2D plasma sheet ion density and temperature profiles for northward and southward IMF

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[1] We previously developed a method for inferring plasma sheet ion temperature and density from ionospheric observations. Using this method and DMSP observations for 1992, we present 2D profiles of the equatorial plasma sheet ion density and temperature for southward and northward IMF for h2i > 64° or Kp < ~3. During periods of northward IMF, cold dense ions can be found plentifully along the plasma sheet flanks. However, during periods of southward IMF, the presence of these cold dense ions has been nearly diminished, especially at the dusk flank where the density peak is less discernable. These cold dense ions have been previously interpreted in terms of magnetosheath ion entry into the plasma sheet. Our result suggests that any mechanism proposed to transport magnetosheath ions from dusk LLBL to the plasma sheet along the dusk flank during periods of northward IMF would have to be able to do so efficiently over a large spatial scale. INDEX TERMS: 2764 Magnetospheric Physics: Plasma sheet; 2748 Magnetospheric Physics: Magnetotail boundary layers; 2744 Magnetospheric Physics: Magnetotail; 2784 Magnetospheric Physics: Solar wind/magnetosphere interactions

1. Introduction

[2] The Earth’s magnetotail plasma is highly variable spatially as well as temporally. The 1D plasma sheet temperature (T), density (n), and pressure (p) profiles along the midnight meridian or along dawn-dusk are well known [e.g., Angelopoulos et al., 1993; Spence et al., 1989; Huang and Frank, 1994; Baumjohann et al., 1989]. These plasma sheet parameters have strong dependence on the geomagnetic activity [e.g., Huang and Frank, 1994; Baumjohann et al., 1989, 1990] and on the solar wind and IMF [e.g., Borovsky et al., 1998; Terasawa et al., 1997]. These parameters are obtained from in situ measurements taken by satellites that sampled only relatively small portions of the magnetotail. As a result, these studies typically have to average over large areas that are in tens to hundreds of cubic Earth radii (Re).

[3] We have previously developed a method to infer the plasma sheet n, T, and p from ionospheric observations. Ionospheric polar orbiting satellites move rapidly, with a typical orbital period near 100 min, allowing them to image the plasma sheet 25 times per day. Plasma in the plasma sheet has been observed to be nearly isotropic [e.g., Spence et al., 1989; Kistler et al., 1992; Huang and Frank, 1994] and as a result p, n, and T are conserved along the field line. Because of the abundance of the ionospheric observations, inferred 2-D spatial profiles of plasma sheet ion temperature, density, and pressure could be constructed at unprecedented fine spatial resolution [Wing and Newell, 1998].

[4] Magnetosheath ion entry into the plasma sheet has been inferred from observations of cold dense ions in the plasma sheet flanks in several Geotail passes [e.g., Fujimoto et al., 1998]. Using observations from the same satellite, Terasawa et al. [1997] show that during periods of northward IMF plasma sheet ions are on average denser and colder and there are temperature minima and density maxima near the dawn and dusk flanks. However, because of limited spatial coverage, these and other similar results from in situ observations were obtained by averaging over a large region, blurring the spatial extent of these cold dense ions. Recently Fairfield et al. [2000] and Otto and Fairfield [2000] present a Geotail event near the dusk flank during a period of northward IMF and an MHD simulation of the same event. Based on their detail analysis, these authors argue for Kelvin-Helmholtz (KH) instability as an important mechanism for bringing magnetosheath ions from the dusk flank into the plasma sheet during periods of strongly northward IMF.

[5] Motivated by these results, this study investigates the effect of the IMF Bz in the 2D equatorial plasma sheet n and T profiles with the method developed in Wing and Newell [1998].

2. Data Set

[6] For this study, we used data obtained from the SSJ4 instrument onboard DMSP satellites F8, F9, F10, and F11 for the entire year of 1992. In 1992, there were at least three DMSP satellites in operation simultaneously (F8, F10, and either F9 or F11); for one month, March, all four were in operation. Because of its upward pointing and limited pitch angle resolution, DMSP SSJ4 measures only highly field-aligned precipitating particles at an altitude of roughly 835 km.

[7] NASA NSSDC OMNIWeb provides the IMP-8 hourly average solar wind data.

