JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. A11, 1399, doi:10.1029/2003JA010187, 2003

Plasmapause response to geomagnetic storms: CRRES results

M. B. Moldwin and S. Mayerberger
Department of Earth and Space Sciences, University of California, Los Angeles, Los Angeles, California, USA

H. K. Rassoul and T. Barnicki
Department of Physics and Space Sciences, Florida Institute of Technology, Melbourne, Florida, USA

R. R. Anderson
Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa, USA

Received 6 August 2003; revised 3 September 2003; accepted 10 September 2003; published 15 November 2003.

[1] The response of the plasmapause following a geomagnetic storm is examined statistically using plasmapause observations made by the Combined Release and Radiation Effects Satellite (CRRES) plasma wave receiver instrument. The plasmapause was identified as the inner most steep density gradient. Due to CRRES' 10-hour orbital period, the plasmapause is generally sampled at two distinct local time sectors each orbit. The results from a study of 22 storms (with minimum $Dst < -30$ nT) show that the plasmapause generally moves earthward one L in the night and dawnside following a storm sudden commencement but is highly variable and statistically moves out in the dusk sector. This new result emphasizes that the plasmapause can have significant local time asymmetries that are amplified due to storm dynamics. *INDEX TERMS:* 2768 Magnetospheric Physics: Plasmasphere; 2730 Magnetospheric Physics: Magnetosphere—inner; 2788 Magnetospheric Physics: Storms and substorms; 2740 Magnetospheric Physics: Magnetospheric configuration and dynamics; *KEYWORDS:* plasmasphere, plasmapause, storms, inner magnetosphere

Citation: Moldwin, M. B., S. Mayerberger, H. K. Rassoul, T. Barnicki, and R. R. Anderson, Plasmapause response to geomagnetic storms: CRRES results, *J. Geophys. Res.*, *108*(A11), 1399, doi:10.1029/2003JA010187, 2003.

1. Introduction

[2] The dynamics of the plasmapause has been extensively studied since the earliest theoretical work explained plasmapause motion in terms of the interplay between the convection electric field and the corotation electric field [e.g., *Nishida*, 1966; *Lemaire and Gringauz*, 1998]. Therefore one can use the position of the plasmapause as a function of geomagnetic activity as an indication of the depth of penetration and strength of the convection electric field [e.g., *Chen et al.*, 1975]. A variety of statistical studies have looked at the relationship between geomagnetic indices (usually some form of average or maximum Kp in some preceding interval) and the plasmapause position using both whistlers and in situ observations [e.g., *Carpenter and Anderson*, 1992; *Moldwin et al.*, 2002; *O'Brien and Moldwin*, 2003]. In general, these studies found a linear relationship between the plasmapause position as a function of L shell and geomagnetic activity, with the plasmapause located at small radial distances for high levels of activity. The scatter in this trend is significant, and recent studies emphasize the variability of the location of the plasmapause for any given activity level, particularly for low levels of geomagnetic activity.

0148-0227/03/2003JA010187$09.00

[3] Other studies examined the dynamics of the plasmapause in response to geomagnetic storms [e.g., *Elphic et al.*, 1996; *Lambour et al.*, 1997]. The studies found systematic behavior of the plasmapause with the radial diameter of the plasmasphere shrinking and the creation of a duskside plasmaspheric plume or bulge that rotated towards noon [e.g., *Maynard and Grebowsky*, 1977; *Carpenter et al.*, 1993]. These studies were generally limited in either the number of storm intervals that could be studied [e.g., *Spasojevic et al.*, 2003] or were from the geosynchronous perspective [e.g., *Moldwin et al.*, 1994; *Elphic et al.*, 1996; *Lambour et al.*, 1997], which more generally describes plume dynamics following storms. The results from these and earlier observational studies were supported by several dynamic modeling studies [e.g., *Grebowsky*, 1970; *Kurita and Hayakawa*, 1985]. These studies predicted the formation of duskside plumes in response to the enhanced convection during storms.

