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# Amplitude Enhancement of SC(H) Events in the South Atlantic Anomaly Region

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## Abstract

South Atlantic Magnetic Anomaly – SAMA due to its weak total geomagnetic field F is known to be a sink of trapped charged particles from the inner radiation belt during both magnetically quiet and disturbed periods. Ionosondes, Riometers and VLF radio propagation monitoring experiments have shown ionospheric effects due to increase of ionization caused by the process of electron precipitation in the ionosphere of SAMA region during the quiet and disturbed periods. The enhanced ionization of the Brazilian SAMA region affects also the processes of the equatorial ionosphere. We have examined the records of geomagnetic variations during quiet periods and also at the time of sudden commencement (SC) in the horizontal component of geomagnetic field from the two stations situated in the SAMA region at the same dip latitude. The SC(H) amplitudes are found to be larger at a station situated close to the center of SAMA viz. São Martinho da Serra – SMS (29.43° S, 53.82° W and 33° dip) compared to the station Vassouras (22°.40 S, 43°.65 W and 33° dip). It is possible that the observed amplitude enhancements of these impulses in H in the SAMA region may be caused by the differential increase of ionization due to the electrons precipitation that took place previous to the sudden impulse and/or due to the complex ionospheric processes connected with the prompt penetration of magnetospheric electric fields in the equatorial and low latitude E and F regions.

Key words. Magnetospheric physics (Energetic particles, precipitations; Energetic particles, trapped; Solar wind-magnetosphere interactions)

## Introduction

Impulsive geomagnetic variations are caused by sudden compressions of the magnetosphere as the solar wind generated shocks, sudden increases in solar wind dynamic pressures and other discontinuities striking the magnetopause. Resulting hydromagnetic waves propagate toward the Earth through the magnetospheric plasma. Schutz et al. (1974) have shown that electric fields are generated in the ionosphere as a result of the interaction between the hydromagnetic waves with the ionosphere and these electric fields drive the ionospheric currents to which ground magnetometers respond as sudden increase in the horizontal north-south geomagnetic field called as Sudden Commencement – SC or sudden impulse – SI.

The impulsive variations at the magnetopause launch isotropic fast mode waves across the magnetospheric magnetic field lines and parallel-propagating Alfven mode waves along the outer magnetic field lines (Southwood and Kivelson, 1990). Tsunomura (1999) has done numerical analysis of global ionospheric currents based on the model of Araki (1977) and showed that the SC/SI impulses observed at the low latitudes are the sum of compressional waves traveling across the magnetic field lines plus a component of polar electric fields reaching the low and equatorial latitudes often referred as prompt penetration. The prompt penetration electric fields could arise from different phases of the storm : interplanetary magnetic field polarity changes, sudden storm commencements or sudden geomagnetic impulses, direct penetration of interplanetary electric field, the DP2 fluctuations, substorm onset, growth and recovery phases of the storm, ring current development and decay (Abdu et al. 2003 and 1995, Fejer et al. 1990, Kikuchi et al. 1996, Kikuchi, 1986) and several references there in). Sudden changes in the solar wind dynamic pressure also produce transient ionospheric zonal electric field and current perturbations, but with generally smaller amplitudes compared to those resulting from large changes in magnetospheric convection. Sibeck et al. (1998) has shown that the large majority of north/south geomagnetic fluctuations with amplitudes ranging 10 to 40 nT observed in dayside equatorial and low latitude ground magnetograms can be explained in terms of either substorm onset or changes in the solar wind dynamic pressure. However, large fluctuations in the solar wind electric field are often highly correlated with corresponding ionospheric electric field and current disturbances from high to low and equatorial latitudes, (Kelley et al. 2003).

In this paper we are examining amplitudes of SC impulses in the H field at stations São Martinho da Serra (SMS) (29°.43 S, 53°.82W) and Vassouras (VSS) (22°.40 S, 43°.65 W), both situated at about 33° dip angle in the South Atlantic Magnetic Anomaly - SAMA region in Brazil. We are trying to examine interplay and effects due to Equatorial Ionization Anomaly – EIA, and the effect of increased ionization over the ionosphere of SAMA, and also F-region vertical plasma drifts at the equator due to prompt penetration of polar electric field, as seen by Abdu et al. 2003 and Abdu et al. 1998, on the sudden impulses observed in the SAMA region. Before moving over to the results of this paper, we present an introduction on the SAMA region.

