LARGE SCALE PLASMA SHEET STRUCTURE - A STATISTICAL APPROACH

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ABSTRACT

When Cluster crosses the magnetotail, the boundary between the lobe and the plasma sheet is clearly defined by a distinct change in the ion flux. The identification of this boundary has, combined with calculations of the neutral sheet location at the time of boundary crossings, been used to estimate the half thickness of the plasma sheet. A method, based on the variation in the dipole tilt angle, has been used to estimate the neutral sheet position relative to the GSM xy-plane for magnetic local times (MLT) near midnight. The plasma sheet thickness was then divided into geomagnetically active an non-active periods and compared with 7 solar wind parameters.

1. INTRODUCTION

It is known that the solar wind has a strong effect on the geomagnetic tail. In this study we want to find the solar wind influence on the structure of the plasma sheet.

Before the Cluster satellites were launched in 2000, it was not possible to study the topography of the plasma sheet at high latitudes, because earlier satellites have been in near equatorial orbits. The plasma sheet is very dynamic and both waves and flapping motion appears frequently. In this study we will focus on the large scale structure and behaviour, by comparing the plasma sheet thickness with variations in the solar wind. A statistical study of the plasma sheet will give a picture of how the dynamic plasma sheet is affected by the solar wind and how the magnetic configuration changes during a storm.

In this study, four years of data from August and September is used. At this time of the year, Cluster orbits close to the midnight tail (±15^o MLT) and measurements made on the tail flanks is not included. This choice of data minimize the effect of tail twisting [5] caused by strong IMF By components in the solar wind.

In the following, we will first describe our method for estimating the plasma sheet thickness. Thereafter we will go through the treatment of the data and finally we will discuss the correlation analysis between the plasma sheet thickness and the solar wind variation.

2. METHOD

The northern plasma sheet boundary layer (PSBL) will in most cases be crossed hours before the southern boundary. During this time interval, the tail may reconfigure significantly. The best solution is to find the plasma sheet thickness each time a Cluster satellite crosses the PSBL. The plasma sheet half thickness can be found by finding the neutral sheet position each time the PSBL is crossed. If we assume that the plasma sheet is symmetric about the neutral sheet we can also estimate the plasma sheet thickness.

2.1 Neutral sheet position

Knowing the configuration of the neutral sheet is important for finding its position relative to the GSM coordinate system.

Close to the Earth the neutral sheet is considered to be in the plane of the magnetic equator. With increasing distance from Earth, the effect of the solar wind gets stronger. At a point the solar wind flow will control the neutral sheet and it is bent away from the magnetic equator and becomes almost parallel to the GSM xy-plane. The point where the neutral sheet no longer follows the magnetic equator is called the hinging point. Using the distance along the xy-plane between the Earth and the hinging point, D_H, the dipole tilt angle, θ, and the distance between the neutral sheet and the GSM xy-plane, Z_N can be found. The geometry in this method is shown in Fig.1.

In order to use this method we have to assume that the neutral sheet is nearly parallel to the GSM xy-plane. This assumption may not be correct at all times, but gives a good approximation between the hinging point

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and x ~ $100R_E$ [8]. The Cluster orbit never exceeds $x = -20R_E$.

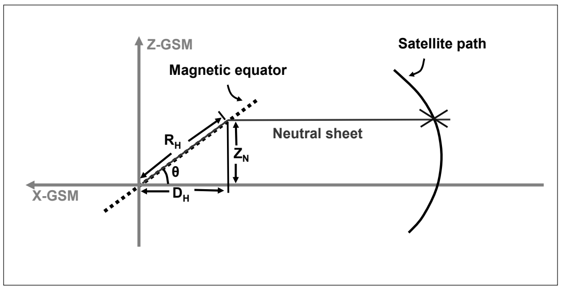

Fig.1. The position of the neutral sheet can be found by using simple geometry. D_H is the hinging distance and θ is the dipole tilt angle.