[4] This study takes advantage of the Combined Release and Radiation Effects Satellite (CRRES) plasma wave receiver database of plasmapause locations developed by *Moldwin et al.* [2002]. The plasmapause was identified as the inner most steep density gradient observed on both the inbound and outbound passes of the geosynchronous transfer orbit CRRES satellite. Over 900 plasmapause locations were identified and, more importantly for this study, 22 storms with Dst less than -30 nT occurred during the CRRES mission lifetime that had clear identifiable plasma-

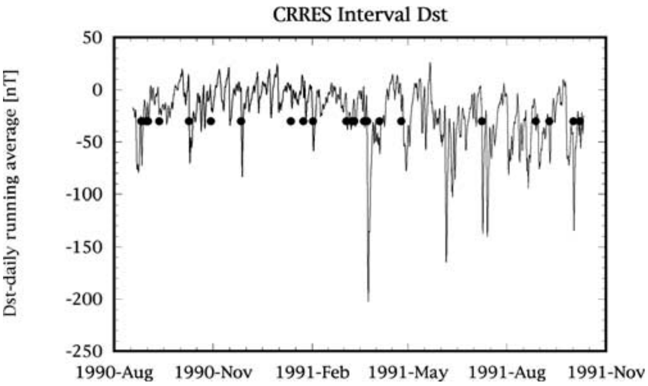

Figure 1. The *Dst* index (24-hour running average) during the CRRES mission lifetime. The solid circles are at −30nT and indicate the storms included in this survey.

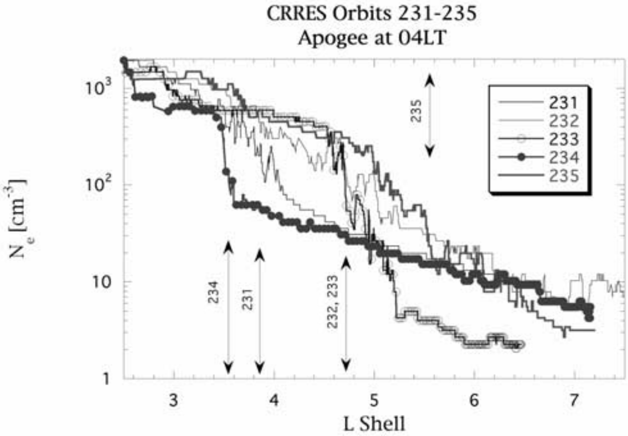

Figure 2. The response of the dawnside plasmapause in response to the 29 October 1990 storm is shown. The CRRES number density profiles for five consecutive orbits are shown. The vertical lines indicate the location of the plasmapause. See color version of this figure in the HTML.

pauses over several orbits around the onset of the storm sudden commencement (SSC). A superposed epoch study of the dynamics of the plasmapause in response to storms is performed with this database using the onset time of the SSC as the temporal fiducial.

2. Data and Methodology

[5] Using the list of storm sudden commencements provided by the National Geophysical Data Center (NGDC), we identified the subset of these SSC that were followed by a storm that had a minimum *Dst* of at least −30 nT and had identifiable CRRES plasmapause data for at least two orbits before and after the SSC. Figure 1 shows *Dst* during the CRRES mission lifetime with solid circles plotted at the time of SSC for the intervals used in this study. The plasmapause database developed by *Moldwin et al.* [2002] was used in this study. The plasmapause is identified as the inner most steep density gradient that has a density decrease of at least a factor of 5 within 0.5 *L*. Each plasmapause was sorted by local time and the time from SSC onset. We then examined by how much the plasmapause location changed between orbits relative to the onset of the SSC. Figure 2 shows the plasmaspheric density profiles for five orbits before and after the 29 October 1990 SSC onset. Each curve shows the inferred number density for the outbound leg of CRRES orbits 231 to 235. The vertical lines show the location of the identified plasmapause for each orbit. The SSC occurred at 2011UT on 29 October 1990 (during orbit 233). For the two orbits prior to the SSC, the plasmapause moved from just inside *L* of 4 to near *L* of 5. The plasmapause was crossed around *L* of 5 on Orbit 233 just 40 min after the SSC. The plasmapause was crossed again at an *L* of 3.5 during the next orbit in the same local time sector 11 hours and 30 min after the SSC. In the next orbit, over 20 hours after the SSC, the plasmapause was at *L* of 5 again. These observations imply that the plasmasphere expanded by about 1.5 *L* over the 20 hours prior to the SSC. Following the SSC the plasmapause moved earthward by about the same amount. Within a day the plasmasphere expanded out back to its prestorm location. The LT of these plasmapause crossings were in the postmidnight to dawn sector.

