

STORM TIME VARIATION OF THE STANDOFF DISTANCE

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Abstract. It is shown that influence of the cross-tail current on the standoff distance during intense storms can be more considerable than that of the solar wind pressure.

Introduction

The geocentric distance to the subsolar point on the magnetopause (the standoff distance) is supposed to depend almost exclusively on the solar wind dynamic pressure, even during intense storms (e.g. [Akasofu and Chapman, 1972]). After the interplanetary magnetic field turns southward the dayside magnetopause moves earthward in spite of the solar wind pressure being unchanged [Aubry *et al.*, 1970]. This phenomenon known as erosion of the dayside magnetosphere, has been explained by the effect of the region 1 Birkeland current [Maltsev and Lyatsky, 1975]. The Birkeland current of the typical magnitude is capable to move the magnetopause by about 1 R_E . During storms, however, considerably greater displacements are observed. This paper estimates the contribution of several factors to the erosion.

Calculations

The standoff distance r_s is determined from the pressure balance condition on the magnetopause:

$$(2\mu_0 p_{st})^{1/2} = B_z^{dip} + B_z^{RC} + B_z^{Birk} + B_z^{TC} \quad (1)$$

where p_{st} is the solar wind pressure in the stagnation point; the right-hand side of (1) contains the sum of the magnetic fields of the Earth's dipole, of the ring, Birkeland, and cross-tail currents, respectively, all the fields being screened by the magnetopause currents. These fields are schematically shown in Fig.1.

The model by Mead [1964] predicts $B_z^{dip} \approx 2.4 M_E / r_s^3$ where M_E is the Earth's magnetic moment.

Similarly we can write $B_z^{RC} \approx 2.4 M_{RC} / r_s^3$, where M_{RC} is the magnetic moment of the ring current. The value of M_{RC}/M_E is usually of the order of 0.1-0.3 [Stern, 1985]. Maltsev and Lyatsky [1975], using a simple model, estimated $B_z^{Birk} \approx \mu_0 I / 2\pi r_s$, where I is the total region 1 Birkeland current.

According to the computations by Tsyganenko and Sibeck [1994], $B_z^{TC} \approx 0.57 B_x^{lobe}$, where B_x^{lobe} is the magnetic field x -component in the magnetotail lobes near the inner edge of the cross-tail current (at $x_{gsm} = -6.6 R_E$ and $z_{gsm} = 5 R_E$). The measurements at $6.6 R_E$ show that $B_x^{lobe} \approx \kappa |Dst|$ during storms [Bolshov, 1995], where factor κ varies from ~ 1 for $Dst = -50$ nT to ~ 2 for $Dst = -100$ nT. Thus we have $B_z^{TC} \approx \alpha |Dst|$, where $\alpha = 0.57\kappa$.

Spreiter *et al.* [1966] calculated $p_{st} \approx 0.88 p$, where p is the solar wind dynamic pressure.

Expressing the magnetic field in nT, p in nPa, r_s in R_E , and I in MA, we rewrite (1) as follows

$$47p^{1/2} \approx 74400 (1 + M_{RC} / M_E) / r_s^3 - 50I / r_s - \alpha |Dst| \quad (2)$$

Equation (2) allows to find the standoff distance:

$$r_s \approx 42 \left(\frac{1 + M_{RC} / M_E}{47p^{1/2} + \alpha |Dst| + 50I / r_s} \right)^{1/3} \quad (3)$$

Since the Birkeland current is unlikely to exceed significantly the magnitude of 3 MA, its magnetic field $B_z^{Birk} \approx 50 I / r_s$ usually presents a small addition to the denominator of the right-hand side of equation (3), so that the standoff distance can be calculated with the help of the iteration method.

For quiet conditions ($Dst \approx 0$, $I \approx 0$), formula (3) is reduced to the well-known expression

$$r_s \approx 11.65 (1 + M_{RC} / M_E)^{1/3} p^{-1/6} \quad (4)$$

Assuming $p = 2$ nPa, $M_{RC}/M_E = 0.2$, we obtain $r_s \approx 11 R_E$.

