Introduction

The Lyon-Feder-Mobarry (LFM) MHD magnetospheric model, and more recently the Coupled Magnetosphere-Ionosphere-Themosphere (CMIT) model are being used to investigate how solar energetic particle (SEP) and galactic cosmic ray (GCR) access to the magnetosphere is modified during geomagnetic storms. Using techniques advanced by Smart and Shea (2001), energetic particle cutoff rigidities are calculated by computing reverse trajectories in model fields. In this work, the International Geomagnetic Reference Field (IGRF) is embedded inside the LFM inner boundary for particle tracing, to obtain accurate cutoffs at the Earth’s surface.

It has been shown previously that a reduction in geomagnetic shielding is correlated with the depression and recovery of the disturbance storm time (Dst) index during magnetic storms (Leske et al., 2001). This lowering of the cutoff can be attributed to a reduction in field strength in the inner magnetosphere due to ring current buildup. However, observations and model results show that significant changes in the cutoff occur in conjunction with shock related enhancements in the solar wind dynamic pressure and interplanetary magnetic field (IMF) on a timescale of minutes, well before ring current buildup (Kress et al., 2004).

Here, we present preliminary results from an investigation of the effects of shock related enhancements in the solar wind dynamic pressure and changes in the IMF on geomagnetic cutoffs by computing energetic particle trajectories in a MHD model of the magnetosphere, which is driven at its upstream boundary by solar wind parameters, and is well suited for modeling the dynamics of the magnetosphere on the short time scales.

Theory and modeling

Störmer (1955) showed that in a pure dipole magnetic field a potential barrier shields particles of a given rigidity (≈60 for Earth) is a constant determined by the dipole

\[ r = \frac{Mg \cos^2 \lambda}{m v^2 c} \]

where \( M \) is the dipole moment, \( \lambda \) is the latitude and \( r \) is the radial distance from the center of the dipole. This equation can be inverted to give the cutoff rigidity at any point in space

\[ R(\theta, \phi) = \frac{\cos^2 \lambda}{r^2 (1 + \frac{1}{4} \cos^2 \lambda)} \]

where \( C \) (≈ 60 for Earth) is a constant determined by the dipole moment. Although Störmer’s analytic result is derived in a pure dipole, well defined but non-axisymmetric cutoffs are observed in geomagnetic fields suggesting that Störmer theory may, in some approximation, be generalized to a time dependently perturbed dipole field.

The cutoff at a point in model magnetospheric fields is located by launching many particles of different rigidities from that point and following time reversed trajectories. If a particle escapes the magnetosphere then its trajectory is a viable inward trajectory, indicating that we are above the cutoff.

The 24 Nov 2001 storm sudden commencement (SSC) provides an example of a large depression in energetic particle cutoffs occurring in conjunction with an increase in the solar wind dynamic pressure, well before a southward turning in the IMF or ring current buildup. Figure 2 shows precipitating heavy ion counts from the LICA instrument on SAMPEX. Note the significant lowering in the cutoff during the SSC at 8UT and in conjunction with a large solar wind density enhancement at 7UT. The maximum compression in the cutoff in the MHD model occurs with this density enhancement (see in Figure 3). Solar wind data and Da for this event are shown in Figure 4.

Data/model comparison

The Nov 2001 results suggest the need for a systematic study of the global behavior of cutoffs under different solar wind conditions. Here we present preliminary results from such a study using the 14-15 May 1997 CMT storm simulation. Solar wind data used to drive the CMIT code is shown in Figure 6. Figure 7 shows contours of constant cutoff rigidity at two time snapshots from the simulation, before and after the arrival of the interplanetary shock.

14-15 May 1997: A global view

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Summary

- In MHD magnetospheric model fields, we find well defined energetic particle cutoffs that exhibit dynamic behavior in response to solar wind conditions.
- A significant lowering of observed and modeled cutoffs occurs in conjunction with the Nov 2001 SSC on a timescale of minutes well before the Dst index reaches a minimum.
- The difference between the modeled pre and post-shock cutoff rigidities calculated in the 14-15 May 1997 CMT storm simulation fields show both increases and decreases approaching ~100%.

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References


