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MHD Simulation of the Effects of the IMF and Dipole Tilt on the Dayside Magnetic Reconnection

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We have used a three-dimensional global magnetohydrodynamic (MHD) simulation of the magnetosphere to evaluate whether antiparallel or subsolar reconnection better describes the magnetic reconnection process at the dayside magnetopause when the interplanetary magnetic field (IMF) and the dipole tilt are non-zero. When we include a positive dipole tilt, the reconnection site in the summer hemisphere shifts sunward and equatorward while the one in the winter hemisphere moves tailward and away from the equator. Reconnection near the magnetic equator becomes less effective because IMF field lines move rapidly through the magnetic equator for the finite tilt. If component reconnection is dominant it should still occur at the subsolar point. However, the reconnection sites always moves to the place where the field lines are antiparallel. Thus antiparallel reconnection is more important at the dayside magnetopause than component reconnection.

1. Introduction

Dynamics of Earth's magnetosphere can be controlled by magnetic reconnection between the geomagnetic field and the IMF. Dayside magnetic reconnection is often described by two different models: antiparallel merging which occurs preferentially where the magnetosheath magnetic field is antiparallel to the geomagnetic field [*Crooker*, 1979] and subsolar merging occurs in the stagnation region where the IMF firstly encounters geomagnetic field [*Sonnerup*, 1974]. There have been many studies of dayside magnetopause reconnection by using global MHD simulations [*Ogino et al.*, 1986; *Siscoe et al.*, 2002]. *Ogino et al.* [1986] showed that if the IMF is rotated from northward via duskward to southward the reconnection occurs on the dayside magnetopause at progressively lower latitudes. Further, they found that reconnection tends to occur preferentially at locations where the geomagnetic field magnitude is minimum. They argued that this is consistent with antiparallel reconnection being dominant at the dayside magnetopause. *Siscoe et al.* [2002] showed high-speed magnetosheath flow through a stationary reconnection site at high latitudes for northward IMF. From the global MHD simulation, the direction of the IMF more strongly influences antiparallel reconnection than subsolar reconnection, but these did not include the effects of dipole tilt in their simulation. The purpose of the present study is to determine which model better describes dayside reconnection and to determine its location on the dayside magnetopause.

2. Simulation Model

We will briefly review the simulation model here since it has been described in detail elsewhere [*Ogino et al., 1986*]. This model solves the normalized resistive MHD and Maxwell's equations as an initial value problem by using a modified two step Lax-Wendroff method. In the simulation a solar wind with a number density n_{sw} = 5 cm^{-3}, velocity V_{sw} = 300 km/s and the temperature $T_{sw} = 2 \times 10^5$ °K, and $\mathbf{B_{IMF}}$ = 5 nT flows into the simulation box. We used a simulation box with dimensions of $-120R_E \leq X \leq 30R_E$, $-60R_E \leq Y \leq 60R_E$, $-60R_E \leq Z \leq 60R_E$, in Cartesian solar-magnetospheric coordinates. The number of grid points is $(n_X, n_Y, n_Z) = (500, 300, 300)$ with a uniform grid spacing of $\Delta x = 0.3R_E$.

3. Simulation Results

We have performed a high-resolution and time dependent three dimensional MHD simulation of the interaction between the solar wind and the Earth's magnetosphere when the dipole tilt, and B_y and B_z components of the IMF are simultaneously included in the whole volume of the simulation box. A quasi-steady state magnetospheric configuration usually resulted after about 3 hours in real time.

Figure 1a shows the configuration of magnetic field lines in a view from the Sun for a simulation with 30° dipole tilt, IMF B_z = -5 nT and B_y = 5 nT during southward IMF. There are two reconnection sites: one in the northern dusk sector (A) and the other in the southern dawn sector (B). In Figure 1b, the minimum magnetic field lines have been projected onto the XZ (top, left), XY (bottom, left) and YZ planes for X > -15 R_E. The two reconnection regions marked by (A) and (B) in Figure 1b can be also seen in Figure 1a. Regions (A) and (B) are not symmetric with respect to the Y and Z-axes. Region (A) shift sunward and it is closer to the equator than region (B) due to the effects of the positive dipole tilt.

Figure 2 shows the configuration of magnetic field lines in a view from the Sun (top) and the projection of the minimum magnetic field (bottom) for a simulation with 30° dipole tilt, IMF B_z = 5 nT and B_y = 5 nT during northward IMF. The magnetic reconnection occurs at high latitudes and antiparallel field regions in the northern dusk (summer) sector and in the southern dawn (winter) sector. The sites shift sunward in the summer hemisphere on the contrary tailward in winter hemisphere for finite tilt. The open field lines, which are generated in the dusk sector and their foot are on the northern ionosphere, move from dusk to dawn in the dayside magne-