First we need to find the distance, D_H. Each time Cluster crosses the neutral sheet, we can find Z_N. By knowing the dipole tilt angle at the time of crossing, D_H can be calculated. Later the average value of D_H is used to estimate Z_N when Cluster crosses the PSBL. D_H is found to be $7.0R_E$. The neutral sheet crossings are identified by the change of sign in the x-component of the magnetic field.

Comparing measured and calculated values of the neutral sheet position, we get a 73% correlation. There were four special days with very large deviation. These measurements were considered outliers and data from these days were left out of our study.

Previously, several studies on the shape of the neutral sheet have been made (e.g. [1] [6] [3]). Tsyganenko and Fairfield [9] have presented a method for determining the neutral sheet position above the GSM xy-plane considering the dipole tilt angle and solar wind conditions. This method used on the same neutral sheet crossings, also resulted in a 73% correlation between measured and calculated values. This indicates that our method which is more simple, gives good results for measurements between $x = R_E$ to $x = -20R_E$.

2.2 New coordinate system

The GSM coordinate system is not the best system to use for studying tail dynamics. Since the tail configuration is strongly dependent on the dipole tilt angle, this should be corrected for. A solar dipolar coordinate system (SD), which is aligned with the dipolar movement of the neutral sheet in the GSM coordinate system, was therefore used. The relation between the GSE, GSM and SD coordinate system is illustrated in Fig.2.

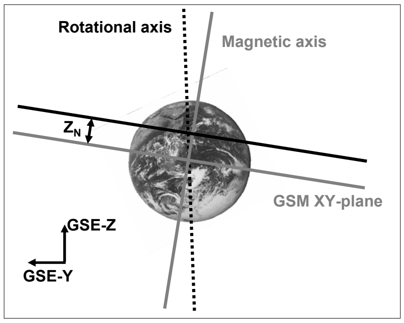

Fig.2. Illustration of the SD coordinate system relative to GSE and GSM coordinates.

3. DATA

3.1 Plasma sheet thickness

The plasma sheet half thickness is then calculated each time the Cluster satellites crosses the PSBL. When the satellite crosses from the lobe into the plasma sheet, the particle density rises dramatically. This gradient in the ion energy flux measured by CIS has been used to identify the PSBL crossings. Using data from 2001 until 2004 resulted in a total of 921 boundary crossings. The half thickness is calculated for different GSM x-positions as can bee seen in Fig.3.

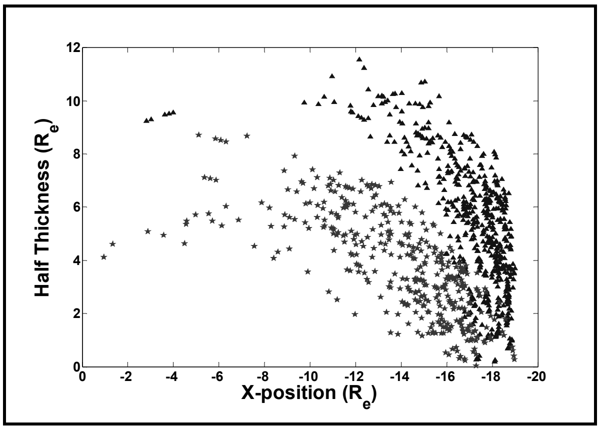

Fig.3. The half thickness of the plasma sheet as a function of the satellite x-position. The two populations in the figure refer to measurements above (stars) and below (triangles) the neutral sheet.

The line of apside for the Cluster satellites has an angle relative to the GSE xy-plane, as illustrated in Fig.4. This makes Cluster encounter the PSBL at higher latitudes below the neutral sheet than above, and we get a larger sampling area.