The SAMA region is known to be a major sink for trapped electrons of the radiation belts, (Dessler, 1959). Vernov et al. (1967) provided experimental evidence of enhanced energetic radiation over this anomaly region. Macdonald and Walt (1962) were first to show that interaction of trapped electrons in the Earth's radiation belts with the scattering atmosphere could be treated as a problem of electron diffusion, that is electrons moving from radiation belts to the lower atmosphere. Roederer (1970) and Schulz and Lanzerotti (1974) described in detail how at the heights below 300 km and $L \leq 1.25$ eastward drifting electrons and westward drifting protons would precipitate intensely in the atmosphere over the SAMA. In this region the intensity of the geomagnetic field is lowest on the global scale and therefore mirror points of the trapped charge particles are shifted to lower altitudes and in interacting with the denser atmosphere they get lost or precipitate much more in this anomaly region than elsewhere. Tsurutani and Lakhina (1997) while reviewing some basic concepts of wave-particle interactions in collision less plasmas have noted that any satellite orbiting just above the ionosphere of SAMA would see more particle flux descending over Brazil. The greater downward charged particle flux also means presence of higher radiation doses in the ionosphere over the SAMA as reported by Badhwar, 1997. In the same paper Badhwar plotted radiation dose rates over SAMA as observed on Skylab and Mir spacecrafts as a function of both longitude and latitude and showed that maxima of this radiation dose for the period of June 1995 was situated at approximately 30° South and 45° West, The maxima of this radiation dose exhibited a longitudinal drift rate of 0.28 ± 0.03° W per year and latitudinal drift rate of 0.08 ± 0.03° N per year which is consistent with the drift rate of the surface magnetic features, that is the drift of F minimum feature. Aeronomic and ionospheric effects of the electron precipitation in the SAMA region are reviewed by several authors, (Pinto and Gonzalez ,1989, Gledhill, 1976 and Paulikas, 1975).

The ionization induced by precipitation of energetic electrons have been investigated using data from the ground-based experiments like riometer, VLF radio signal monitoring and ionosondes. Abdu et al. (1973), and Nishino et al. (2002) have noted absorption of cosmic radio noise in the ionosphere due to electron precipitation specially during the main and recovery phases of a magnetic storm. Abdu et al. (1981) have noted significant perturbation due to the lowering of VLF reflection height in the SAMA region. Abdu and Batista (1977a), and Batista and Abdu (1977b) have reported sporadic E-layer enhancements and regular night-time ionization source in the SAMA region using ionosonde data. Also Gledhill and Hoffman (1981) have reported 0.2 to 26 keV electron flux precipitating in the SAMA region capable of producing detectable effects in the D and E regions of the ionosphere during the night-time. It has been recognized for many years, since the report by Zmuda (1966), that there must be a continuous loss of electrons and ions from the magnetosphere into the atmosphere of SAMA region and often reaching detectable level of ionization. Geophysical disturbance events produce a related electron dumping superposed on the quiescent conditions found on magnetically quiet periods.

**Data set**

We measured the amplitudes of SC (H) for the published list of SC events for the period from September 2000 to December 2001. from the magnetic data of our station São Martinho da Serra. – SMS. For the same events we measured SC(H) amplitudes for Vassouras – VSS, using the Intermagnet digital data available on CD-ROM. The Table 1 gives the coordinates and geomagnetic parameters of the stations referred in this paper.

Table 1. Coordinates and geomagnetic parameters for the year 2000 at the stations. (www.geomag.bgs.ac.uk/cgi-bin/WMMSYNTH)

| Station | Code | Geographic | | H nT | F nT | Z nT | I (°) |
|---|---|---|---|---|---|---|---|
| | | Lat. (°n) | Long (°W) | | | | Dip Angle |
| Vassouras | VSS | –22.40 | 43.65 | 19400 | 23368 | –13027 | –33.80 |
| São Martinho da Serra | SMS | –29.43 | 53.82 | 19024 | 22874 | –12700 | –33.80 |

**Results**

We downloaded the list of sudden commencement events (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUDDEN_COMMENCE…/STORM2.SS/) for the period September 2000 to December 2001 as we have reliable digital geomagnetic data for SMS from September 2000 onwards. Besides the INTERMAGNET data also in digital form for VSS was available till December 2001. Also this provides reasonable statistics for observing amplitudes of sudden impulses in the magnetic anomaly region. We read values of the sudden commencement amplitudes in the H component of the geomagnetic field at SMS, and VSS for the above mentioned period. The data is presented below in Table 2. In this table are listed 16 night-time events (18 to 06 LT) and 21 day-time events (06 to 18 LT) . We could get simultaneous data at all the three stations for only 37 SC events. In this zone LT = UT – 3 hours. Some large events have large amplitude enhancement at the station SMS and smaller enhancement at VSS. Some events show weak or even insignificant enhancement at SMS. One large event on 31 March 2001 shows no enhancement at all and the SC(H) amplitudes at both the stations are almost the same. We think that on the day and the hour of SC(H) amplitude enhancement, ionization and consequently electron density was increased in the D and E regions of the ionosphere.