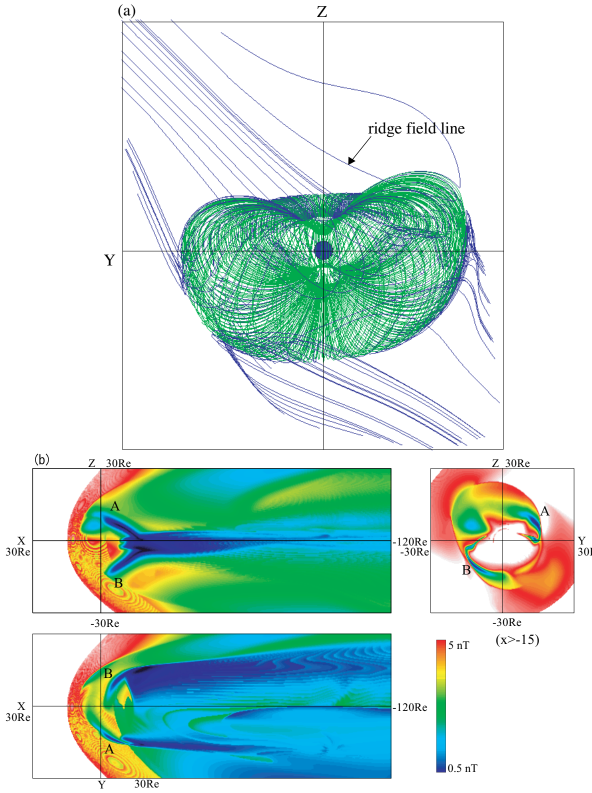

Fig. 1. The configuration of magnetic field lines viewed from the Sun (a) and the projection of minimum magnetic field strength blue (b) for dipole tilt of 30°, IMF B_z = -5 nT and IMF B_y = 5 nT.

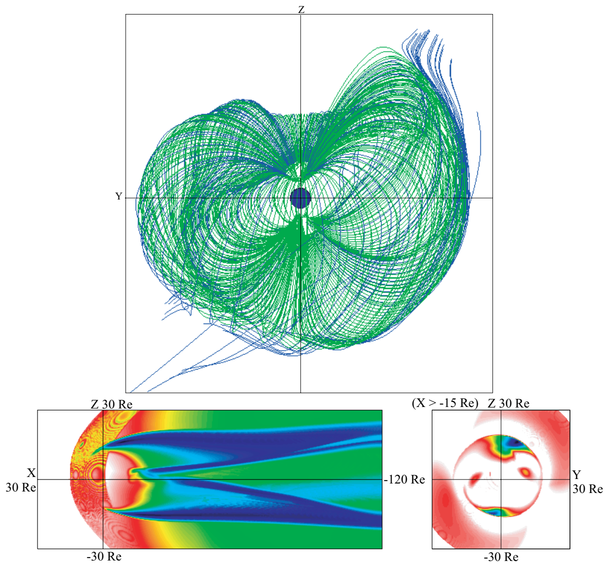

Fig. 2. The configuration of magnetic field lines viewed from the Sun (a) and the projection of minimum magnetic field strength blue (b) for dipole tilt of 30°, IMF B_z = 5 nT and IMF B_y = 5 nT.

topause and then come back to dusk in the tail. Tail reconnection successively occurs in the slant and elevated plasma sheet.

4. Discussion and Summary

We have studied dayside magnetic reconnection by using a full 3-D global MHD simulation as a function of dipole tilt, IMF B_y and B_z components. For the case of positive dipole tilt, and IMF angle is 315° (IMF B_z = -5 nT, B_y = 5nT) during southward IMF, we find that the reconnection site shifts sunward and equatorward in the summer hemisphere, and moves tailward and away from equator in the winter hemisphere. The dipole tilt has created north-south asymmetry that strongly affects the direction of the plasma flow following reconnection. The transverse velocity from the reconnection in the dusk sector is faster and moves from dusk to dawn in the summer hemisphere while it is slower and moves tailward in the winter hemisphere. For the case of positive dipole tilt, and IMF angle is 45° (IMF B_z = 5 nT, B_y = 5nT) during northward IMF, magnetic reconnection occurs at high latitudes in the northern dusk due to antiparallel field condition in the summer hemisphere for $B_y > 0$ and creates open field lines. The open field lines move from dusk to dawn in dayside and then do from dawn to dusk in the tail. The reconnection removes large amount of tail magnetic flux.

For finite dipole tilt, reconnection tends to occur preferentially at locations where the geomagnetic field magnitude is minimum, indicating that the condition $|\mathbf{B_{IMF}}| \approx |\mathbf{B_g}|$. However other factors are often more important. For adding a finite IMF B_y, the dayside magnetic reconnection near the magnetic equator becomes less effective because IMF field lines move rapidly through the magnetic equator. Moreover, subsolar (component) reconnection becomes less effective for finite tilt because the subsolar region does not satisfied either condition of the antiparallel field or the minimum magnitude. Thus we conclude that antiparallel reconnection is more dominant than component reconnection at the dayside magnetopause when either finite dipole tilt or IMF B_y component exists.

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