INSTITUTO DE PESQUISAS ESPACIAIS
Ministério da Ciência e Tecnologia

AUTORIZAÇÃO PARA PUBLICAÇÃO
AUTHORIZATION FOR PUBLICATION

PALAVRAS CHAVES/KEY WORDS

SOUTH ATLANTIC MAGNETIC ANOMALY
X-RAYS

AUTORIZADA POR/AUTHORIZED BY

V.W.J.H. Kirchhoff
Director Space Atmos.Sci.

AUTOR RESPONSÁVEL / RESPONSIBLE AUTHOR

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- [ ] INTERNA / INTERNAL
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Editor Space Atmos. Sci.

CDU/UDC

550.382.7

DATA / DATE

July 1987

PUBLICAÇÃO Nº / PUBLICATION NO

INPE-4400-PRE/1217

ORIGEM / ORIGIN

DGE

PROJETO / PROJECT

MAGNET

Nº DE PAG. / NO OF PAGES

15

ÚLTIMA PAG. / LAST PAGE

14

VERSÃO / VERSION

Nº DE MAPAS / NO OF MAPS

TÍTULO/TITLE

TIME VARIATIONS OF X RAY FLUXES AT THE SOUTH ATLANTIC MAGNETIC ANOMALY IN ASSOCIATION WITH A STRONG GEOMAGNETIC STORM

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RESUMO - NOTAS / ABSTRACT - NOTES

This paper describes the temporal characteristics of the X ray fluxes measured by a balloon-borne scintillation detector on April 14, 1981, due to electron precipitation at the South Atlantic Magnetic Anomaly an in association with a strong geomagnetic storm. The data clearly indicate the dynamical nature of the precipitation process and also give some clues on physical mechanisms that could be responsible for it. As a result, it is suggested that the modulation of the electron precipitation during this storm would have been caused by processes involving wave-particle or wave-modulated wave-particle interactions.

OBSERVAÇÕES / REMARKS

This work is in press in J. Geophys. Res.

TIME VARIATIONS OF X RAY FLUXES AT THE SOUTH ATLANTIC MAGNETIC ANOMALY IN ASSOCIATION WITH A STRONG GEOMAGNETIC STORM

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Abstract. This paper describes the temporal characteristics of the X ray fluxes measured by a balloon-borne scintillation detector on April 14, 1981, due to electron precipitation at the South Atlantic Magnetic Anomaly and in association with a strong geomagnetic storm. The data clearly indicate the dynamical nature of the precipitation process and also give some clues on physical mechanisms that could be responsible for it. As a result, it is suggested that the modulation of the electron precipitation during this storm would have been caused by processes involving wave-particle or wave-modulated wave-particle interactions.

Introduction

Balloon measurements of bremsstrahlung X rays in the auroral region have shown the presence of diverse temporal structures, from a few milliseconds to hundreds of seconds (for a review, see Brown [1966] and Lazutin [1986]). In particular, the occurrences of pulsations with quasi-periodicities of several tens of seconds (continuous magnetic pulsation range) have been reported and studied by a variety of authors [e.g., Evans, 1963; Barcus and Christensen, 1965; Ullaland et al., 1967; Parks et al., 1968; Bewersdorff et al., 1968; Arthur et al., 1979]. Pulsations have also been identified by riometer studies (see Olson et al. [1980] and references therein) and similar studies at mid-latitudes [Rosenberg et al., 1971; Lanzerotti et al., 1978, 1980, 1985]. Such structures are thought to be direct evidences of wave-particle interactions in the magnetosphere [Arthur et al., 1979; West and Parks, 1984; Kremser et al., 1986].