[6] Figure 3 shows the response of the plasmapause during the 9 September 1991 storm. Three duskside orbits are shown immediately following the SSC. As in Figure 2, the arrows show the location of the plasmapause for each orbit. Unlike the previous example that showed an apparent rapid inward motion of the plasmapause following the SSC, the plasmapause moves outward by approximately 1 *L* over the day following the storm. Note the significant density structure (plumes) observed beyond the inner most steep density gradient that developed in the aftermath of the storm (i.e., no density structure was observed beyond the plasmapause on orbit 990, whereas several dense plasmaspheric-like density intervals appear at high *L* beyond the inner most steep density gradient during orbits 991 and 992).

[7] From intervals such as those shown in Figures 2 and 3, we developed a database of the change in plasmapause location (ΔLpp) as a function of time since SSC (ΔTssc).

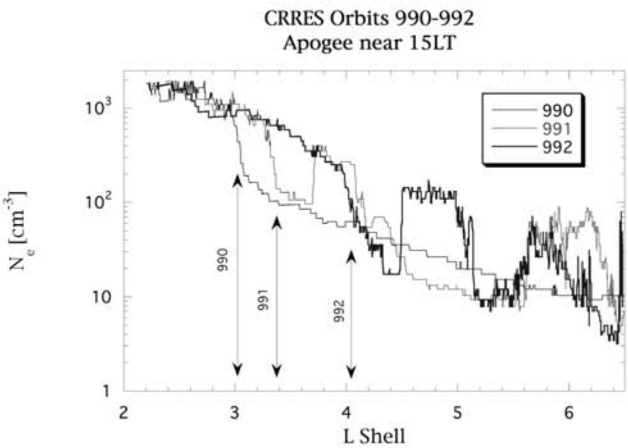

Figure 3. The response of the dusk-side plasmapause in response to the 9 September 1991 storm is shown. The CRRES number density profiles for three consecutive orbits are shown. The vertical lines indicate the location of the plasmapause. Note the development of plasmaspheric-like density structures beyond the plasmapause in the aftermath of the storm. See color version of this figure in the HTML.

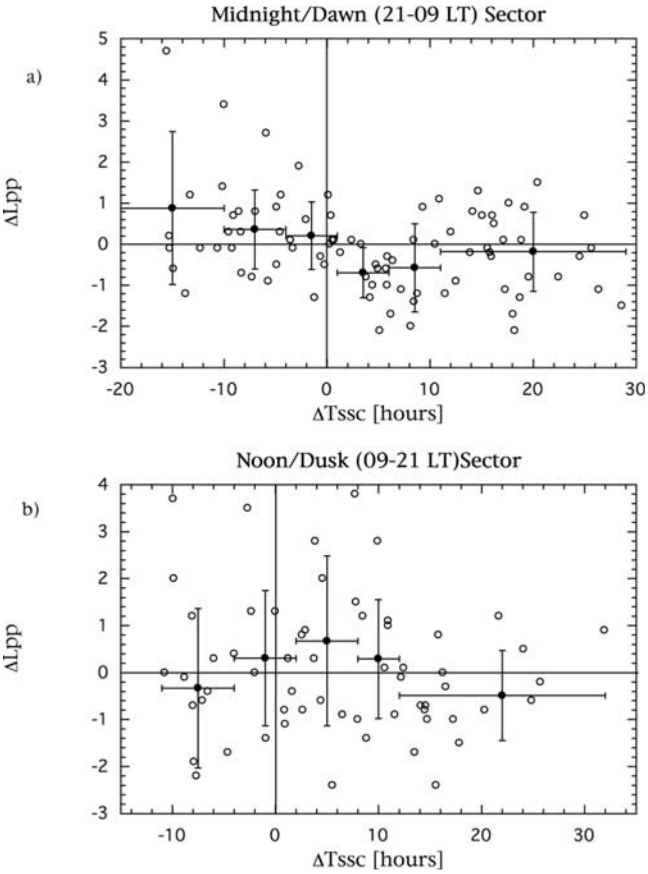

Figure 4. (a) The change in plasmapause position as a function of time since SSC is shown for the midnight/dawn sector. The vertical bars show the standard deviation about the mean (solid circle) for each bin whose width is indicated by the horizontal error bars. The actual data points are shown as open circles. (b) Same as Figure 4a except for the noon/dusk sector.