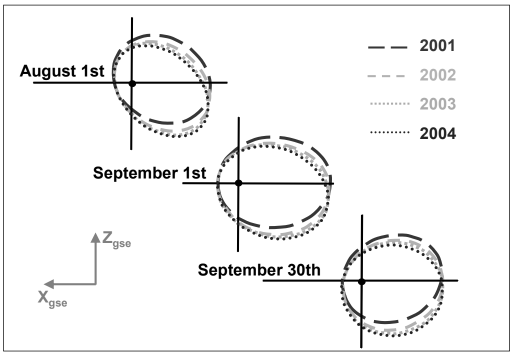

Fig.4. Changes in the Cluster orbit relative to the GSE x-coordinate system during four years of study.

The plasma sheet is in general thicker closer to earth than further out in the tail and an average thickness for 3 different x-positions is calculated and listed in Tab. 1.

Tab.1. Average plasma sheet half thickness measured at different x-positions.

X-position	Average half thickness
-13 R_E - -15 R_E	5.6 $R_E \pm 3$ R_E
-15 R_E - -17 R_E	4.5 $R_E \pm 2$ R_E
-17 R_E - -19 R_E	4.0 $R_E \pm 2$ R_E

Kaufmann et al. [4] found a plasma sheet half thickness of 2.5R_E in the midnight tail and about 5R_E on the tail flanks. We find smaller values for the plasma sheet half thickness than Kaufmann et al. The difference is most likely affected by the difference in the x-position at which the measurements were taken. Kaufmann et al. [4] uses data from Geotail which crosses the tail between -10R_E and -30R_E along the x-axis. This is about 10R_E further out than the Cluster orbit and the plasma sheet is thinner at these distances from the Earth. Another issue is that since Geotail is in an equatorial orbit the method for calculating the plasma sheet thickness is very different from the one used in this study. This may also cause a slight difference.

4. SOLAR WIND CORRELATION

4.1 Time delay

Different solar wind parameters (listed in Tab.2.) calculated with data from the ACE satellite, are then compared with the plasma sheet half thickness. The time delay from the satellite to the magnetopause is found by using the solar wind speed and the distance to the magnetopause [7].

Eriksson et al. [2] have tried to find how long time it takes before the tail responds to changes in the solar wind at the magnetopause. They found a maximum correlation at two time intervals, 35 minutes and 65 minutes. The short time interval is related to a direct response while the hour long interval is related to the release of energy build up in the tail. A 35 minutes time delay is used in this study since we are interested in the direct relation between the solar wind and the tail.

A problem using a fixed time delay is that the time it takes for the tail to respond to changes at the magnetopause can vary between the different PSBL crossings. To lower this uncertainty, the solar wind data is averaged over 20 minutes, 10 minutes before and after each time Cluster crosses the PSBL. Doing this we eliminate some of the variation in the solar wind which may have a good correlation with the variation in the plasma sheet half thickness.

4.2 Geomagnetic activity

Before we start the correlation analysis, the data are divided into high and low geomagnetic activity. We use the AE/AL index to indicate the geomagnetic activity. A quiet period is defined as a period with an average $AE_{average} < 50$nT and $AE_{maximum} < 100$nT. For a tail crossing to qualify as a quiet period these conditions has to last for six hour before the period start to make sure there are no disturbances left in the system. An active period is defined by an $AE_{average} > 500$nT and an $AE_{maximum} > 1000$nT. The days that fall between active and quiet periods is not considered any further in this study.

After this selection we are left with 122 measurements made during low geomagnetic activity, and 212 measurements during high geomagnetic activity.

4.3 Correlation analysis

The best correlation is achieved during periods with low geomagnetic activity. The IMF Bz has a correlation of 0.5 with the plasma sheet thickness which is the highest value achieved in this study. This is a significant correlation, but the low value implies that the solar wind is not the only contribution to the reshaping of the plasma sheet. The different parameters that are tested are listed in Tab.2. with the corresponding correlation coefficients, cc, calculated during high and low geomagnetic activity.

Tab.2. Correlation coefficients between solar wind parameters and the plasma sheet half thickness. The two columns correspond to high and low geomagnetic activity.