3. Method for Inferring Plasma Sheet Ion n, T, and p from Ionospheric Observations

[8] The method for inferring the plasma sheet ion n, T, and p from the DMSP SSJ4 measurements has been described fully elsewhere [Wing and Newell, 1998, 2000] and is briefly summarized here.

[9] It has been known for more than two decades that energetic ions observed in the topside ionosphere are isotropic above a certain latitude [e.g., Bernstein et al., 1974]. Likewise, an overwhelming number of in situ observations in the plasma sheet tailward of ~8–10 RE indicate that plasma is nearly isotropic, irrespective of activity levels [e.g., Kistler et al., 1992; Spence et al., 1989; Huang and Frank, 1994]. As a result, n, T, and p are approximately conserved along the magnetic field line. The ions maintain their isotropy by pitch angle scattering in the tail current sheet [Lyons and Speiser, 1982]. Nearer to Earth (typically earthward of ~8–10 RE, although this distance varies with magnetic activity), the field line becomes more dipolar, and the pitch angle scattering ceases. As a result, our method does not work in this region. Newell et al. [1996, 1998] have developed a computer algorithm for identifying the equatorward isotropy boundary in the ionosphere (b2i) or equivalently the earthward boundary of the central plasma sheet. Sergeev et al. [1993]
showed that the ion isotropy boundary (or b2i) highly correlates with the tail inclination angle measured in the same local time sector by GOES geosynchronous satellites (correlation coefficient = 0.9). Therefore b2i can be used to modify and improve ionosphere-magnetosphere T89 magnetic field model [Tsyganenko, 1989] tail mapping [Sergeev et al., 1993] and has been adapted into our method. Because b2i has a local time variation, it is normalized to its midnight value.

[10] Electron acceleration events are excluded from the data because they distort the plasma sheet ion spectra, resulting in distributions that do not represent those in the plasma sheet. Instead of computing moment, which is widely used, each ion spectrum is fitted to distribution functions (one-component Maxwellian, two-component Maxwellian, and $\kappa$) and the best fit is selected. This takes into account ions outside the detectors’ energy range.

4. The Quiet Time 2D Plasma Sheet T, n, and p Profiles

[11] The inferred 2D magnetically quiet time ion $p$, $T$, and $n$ profiles in the neutral sheet averaged in $1 \times 1$ $R_E$ bins are shown in Figures 1a–1c respectively. The data in these figures have an average $Kp \sim 1.5$ and $b2i = 66^\circ – 68^\circ$. As shown in Figures 1a and 1b, pressure and temperature are higher in the dusk-premidnight than in the postmidnight-dawn sector in the near Earth region, between $\sim 8–10$ $R_E$ from the Earth. This result is consistent with

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**Figure 1.** Two-dimensional equatorial profiles of plasma sheet ion (a) pressure, (b) temperature, and (c) density during quiet time, normalized b2i = 66°–68°, average Kp $\sim$1.5 (from plates 1, 3, and 4 of Wing and Newell [1998]). The ion density profile for combined quiet and moderate time, normalized b2i $> 64^\circ$ or Kp $< 3$ is shown in (d). Each point is averaged over $1 \times 1$ $R_E$ regions. Some regions are left blank either because of insufficient data points or because plasma is anisotropic (in the region closer to the Earth).
the $E \times B$ and the gradient/curvature motions of ions originating from the deep tail and low-latitude boundary layer (LLBL). The $E \times B$ convection moves ions of all energies Earthward, but the curvature and gradient duskward (or westward) drift separates the ions by energy. Colder ions convect Earthward with little westward/duskward displacement, but hotter ions drift further duskward, resulting in a higher temperature and pressure in the dusk-premidnight sector at approximately 8–10 RE away from the Earth. Figures 1b and 1c show that the temperature is colder and density higher near both flanks, where most likely there is mixing of colder magnetosheath like ions from LLBL and hotter ions from the plasma sheet [e.g., Fujimoto et al., 1998; Eastman et al., 1985; Spence and Kivelson, 1993]. The Finite-width magnetotail convection model calculation, which takes into account deep tail and dawn LLBL ions undergoing $E \times B$ and gradient/curvature drifts, shows that (a) pressure and temperature have a maximum in the near-Earth dusk sector and (b) along the dawn flank, the temperature has a minimum and the density has a maximum [Spence and Kivelson, 1993]. The model does not include the dusk LLBL ion source, which explains the absence of the temperature minimum and the density maximum in the dusk flank. Figures 1b and 1c suggest that LLBL ions may enter the plasma sheet along the dusk flank, which is the main topic in the next two sections of this paper. The plasma pressure also has a maximum near midnight that may have resulted partly from weaker magnetic field and pressure balance. In addition, bursty bulk flows (BBFs) which occur more frequently near the midnight meridian may also contribute to the higher pressure and temperature near midnight meridian [e.g.,