Table 2. List of SC(H) maximum amplitudes studied at the stations SMS, and VSS

| | Date of Event | Time (UT) | Amplitude nT (SMS) | Amplitude nT (VSS) | Amplitude. Ratio SMS/VSS |
|---|---|---|---|---|---|
| 1 | 15/09/2000 | 04:50 | 28 | 27 | 1.03 |
| 2 | 15/09/2000 | 19:12 | 14 | 12 | 1.16 |
| 3 | 18/09/2000 | 14:44 | 100 | 95 | 1.05 |
| 4 | 03/10/2000 | 00:54 | 20 | 18 | 1.11 |
| 5 | 05/10/2000 | 03:26 | 41 | 36 | 1.13 |
| 6 | 12/10/2000 | 22:28 | 38 | 29 | 1.37 |
| 7 | 28/10/2000 | 09:54 | 40 | 53 | 0.75 |
| 8 | 31/10/2000 | 17:14 | 70 | 50 | 1.40 |
| 9 | 04/11/2000 | 02:21 | 34 | 33 | 1.03 |
| 10 | 06/11/2000 | 09:47 | 29 | 33 | 0.88 |
| 11 | 10/11/2000 | 06:28 | 95 | 70 | 1.36 |
| 12 | 26/11/2000 | 07:58 | 44 | 36 | 1.22 |
| 13 | 26/11/2000 | 11:58 | 55 | 56 | 0.98 |
| 14 | 22/12/2000 | 19:25 | 11 | 7 | 1.58 |
| 15 | 17/01/2001 | 1631 | 40 | 31 | 1.29 |
| 16 | 12/02/2001 | 1614 | 19 | 13 | 1.47 |
| 17 | 31/03/2001 | 0052 | 120 | 118 | 1.08 |
| 18 | 27/5/2001 | 1459 | 30 | 29 | 1.03 |
| 19 | 18/06/2001 | 0259 | 27 | 23 | 1.17 |
| 20 | 03/08/2001 | 07:16 | 25 | 22 | 1.13 |
| 21 | 12/08/2001 | 11:35 | 45 | 46 | 0.98 |
| 22 | 17/08/2001 | 11:03 | 32 | 32 | 1.00 |
| 23 | 25/09/2001 | 20:25 | 85 | 62 | 1.37 |
| 24 | 29/09/2001 | 09:40 | 25 | 23 | 1.08 |
| 25 | 30/09/2001 | 19:24 | 25 | 28 | 0.89 |
| 26 | 11/10/2001 | 17:01 | 82 | 64 | 1.28 |
| 27 | 21/10/2001 | 16:48 | 115 | 90 | 1.28 |
| 28 | 25/10/2001 | 08:50 | 39 | 39 | 1.00 |
| 29 | 28/10/2001 | 03:19 | 40 | 26 | 1.54 |
| 30 | 31/10/2001 | 13:48 | 40 | 38 | 1.05 |
| 31 | 06/11/2001 | 01:52 | 165 | 125 | 1.32 |
| 32 | 15/11/2001 | 15:09 | 42 | 35 | 1.20 |
| 33 | 19/11/2001 | 18:15 | 40 | 30 | 1.33 |
| 34 | 24/11/2001 | 05:56 | 88 | 57 | 1.54 |
| 35 | 23/12/2001 | 23:16 | 25 | 22 | 1.13 |
| 36 | 29/12/2001 | 05:38 | 68 | 57 | 1.19 |
| 37 | 30/12/2001 | 20:05 | 54 | 39 | 1.38 |
| Mean | Night | Events | 56 | 46 | 1.21 |
| Mean | Day | Events | 47 | 41 | 1.14 |

.From the above mentioned data one surmises that generally the amplitude of sudden impulses in H component are larger at the center of SAMA that is at SMS compared to those observed at a station (VSS) closer to the border of SAMA.