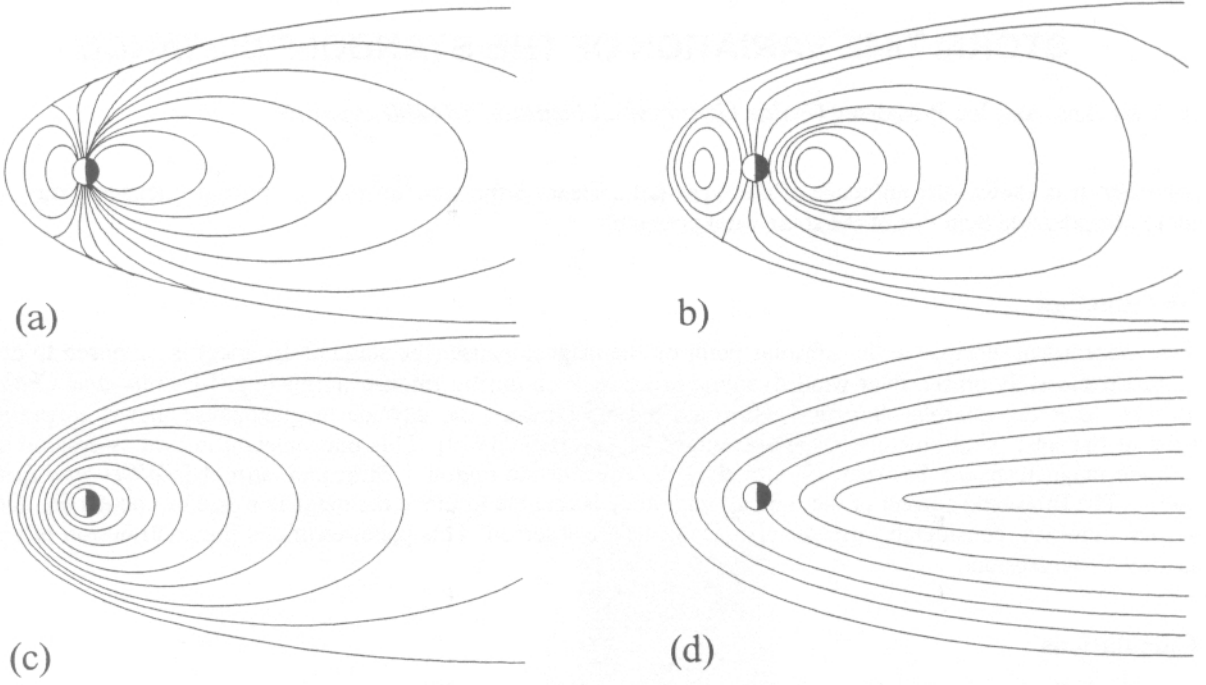


Figure 1. Magnetic field lines (a) of the Earth's magnetic dipole, (b) of the ring current, (c) of the Birkeland and (d) of the cross-tail currents, all the fields being shielded by the magnetopause currents.

During disturbed periods both I and $|Dst|$ grow. The cross-tail current effect during strong storms can dominate. Assuming $\alpha |Dst| \gg 47 p^{1/2} \gg 50 I / r_s$, we obtain

$$r_s \approx 42 \left(\frac{1 + M_{RC} / M_E}{\alpha |Dst|} \right)^{1/3} \quad (5)$$

Thus the standoff distance during intense storms practically does not depend on the solar wind pressure. However expression (5) is unlikely to be typical because most storms happen under enhanced solar wind pressure. We use the more general expressions (2) and (3) to analyse results of some experiments.

Comparison with observations

Rufenach *et al.* [1989] studied 64 crossings of the magnetopause by a geosynchronous satellite. The standoff distance r_s was not determined precisely because all crossings in the whole dayside sector from 06 to 18 LT were examined. Since the subsolar point is closer to the Earth than any other points on the magnetopause we may conclude that the average r_s was smaller than $6.6 R_E$. Average Dst for 64 crossings was -108 nT, the average solar wind dynamic pressure p was 15 nPa. Substituting such Dst and p into (3), and assuming $M_{RC}/M_E = 0.2$, $I = 3$ MA, and $\alpha = 1$, we obtain $r_s \approx 6.4 R_E$ which is close to the observed value.

The magnetopause was detected at the distance of $r_s \approx 5.2 R_E$ during extremely strong storm of February 8-9, 1986 [Hamilton *et al.*, 1988]. The value of Dst was equal to -257 nT at that moment, the solar wind velocity was greater than 1200 km/s, the proton density was not measured, however Hamilton *et al.* [1988] suppose it to be higher than 10 cm^{-3} which gives $p > 25$ nPa. Substituting $Dst = -257$ nT and $r_s \approx 5.2 R_E$ to (2), and assuming $I = 3$ MA, $M_{RC}/M_E = 0.2$, we obtain that the condition $p > 25$ nPa leads to $\alpha < 1.44$.

