and bright auroral displays.

In 1896, a Norwegian scientist, Kristian Birkeland, assumed that a stream of electrons from the Sun could reach the geomagnetic field and produce geomagnetic disturbances. In his "Terrella" experiment, he projected cathode rays (electrons) toward a spherical magnet (Earth) and demonstrated that many of the cathode rays were directed toward the poles, leaving a toroidal region around the equator void of electrons. Thirty years later, Englishman Sydney Chapman postulated that solar corpuscular streams were responsible for ionizing the ionosphere. In a series of papers in the early 1930s, Sydney Chapman and Vincent Ferraro explained the "geomagnetic storm" (concurrent geomagnetic disturbance and auroral display) as resulting from the impact of a charge-neutral plasma cloud from the Sun on the terrestrial magnetic field.

2.2 Magnetospheric Structure: Fields and Plasmas

Today, we know that the Sun emits a continuous stream of charged particles together with the extension of the solar magnetic field into interplanetary space. The interaction of the solar wind with the internal geomagnetic field gives the magnetosphere its comet-like shape: the flow compresses the dayside magnetosphere toward the Earth and elongates the nightside magnetotail to far beyond the lunar orbit. The variability in the solar wind and interplanetary magnetic field characteristics are the drivers of dynamic processes in the magnetosphere, which we record on Earth's surface as magnetic disturbances and auroral displays.

The magnetosphere thus formed by interaction between the nearly dipolar internal geomagnetic field and the solar wind has three topologically distinct field line regions (see Figure 1). The closed field lines in the quasidipolar regions at low latitudes and near Earth have both ends connected to Earth. The solar wind plasma has only limited access to this region. The open field lines have only one end tied to Earth, the other being connected to the interplanetary field lines. Along these field lines, plasma can gain access to the magnetosphere. The fully disconnected interplanetary field lines have no connectivity to Earth's intrinsic field.

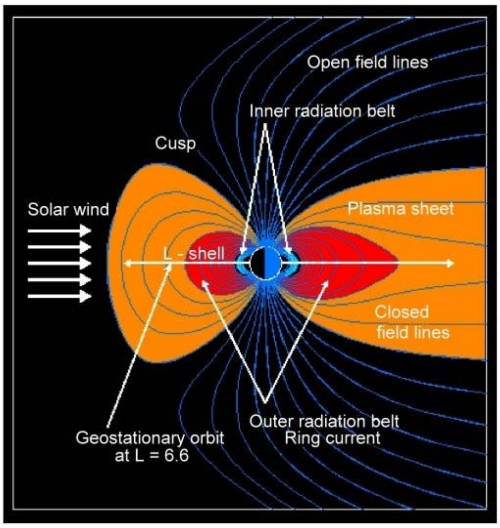

Figure 1. Schematic representation of the magnetosphere. The direction of the Sun is to the left. The inner and outer radiation belts, the ring current, and the plasma sheet are shown with different shadings.

The closed field line region in the inner magnetosphere hosts several dynamically important plasma populations. The westward-directed ring current encircling Earth at L between 4 and 6 varies in intensity as a response of the variable driving of the solar wind and interplanetary magnetic field. The inner van Allen radiation belt at around L = 2 consists mainly of protons at and above MeV energy range, and is relatively stable. On the other hand, the outer van Allen belt consists of MeV energy electrons, and varies strongly both in location and intensity as a response to the enhancements in solar wind driving. The plasma sheet separating the two tail lobes almost void of plasma hosts plasmas in the keV energy range, and is a key region for many processes associated with geomagnetic activity.

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Biographical Sketch

Prof. Tuija I. Pulkkinen ,is a research professor in space physics at the Finnish Meteorological Institute. Prof. Pulkkinen obtained her Ph.D. from the University of Helsinki in 1992. She has worked during several periods at the Goddard Space Flight Center in Maryland, US during 1990–1992. She was a Fulbright scholar at the University of Colorado in Boulder, CO, US, in 1996–1997. Her main research interests are in the field of Sun–Earth connections. She has worked widely in ionospheric and magnetospheric dynamics, especially concentrating on processes that occur during geomagnetic storms and substorms. She has developed magnetic field models for the magnetotail during magnetospheric substorms, and used the models to examine the connections of auroral brightenings and instability development in the magnetosphere. Prof. Pulkkinen has authored or co-authored more than 90 publications in refereed scientific journals. In 1998 she was awarded the American Geophysical Union James B. Macelwane Medal, and in 1999 she received the City of Helsinki Science Award.