**Discussion**

Jayanthi et al. (1997) have shown that geomagnetic variations in the H field on the ground station situated in the SAMA region are inversely correlated with the X-ray flux generated by the precipitating electrons (18-120 keV) measured by a balloon launched instrument at 5 milli-bar height. It means that when H field decreases the mirror heights are lowered and consequently more electrons are precipitated generating increased X-ray flux. Following the same explanation , during a sudden impulse, increase of H field should note a increase in height of mirror points and lesser electron precipitation and should register decrease in X-ray flux at a balloon height. However exactly opposite has been reported by Martin et al. (1973). They presented a direct evidence for the precipitation of electrons of energies > 7.5 MeV in the atmosphere at balloon altitudes (35 to 40 km.) in the region of SAMA, accompanied by a sudden commencement of nearly 40 nT at 1418 UT on December 17 of 1971 observed at São Jose dos Campos situated close to the position of balloon in the stratosphere. Ap index was 3 till 15 UT of 16th December and the following 3 hourly mean (Ap indexes were 18, 32, 56, 56, 32, 18, 32, 132, 154, and 56). At the time of SC on 17th. December 1971 Ap index was 132. (http://web.dmi.dk/fsweb/cgi-bin/webin_wdcget.sh/objtype=idxsrch&data_type=kpap)

At the instance of 40 nT SC(H) measured particle flux increased at the balloon height by ~1.35 particles per centimeter square per second, which can be considered too low to produce measurable visual or radio effects. Abdu et al. (1973) reported azimuthal drift and precipitation of electrons into the SAMA region during a SC magnetic storm of August 4 of 1972. They failed to see ionospheric absorption from the riometer record corresponding to the SC of 4 August, 1972 which took place at 2100 UT but reported a absorption event corresponding the sudden impulse that followed the SC at 2240 UT, just after one hour and forty minutes,  still during the initial phase of the storm.

Also in the data presented in this paper more than half of the total sudden impulses (SC) have shown considerable enhancement of the amplitudes of sudden impulses in H component near the center of SAMA. We have two arguments telling us that electron precipitation is unlikely to be triggered by a sudden impulse. First, at the increase of H field according to Jayanthi et al. (1997) one expects increase in the height of mirror points reducing the electron precipitation and not increasing as observed. The second argument is developed by Wentzel (1961) who presented theoretical estimates on the nature of hydromagnetic waves in the magnetosphere and showed that under the normal circumstances the electrons in the inner magnetosphere are not affected by hydromagnetic waves corresponding to sudden impulses. In the same paper he also showed that hydromagnetic waves can influence mirror-point distribution of the relativistic Argus electrons during a geomagnetic storm and also when solar wind dynamic pressure increased several fold. However the time necessary to change $\mu$ magnetic moment of electrons significantly would be close to 24 hours. The time taken for the excursion of sudden impulse in H is very much smaller than 1 day, a time insufficient for producing significant change in $\mu$ magnetic moment of electrons in the inner magnetosphere, thus not producing any change in its mirror height. However Paulikas (1975) has noted that variations in the inner-zone electron flux or disturbances affecting the existing electron flux in the inner-zone, are rapidly communicated along the field lines to low altitudes through pitch angle diffusion.

Badhwar (1997) has detected a peak of greater downward charged particle flux near the center of SAMA that is higher radiation doses in the ionosphere over the center of SAMA. This tells that maximum electron precipitation is concentrated around the position of F minimum and falls off away from it. We note that SC(H) enhancements at the center of the SAMA could be a result of the increasing ionization in D and E regions of the SAMA ionosphere due to a downward flux of charged particles (electrons) at the center of SAMA. Able and Thorne (1997) also have shown this by numerical simulation that precipitating electrons should be a prominent ionization source near the SAMA but relatively insignificant elsewhere. We see exactly this through our analysis, increased E- region ionization over the station SMS compared to the increase of ionization over the station VSS situated some 1200 km East of SMS however on the same magnetic or dip latitude.

One may be tempted to argue that the $\Delta$H impulse is found larger at the center of the SAMA as the background magnetic field is weaker. The background H magnetic field at VSS is approximately 19400 nT and at SMS is approximately 19024 nT; that is the ratio of H field VSS/SMS is 1.02. The ratio of F field values at VSS/SMS is 1.03. This could mean that acceptable ratio of SC(H) amplitudes between VSS and SMS should be around 1.03 and not very much more. From the table 2 we can see that this ratio is higher than 1.03 for at least 50% of the events and even the mean value of this ratio for all the 37 events listed in table 2 is 1.18.