We defined inward motion as negative and outward motion as positive ΔLpp. Each CRRES orbit used in this study had two plasmapause crossings at two different LT sectors, one outbound plasmapause crossing and one inbound crossing. Consecutive inbound or consecutive outbound plasmapause crossings were used to define a ΔLpp. We used the UT and LT time of the second (later in time) plasmapause crossing to determine ΔTssc and sort by local time. The difference in local time between the two plasmapause observations used to determine a particular ΔLpp were generally on the order of an hour or less.

3. Statistical Results

[8] Figure 4 shows the change in plasmapause location as a function of time since SSC divided into two broad local time sectors. Figure 4a shows the plasmapause crossings that occurred in the 2100 through midnight to 0900 LT sector, while Figure 4b shows the results for the 0900 through noon to 2100 LT sector. Each point represents the difference in *L* shell between a pair of plasmapause crossings. The time associated with each point is the time since SSC of the second plasmapause crossing. The large circles with error bars are the means of different bins. The spacing of the bins in time is not uniform but is selected to require at least 10 data points in each bin. The first bin after ΔTssc = 0 was selected to begin at ΔTssc = 1 hour to account for the response time of the plasmasphere to the SSC.

[9] Figure 4a shows that prior to an SSC the plasmasphere general grows in size but with significant scatter. After the SSC there is a decrease in the size of the plasmasphere in this local time sector of about 1 *L* (as is shown in the case study presented in Figure 2). Note the near absence of intervals of expanding plasmasphere within the first 10 hours following the storm. However, after 11 or so hours the plasmapause location begins to behave similarly to prestorm intervals.

[10] Figure 4b shows the behavior of the plasmapause in response to a storm in the noon to dusk sector. Though the scatter is more significant than in the midnight to dawn sector, the average behavior is for the plasmapause to expand following an SSC (as is shown in the case study presented in Figure 3). From case to case the plasmapause can move significantly, either expanding or contracting.

4. Discussion

[11] The classic picture of plasmaspheric dynamics following a storm is that the plasmapause moves in while a drainage plume develops in the dusk sector [e.g., *Chen et al.*, 1975; *Elphic et al.*, 1996]. The results of this study confirms this picture but demonstrates that the midnight/dawn-noon/dusk asymmetry in the location of the plasmapause is often accentuated in the aftermath of a storm due to the inward motion in the midnight/dawn sector and the outward motion on the noon/dusk sector. Because most of the plasmapause crossings occur while CRRES was making nearly radial cuts through the plasmasphere, we have been able to distinguish between the plumes and the inner most steep density gradient. Therefore the expansion of the plasmasphere in the noon/dusk sector appears to be due to the build up of plasma corotating into the stagnation region accompanied by the sunward drift of the plasma and the formation of the plume. Indeed, IMAGE EUV observations show that in the aftermath of several storms a stationary plume can develop in the dusk sector while other azimuthal features in the midnight-to-noon sector corotate over to the plume [*Spasojevic et al.*, 2003].

[12] This highly dynamic and variable behavior shown following a storm in the noon/dusk sector indicates that the duskside drainage plume plays a role in not only providing structure beyond the plasmapause but also acts to locally expand the main plasmasphere. The absence of any significant outward motion of the plasmapause within 10 hours of an SSC in the midnight/dawn sector indicates that the plasmasphere reacts quickly and relatively smoothly to enhanced convection electric fields in this region. This clear and rapid nightside plasmapause behavior has recently been observed in a storm using IMAGE EUV confirming this studies statistical result [e.g., *Goldstein et al.*, 2003].

5. Conclusions

[13] The plasmasphere in the night and dawn sector systematically responds within approximately an hour fol-

lowing the onset of an SSC. In this local time sector the response is a radial inward motion of about 1 *L*. On the dusk side, plasmapause motion is variable but, in general, outward. These in situ observations further demonstrate the complexity of plasmaspheric behavior and indicate that storms give rise to enhanced local time asymmetries in the location of the plasmapause. A study of IMAGE EUV plasmapause locations following storms as a function of local time is planned to validate and further elucidate these findings.