Figure 2. The IMF $B_z$ dependence of the plasma sheet ion density and temperature constructed from the same data set used in Figure 1d, $b2i > 64^\circ$ or $Kp < 3$. The ion density 2D profiles for the northward and southward IMF are shown in (a) and (b) respectively and their corresponding temperature profiles are shown in (c) and (d) respectively.
5. IMF $B_z$ Effect on Plasma Sheet Ion $n$ and $T$

We have previously separated the plasma sheet ion $n$, $T$, and $p$ by $b_2$ or magnetic activity [Wing and Newell, 1998]. Motivated by recent results [e.g., Fairfield et al., 2000; Otto and Fairfield, 2000], we searched for the IMF $B_z$ dependence of the plasma sheet ion $n$ and $T$. In order to increase the number of points, we included data for quiet and moderate time, normalized $b_2 > 64$° or $K_p < 3$. Figure 1d shows the 2D equatorial density profile when data for all IMF $B_z$. Figure 1d shows that the density is generally higher than the quiet time density, in agreement with previous in situ measurements [e.g., Baumjohann et al., 1989]. Apart from the higher density in Figure 1d, Figures 1d and 1c are similar in that both show the presence of density peaks at both the dusk and dawn flanks. However, starkly contrasting pictures of the plasma sheet flanks emerge when the data in Figure 1d are separated by the sign of the 2-component of IMFs. This was done using IMF 8-hourly average IMF data. The results are shown in Figures 2a and b for northward and southward IMF, respectively. As previously reported, the plasma sheet ion density is higher during periods of northward IMF than southward IMF [e.g., Terasawa et al., 1997], but the profile is presented here in more detail in 2D. During periods of northward IMF, density peaks appear along the plasma sheet dusk and dawn flanks. However, during periods of southward IMF, in the dawn flank the density peak is weaker and broader (in the $y$ direction) and in the dusk flank it is even less discernable. During periods of northward IMF, the temperature minimum is smaller and weaker, as shown in Figure 2c. However, during periods of southward IMF, the temperature minimum is smaller and narrower, as shown in Figure 2d.

6. Discussion and Summary

For the first time, the IMF $B_z$ dependence of the plasma sheet ion $n$ and $T$ profiles is exhibited in fine spatial detail in 2D. The plasma sheet ion $n$ and $T$ profiles generally differ for the northward and southward IMF cases, but the most remarkable contrast occurs in the density profiles along the plasma sheet dusk flank. During periods of northward IMF, ions are colder and denser along both flanks of the plasma sheet, i.e. adjacent to the magnetopause. However, during periods of southward IMF, this density peak is smaller along the dawn flank, and it is barely discernable along the dusk flank. Likewise, the temperature minima are smaller and narrower at the flanks, but the dawn-dusk asymmetry appears not to be as strong as in the density profile. This result is consistent with the previous Geotail observations [Terasawa et al., 1997], but here the spatial extent of these cold dense ions is shown in detail in 2D. The presence of the cold dense ions along the plasma sheet flanks has been interpreted as a strong indication of magnetosheath ion entry [e.g., Fujimoto et al., 1998]. Consequently, the result here indicates that far more magnetosheath ions enter from the dusk LLBL during periods of northward IMF than during periods of southward IMF. Otto and Fairfield [2000] and Fairfield et al. [2000] demonstrate that KH instability can transport massive magnetosheath ions effectively across the magnetopause dawn and dusk flanks. Other mechanisms may also be possible and need to be investigated. However, the result here indicates that any such mechanism would have to be able to transport ions efficiently over a very large spatial scale.

References


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