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Magnetosphere-ionosphere coupling in Jupiter's middle magnetosphere: computations including a self-consistent current sheet magnetic field model

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Abstract

In this paper we consider the effect of a self-consistently computed magnetosdisc field structure on the magnetosphere-ionosphere (M-I) coupling current system at Jupiter. Specifically, we we incorporate the calculation of the plasma angular velocity profile using Hill-Pontius theory into the magnetodisc model of [1], such that the resulting magnetosphere-ionosphere currents are computed using values of the equatorial magnetic field self-consistent with the plasma angular velocity profile. In doing so we update the model results of [1] using more realistic plasma parameters, including values obtained from Galileo data. We find that the azimuthal current intensity, and thus the stretching of the magnetic field lines, is dependent on the magnetosphere-ionosphere coupling current system parameters, i.e. the ionospheric Pedersen conductivity and iogenic plasma mass outflow rate. Overall, however, the equatorial magnetic field profiles obtained are similar in the inner region to those used previously, such that the currents are of the same order as previous solutions obtained using a fixed empirical equatorial field strength model, although in the outer region the fringing field of the current disc acts to reverse the field-aligned current. We also find that, while the azimuthal current in the inner region is dominated by hot plasma pressure, as is generally held to be the case at Jupiter, the use of a realistic plasma angular velocity profile actually results in the centrifugal current becoming dominant in the outer magnetosphere. In addition, despite the dependence of the intensity of the azimuthal current on the magnetosphere-ionosphere coupling current system parameters, the location of the peak field-aligned current in the equatorial plane also varies, such that the ionospheric location remains roughly constant. It is thus found that significant changes to the mass density of the iogenic plasma disc are required to explain the variation in the main oval location observed using HST.

1. Introduction

The jovian M-I coupling current system has been studied theoretically [e.g. [2, 3, 6]], but a key limitation of the preceding studies is that they have all employed fixed magnetic field models as the basis for the computations. However, [1] showed that the stretching of Jupiter's middle magnetosphere field lines is caused in part by the centrifugal force of iogenic plasma, a quantity specifically associated with the iogenic plasma mass density and angular velocity profile. He used a corotation breakdown scale distance ρ_H of 20 $\mathrm{R_J}$ in conformity with the value deduced by [4], and in his model the plasma angular velocity thus falls to ~17% of rigid corotation by 60 $\mathrm{R_J}$. However, observational studies have reported that the plasma angular velocities remain at ~50% of rigid corotation out to ~60 $\mathrm{R_J}$, and [5] later revised his estimate of ρ_H to 30 $\mathrm{R_J}$, such that the middle magnetosphere plasma angular velocities employed by [1], and thus the centrifugal force imparted by the iogenic plasma, are somewhat lower than realistically expected. The purpose of the present paper is thus twofold. First, we incorporate the calculation of the plasma angular velocity profile using Hill-Pontius theory into the model of [1], such that the resulting magnetosphere-ionosphere currents are computed using values of the equatorial magnetic field self-consistent with the plasma angular velocity profile. Second, in doing so we will update the model results of [1] using more realistic plasma parameters, including values obtained from Galileo data.

2. Results

We have employed ranges of values of the ionospheric Pedersen conductance Σ_P^* and the iogenic plasma mass outflow rate $\dot{M}$, two parameters whose exact values are unknown. Figure 1 shows the structures of the magnetic field (black contours) and total azimuthal current density (colours) as computed using

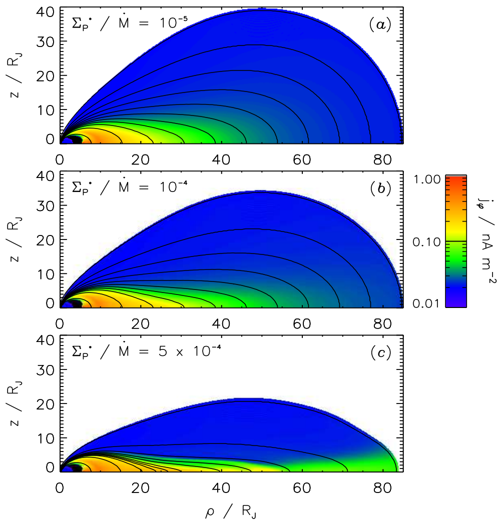

Figure 1: Plot showing the magnetic field and current sheet structures as computed using 3 values of the quotient (Σ_P^* / $\dot{M}$), i.e. (a) 10^{-5}, (b) 10^{-4}, and (c) 5×10^{-4} mho s kg^{-1}. The black lines are contours of α, thus indicating magnetic field lines, and the colours indicate the azimuthal current density j_φ in nA m^{-2}.

3 values for the quotient $(\Sigma_P^*/\dot{M})$ = 10^{-5}, 10^{-4}, and 5×10^{-4} mho s kg^{-1}. [6] showed that higher values of $(\Sigma_P^*/\dot{M})$ result in higher plasma angular velocity values, and it is apparent that higher values of this quotient result in a more stretched magnetic field structure with a thinner, more intense current sheet, particularly in the region outward of $\sim$20 $\mathrm{R_J}$. The increased azimuthal current for higher values of $(\Sigma_P^*/\dot{M})$ is required to balance the elevated centrifugal force imparted by the faster-rotating equatorial plasma for higher values of $(\Sigma_P^*/\dot{M})$, and it is this centrifugal component which is responsible for the thickening of the current sheet in the outer region of Figure 1c. We have also computed the various M-I coupling current system parameters, and the results are summarised in the following section.

3. Summary and Conclusions

Overall, the equatorial magnetic field profiles obtained are similar in the inner region to those used previously, such that the currents are of the same order as previous solutions obtained using a fixed empirical equatorial field strength model, although in the outer region the fringing field of the current disc acts to reverse the field-aligned current. We also find that, while the azimuthal current in the inner region is dominated by hot plasma pressure, as is generally held to be the case at Jupiter, the use of a realistic plasma angular velocity profile actually results in the centrifugal current becoming dominant in the outer magnetosphere. In addition, despite the dependence of the intensity of the azimuthal current on the magnetosphere-ionosphere coupling current system parameters, the location of the peak field-aligned current in the equatorial plane also varies, such that the ionospheric location remains roughly constant. It is thus found that significant changes to the mass density of the iogenic plasma disc are required to explain the variation in the main oval location observed using HST.

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