[14] **Acknowledgments.** This work was supported by NASA SR&T grants (NAG5-5153 and NAG5-4897). Geomagnetic indices and the list of SSC were provided by the NGDC (http://www.ngdc.noaa.gov/stp/GEOMAG/geomag1.shtml).

[15] Arthur Richmond thanks Richard Lambour and Maria Spasojevic for their assistance in evaluating this paper.

References

Carpenter, D. L., and R. R. Anderson, An ISEE/Whistler model of equatorial electron density in the magnetosphere, *J. Geophys. Res.*, *97*, 1097, 1992.

Carpenter, D. L., B. L. Giles, C. R. Chappell, P. M. E. Decreau, R. R. Anderson, A. M. Persoon, A. J. Smith, Y. Corcuff, and P. Canu, Plasmasphere dynamics in the duskside bulge region: A new look at an old topic, *J. Geophys. Res.*, *98*, 19,243, 1993.

Chen, A. J., J. M. Grebowsky, and H. A. Taylor Jr., Dynamics of midlatitude light ion trough and plasma tails, *J. Geophys. Res.*, *80*, 968, 1975.

Elphic, R. C., L. A. Weiss, M. F. Thomsen, D. J. McComas, and M. B. Moldwin, Evolution of plasmaspheric ions at geosynchronous orbit during times of high geomagnetic activity, *Geophys. Res. Lett.*, *23*, 2189, 1996.

Goldstein, J., B. R. Sandel, W. T. Forrester, and P. H. Reiff, IMF-driven plasmasphere erosion of 10 July 2000, *Geophys. Res. Lett.*, *30*(3), 1146, doi:10.1029/2002GL016478, 2003.

Grebowsky, J. M., Model study of plasmapause motion, *J. Geophys. Res.*, *75*, 4329, 1970.

Kurita, K., and M. Hayakawa, Evaluation of the effectiveness of theoretical model calculation in determining plasmapause structure, *J. Geophys.*, *57*, 130, 1985.

Lambour, R. L., L. A. Weiss, R. C. Elphic, and M. F. Thomsen, Global modeling of the plasmasphere following storm sudden commencements, *J. Geophys. Res.*, *102*, 24,351, 1997.

Lemaire, J., and K. I. Gringauz, *The Earth's Plasmapause*, 350 pp., Cambridge Univ. Press, New York, 1998.

Maynard, N. C., and J. M. Grebowsky, The plasmapause revisited, *J. Geophys. Res.*, *82*, 1591, 1977.

Moldwin, M. B., M. F. Thomsen, S. J. Bame, R. C. Elphic, J. T. Gosling, D. J. McComas, and K. R. Moore, The structure and dynamics of the outer plasmasphere: A multiple geosynchronous satellite study, *J. Geophys. Res.*, *99*, 11,475, 1994.

Moldwin, M. B., L. Downward, H. K. Rassoul, R. Amin, and R. R. Anderson, A new model of the location of the plasmapause: CRRES results, *J. Geophys. Res.*, *107*(A11), 1339, doi:10.1029/2001JA009211, 2002.

Nishida, A., Formation of plasmapause, or magnetospheric plasma knee, by the combined action of magnetospheric convection and plasma escape from the tail, *J. Geophys. Res.*, *71*, 5669, 1966.

O'Brien, T. P., and M. B. Moldwin, Empirical plasmapause models from magnetic indices, *Geophys. Res. Lett.*, *30*(4), 1152, doi:10.1029/2002GL016007, 2003.

Spasojevic, M., J. Goldstein, D. L. Carpenter, U. S. Inan, B. R. Sandel, M. B. Moldwin, and B. W. Reinisch, Global response of the plasmasphere to a geomagnetic disturbance, *J. Geophys. Res.*, *108*(A9), 1340, doi:10.1029/2003JA009987, 2003.

R. R. Anderson, Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242, USA. (rra@space.physics.uiowa.edu)

T. Barnicki and H. K. Rassoul, Department of Physics and Space Sciences, Florida Institute of Technology, 150 W. University Blvd., Melbourne, FL 32901, USA. (rassoul@pss.fit.edu)

S. Mayerberger and M. B. Moldwin, Department of Earth and Space Sciences, University of California, Los Angeles, 3845 Slichter Hall, Los Angeles, CA 90095-1567, USA. (sabrina@ess.ucla.edu; mmoldwin@igpp.ucla.edu)