During the strongest storm of the 20th century occurred on March 13, 1989, when Dst reached -599 nT, the standoff distance was $4.7 R_E$ [Allen *et al.*, 1989]. The solar wind pressure is not available for this period. However if we neglect the effects of the pressure and Birkeland current in (2) or (3), we obtain the relation between the observed Dst and r_s under rather reasonable value of $\alpha \approx 1.4$.

The November 24, 1981 storm with $Dst = -70$ nT occurred under very low solar wind dynamic pressure, $p = 0.77$ nPa. The standoff distance was $r_s \approx 10.1 R_E$ from 04 to 08 UT [Malkov and Sergeev, 1991]. The Birkeland current may be roughly estimated from the observed $AL \approx 250$. The AL index is of the order of the H component of the magnetic disturbance under the westward auroral electrojet. We know that a plane with the surface current density J produces the disturbance $H \approx 0.63 J$ (providing H is in nT, J is in A/km). Assuming $H = 250$ nT, we get $J \approx 400$

A/km. Supposing 1000 km for the electrojet width, one can obtain the total auroral electrojet current of ~ 0.4 MA. This is about a half of the Birkeland current because the other half is closed in the polar cap. Assuming $I = 0.8$ MA, we obtain from (3) that the observed standoff distance requires $\alpha = 0.6$.

The above-mentioned four experiments yield somewhat differing values of the coefficient α . It may be connected with different intensity of the storms studied. Perhaps the value of α grows with the storm time depression owing to the earthward displacement of the cross-tail current.

Conclusions

Four factors contribute to the value of the standoff distance: the solar wind dynamic pressure, the cross-tail current, the region 1 Birkeland current, and the ring current. During quiet periods, the influence of the solar wind pressure dominates. During storms, the effects of the solar wind and cross-tail current become comparable. During very intense storms, the cross-tail current can be the main factor affecting the standoff distance.

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References

- Akasofu, S.-I., and S. Chapman, Solar-terrestrial physics, *Oxford, Clarendon Press*, 1972.
- Allen, J., H.Sauer, L.Frank, and P.Reiff, Effect on March 1989 solar activity, *EOS Trans. AGU*, 70, 1488, 1989.
- Aubry, M.P., C.T.Russell, and M.J.Kivelson, On inward motion of the magnetopause before a substorm, *J.Geophys.Res.*, 75, 7018, 1970.
- Bolshov, I.I., On the conditions of appearance of thin current layers in vicinity of the geostationary orbit, paper presented at 18th Seminar on Physics of Auroral Phenomena, Polar Geophysical Institute, Apatity, Russia, February 28 to March 3, 1995.
- Hamilton, D.C., G. Gloeckler, F.M. Ipavich, W. Studemann, B. Wilken, and G. Kremser, Ring current development during the great geomagnetic storm of February 1986, *J. Geophys. Res.*, 93, 14,343, 1988.
- Malkov, M.V., and V.A.Sergeev, Peculiarities of the magnetospheric configuration under steady convectional activity, *Geomagnetism and aeronomy*, 31, 722, 1991.
- Maltsev, Y.P., and W.B. Lyatsky, Field-aligned currents and erosion of the dayside magnetosphere, *Planet. Space Sci.*, 23, 1257, 1975.
- Mead, G.D., Deformation of the geomagnetic field by the solar wind, *J. Geophys. Res.*, 69, 1181, 1964.
- Rufenach, C.L., R.F. Martin Jr., and H.H. Sauer, A study of geosynchronous magnetopause crossings, *J. Geophys. Res.*, 94, 15,125, 1989.
- Spreiter, J.R., A.L. Summer, and A.Y. Alksne, Hydromagnetic flow around the magnetosphere, *Planet. Space Sci.*, 14, 223, 1966.
- Stern, D.P., Parabolic harmonics in magnetospheric modelling: the main dipole and the ring current, *J. Geophys. Res.*, 90, 10,851, 1985.
- Tsyganenko, N.A., and D.G. Sibeck, Concerning flux erosion from the dayside magnetosphere, *J. Geophys. Res.*, 99, 13,425, 1994.