The sudden impulses in H may not trigger the electron precipitation over SAMA, but at the time of occurrence of the sudden impulse, if there exists already increased ionization due to preceding electron precipitation, amplitudes of the sudden impulses may be enhanced. Abdu et al. (1998) have noted presence of increased ionization in the ionosphere of the SAMA region that shows effects on equatorial ionosphere. The enhancement of SC(H) amplitudes near the center of SAMA supports the views expressed by Abdu and Batista (1977) that there are regular particle ionization sources in the E region of the SAMA. It seems to us from this analysis that the E-region of the SAMA ionosphere shows increased ionization regularly, greater increase at the center of the anomaly compared to the region far from the center. One needs to conduct detailed study of the interplay of the Equatorial Ionization Anomaly-EIA features ( that is reduction of electron density over the equator and increase of ionization at latitudes farther from the magnetic equator), prompt penetration of polar electric field to low latitude region ( that is verical plasma drift in F region ) and the general increase of ionization in the ionosphere over SAMA region by direct precipitation and through EIA, inferred from the geomagnetic data as has been reported from the ionospheric data, (Abdu et al., 2003,1998 and Abdu and Batista,1977 and the references there in).

Huang and Cheng (1991) have reported Doppler frequency shift , meaning increase of ionization in the ionosphere, due to sudden commencement. However in the SAMA region what is more important is the differential increase of ionization. Nishino et al. (2002) have also reported that a riometer experiment showed an event of increased ionization over SMS however no ionospheric effects due to the precipitating electrons was noted at Cachoeira Paulista situated 1000 km eastward from SMS.

## Conclusion

There seems to be regular increase of ionization in the ionosphere of SAMA region, greater increase at the center of the SAMA compared to away from it. Hence the electric field of sudden impulses drive the available ionospheric currents showing greater amplitudes of the sudden impulses at the center of SAMA.


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## References


Abdu, M. A., S. Ananthkrishnan, E. F.Coutinho, B. A. Krishnan, and E.M. da S. Reis, 1973, Azimuthal drift and precipitation of electrons into the South Atlantic geomagnetic anomaly during a SC magnetic storm, J. Geophys. Res., 78, 5830-5836.

Abdu, M. A., Batista, I.S., Piazza, L.R., and Massambani, O., 1981, Magnetic storm associated enhanced particle precipitation in the South Atlantic anomaly: Evidence from VLF phase measurements, J. Geophys. Res., 86, 7533-7542.

Abdu, M. A. And I. S. Batista, 1977, Sporadic E-layer phenomena in the Brazilian geomagnetic anomaly: evidence for a regular particle ionization sources, J. Atmos. Terr. Phys., 39, 723-731.

Abdu, M. A., I. S. Batista, H. Takahashi, J. MacDougall, J. H. A. Sobral, A. F. Medeiros, and N. B. Trivedi, 2003, Magnetospheric disturbance induced equatorial plasma bubble development and dynamics : A case study in Brazilial sector, J. Geophys. Res., 108(A2), 1449, doi:10.1029/2002JA009721.

Abdu, M. A , P. T. Jayachandran, J. MacDougall, J. F. Cecile, and J. H. A. Sobral, 1998, Equatorial F region zonal plasma irregularity drifts under magnetospheric disturbances, Geophys. Res. Lett., 25, 4137-4140.

Abel , B., and Thorne, R.M., 1999, Modeling energetic electron precipitation near the South Atlantic anomaly, J. Geophys. Res., 104 (A4), 7037-7044.

Badhwar, G. D., 1997, Drift rate of the South Atlantic anomaly, J. Geophy. Res., 102, 2343-2349.

Batista, I. S. and M. A. Abdu, 1977, Magnetic storm associated delayed sporadic E enhancements in the Brazilian geomagnetic anomaly, J. Geophys. Res., 82(29), 4777-4783.

Dessler, A. J., 1959, Effect of magnetic anomaly on particle radiation trapped in geomagnetic field, J. Geophys. Res., 64, 713-719.

Fejer, B. G., M. C. Kelley, C. Senior, O. De La Beaujardiere, J. A. Holt, C. A. Tepley, R. Burnside, M. A. Abdu, J. H. A. Sobral, R. F. Woodman, Y. Kamide, and R. Lepping, 1990, Low and mid-latitude ionospheric electric fields during the January 1984 GISMOS Campaign, J. Geophys. Res., 95(A3), 2367-2377.