Parameter	cc_{high}	cc_{low}
SW Pressure	-0.1	0.3
Epsilon	-0.2	0.3
IMF |B|	-0.1	0.3
IMF Bx	0.0	0.1
IMF By	0.1	0.2
IMF Bz	0.3	0.5
Clock angle	-0.4	-0.4

During periods with negative Bz a reconnection on the dayside magnetopause is likely to occur. The solar wind then transports the newly opened field lines from the dayside magnetosphere to the tail. This leads to an increase in the tail magnetic flux and thus a thinner plasma sheet. As negative Bz leads to thinner plasma sheet a positive correlation is expected. The z-component of the solar wind is plotted versus the plasma sheet half thickness in Fig.5.

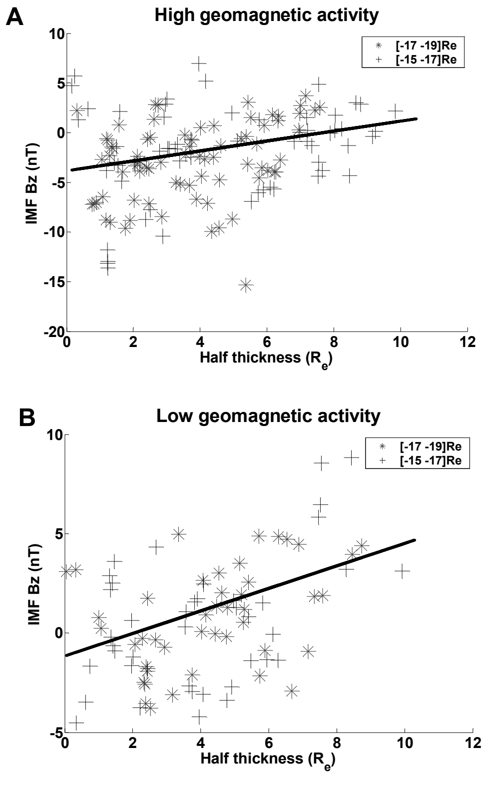

Fig.5. The z-component of the solar wind magnetic field compared with the plasma sheet half thickness during high and low geomagnetic activity.

For low geomagnetic activity the correlation is 0.5 and for high activity the correlation is 0.3. The regression line drawn for the high activity period (Fig.5a) has a slightly steeper slope than during low activity periods (Fig.5b) (note the different scales on the z-axis). The figure shows that the Bz component is more often negative during high magnetic activity. The positive correlation coefficient is in agreement with the expected results.

During high geomagnetic activity there is a upper boundary of about $6R_E$ in the plasma sheet half thickness measured between $-17R_E$ and $-19R_E$. This cut-off is not seen in Fig.5b., indicating that the plasma sheet is not influenced by magnetic reconnection or current sheet thinning during low geomagnetic activity.

5. SUMMARY AND CONCLUSION

The orbits of the Cluster spacecrafts allow for observations of the PSBL at higher latitudes than previously possible with satellites at lower latitudes.

In this study we have presented a new method for estimating the plasma sheet thickness by finding the position of the neutral sheet and using data from the Cluster satellites. Depending on the distance from Earth, the plasma sheet half thickness found in this study, varies from $4.0R_E$ to $5.6R_E$ close to the magnetic midnight sector.

The correlation between the plasma sheet thickness and solar wind parameters were generally low. The best correlation was found during low geomagnetic activity. A reason for this might be that the magnetic configuration is less disturbed and the configuration and motion of the tail is not as complex as during high geomagnetic activity.

Changing the time delay between the magnetopause to the tail did not have a significant impact on the correlation. A reason for this might be the 20 minutes averaging of the solar wind data.

To achieve a better correlation we probably need to know the position and movement of the PSBL between each time Cluster crosses the boundary. The half thickness could be directly compared without averaging the solar wind data, loosing the dynamic variations. One way to do this is by using all four satellites in periods when the spacecrafts have large separation in the z-direction. It will then be possible to see the movement of the plasma sheet in more details.

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