Gledhill, J. A., 1976, Aeronomic effects in the South Atlantic anomaly, Rev. Geophys. Space Res., 14, 173-187.

Gledhill, J. A. and R. A. Hoffman, 1981, Night-time observations of 0.2 to 26 keV electrons in the South Atlantic anomaly made by Atmospheric Explorer-C, J. Geophys. Res., 86, 6739-6744.

Huang, Y. N. and Kang Cheng, 1991, Ionospheric disturbances at the equatorial anomaly crest region during the March 1989 magnetic storms, J. Geophys. Res., 96 (A8), 13,953-13,965.

Jayanthi , U. B. , M. G. Pereira, I. M. Martin, Y. Stozkov, F. D'Amico, and T. Villela , 1997, Electron precipitation associated with geomagnetic activity: Balloon observations of x ray flux in south atlantic anomaly, *J. Geophys. Res*., **102**, 24,069-24,073.

Kelley, M. C., J. J. Makela, J. L. Chau, M. J. Nicolls, 2003,Penetration of the solar wind electric field into the magnetosphere/ionosphere system, Geophys. Res. Lett., 30(4), 1158, doi:10.1029/2002GL016321.

Kikuchi, T., 1986, Evidence of transmission of polar electric fields to the low latitude at times of geomagnetic storm commencements, J. Geophys. Res., 91, 3101-3105.

Macdonald, W. M., and M. Walt, 1962, Diffusion of electrons in the Van Allen radiation belts, 2 , Particles with mirroring points at low altitude, *J. Geophy. Res*., **67**, 5025-5035.

Martin, I.M., Rai, D.B., Da Costa, J.M., Palmeira, R.A.R., and Trivedi, N.B., 1973, Enhanced electron precipitation in Brazilian Magnetic Anomaly in association with Sudden commencement. Nature, 240:84-86.

Nishino, M., Makita, K., Yumoto, K., Rodrigues, F.S., Schuch, N.J., and Abdu, M.A., 2002, Unusual ionospheric absoption characterizing energetic electron precipitation into the South Atlantic magnetic anomaly, Earth Planets Space, 54, 907-916.

Paulikas, G. A., 1975, Precipitation of particles at low and middle latitudes, Rev. Geophysics and Space Physics, 13, 709-734.

Pinto, O Jr. , and W. D. Gonzalez , 1989b, Energetic electron precipitation at the south atlantic magnetic anomaly: A review J. *Atmos. Terr. Phys* , **51**, 3351-365.

Roederer , J. G., 1970, Dynamics of geomagnetically trapped radiation , Springer-Verlag.

Schulz, M., and Lanzerotti, L. J., 1974, Particle diffusion in the radiation belts, Springer-Verlag, New York.

Schutz, S., G. J. Adams, F. S. Mozer, 1974, Electric and magnetic fields measured during a sudden impulse, J. Geophys. Res., 79, 2002-2004.

Sibeck, D. G., Baumjohann, W., Elphic, R.C., Fairfield, D.H., Fennel, J.F., Gail, W.B., Lanzerotti, L.J., Lopez, R.E., Luhr, H., Lui, A.T.Y., Maclenan, C.G., McEntire, R.W., Potemra, T.A., Rosenberg, T.J., and Takahashi, K., 1989, The magnetospheric response to 8-min- period strong amplitude upstream pressure variations, J. Geophys. Res., 94, 2505-2519.

Southwood, D. J., and Kivelson, M.G., 1990, The magnetohydrodynamic response of the magnetospheric cavity to changes in solar wind pressure, J. Geophys. Res., 95, 2301-2310.

Sugiura, M., 1953, The solar diurnal variation in the amplitude of sudden commencements of magnetic storms at the geomagnetic equator, J. Geophys. Res., 58, 558-559.

Tsurutani, B. T., and G. S. Lakhina, 1997, Some basic concepts of wave particle interactions in collisionless plasmas, Rev. Geophys., 35, 4, 491-501.

Vernov, S. N., E. V. Gorchakov, P. I. Shavrin, and K. N. Sharvina, 1967, Terrestrial corpuscular radiation and cosmic rays, *Space Science Review,* **7**, 490-533.

Wentzel, D. G., 1961, Hydromagnetic waves and the trapped radiation: part 2, displacements of the mirror points., J. Geophys. Res., 66,363-369.

Zmuda, A. J., 1966, Ionization enhancement from Van Allen Electrons in the South Atlantic anomaly, J. Geophys. Res., 71, 1911-1918.