The purpose of this paper is to discuss the temporal characteristics of the X ray measurements obtained by a balloon-borne scintillation detector on April 14, 1981, at the South Atlantic Magnetic Anomaly (SAMA), in association with a strong geomagnetic storm (Dst_{max} = -291 nT) and described in the paper by Pinto and Gonzalez [1986b] (hereafter called paper 1). The detector used consisted of a NaI(Tl) crystal with dimensions of 3 inches x 1/2 inch (effective area equal to 30.4 cm^2) set up to look upward to an approximately 2π sr solid angle. Three differential discriminators were selected on 30-50 keV, 50-70 keV, and 70-150 keV. The detector was launched from São José dos Campos, Brazil (geographic coordinates 23 12'S, $45^{o}51$'W and L ~ 1.13) and during the flight drifted toward the west, staying at approximately the latitude of São José dos Campos and covering a longitudinal interval < 4^{o}. The measurements detected an intensification in the X ray flux in association with a strong geomagnetic storm. In paper 1, such intensification was shown to be related to energetic electron precipitation from the inner radiation belt. In this paper, the temporal variation of this electron precipitation is investigated. The data clearly indicate the dynamical nature of the precipitation process and also give some clues about physical mechanisms that could be responsible for it.

Data Set and Analysis

Figure 1 shows the X ray flux between 30 keV and 50 keV measured on April 14 at 4 g cm^{-2} atmospheric depth, during a strong geomagnetic storm, as a function of local time. The data were processed on board, giving one value to each 30 s. In this figure, the mean value and the 3σ standard deviation are also shown. Time variations with amplitudes equal to or greater than 3σ are found to exist. However, for the other energy channels (not shown here), these time variations are not quite evident (the amplitudes remained within 2σ and 3σ around the mean value). Unfortunately, it was not possible to study in detail the time variations in the measurements obtained during a quiet time interval by an other balloon flight (see paper 1 for details of this flight), since during that flight the balloon, after reaching the ceiling altitude of 5.5 g cm^{-2} , did not remain at a constant level. The balloon had a slow descent motion, ending the flight at approximately 7.5 g cm^{-2} (see below).

In order to search for possible periodicities associated with those time variations, the numerical statistical technique of power spectrum analysis was used. The power spectrum analysis was carried out in a similar way to that of Gonzalez and Gonzalez [1987], using the description given by Jenkins and Watts [1968]. Figure 2 shows the power spectrum's density (PSD) as a function of frequency for the 30 50 keV range. The data set covered the 0443 LT to 0708 LT interval with a 30-s time resolution. The truncation point, that is, the maximum number of autocorrelations to be considered, was chosen to be equal to 25 min. In this figure, the PSD was plotted in a decimal logarithmic scale, since, in this case, the confidence intervals are independent of the frequency. In addition, the bandwidth of the spectral window was also estimated. It gives an idea of the detail that can be resolved in the spectrum.

From the results of the power spectrum analysis, shown in Figure 2, there seems to be a periodicity in the measured 30-50 keV X ray flux. In fact, there is a spectral peak around the frequency of 0.56 cycle min^{-1}, which corresponds to a period of 1.8 min (108 s), with a level of confidence of about 90%. There are also other peaks in the PSD, but all of them are below the 80% level. In the other channels all peaks are below the 80% confidence level. Considering the data set used, only periodicities with period less than approximately 10 min can be investigated.

In order to investigate in more detail the confidence of the peak around 108 s, we have computed the PSD by using a high pass filter, as described by Shapiro [1969], in order to remove the power at very low frequencies. This power may be related to Pc 5 magnetic fluctuations clearly seen at local magnetograms (not shown here). Also, we have incorporated in the analysis a Markov red noise spectrum computed in the way described by Mitchell et al. [1966] and compared the confidence level so obtained to the value obtained by the multiplication law governing the joint probability for independent events [Mitchell et al., 1966]. We found that the confidence level of the peak for the filtered data is greater than the value that can be attributed to pure chance. The same analysis described above, when applied to the other energy channels, as well as for the 30-50 keV channel during the ascension of the balloon, does not show any other significant peak.

Figure 3 shows the dynamic power spectrum of the measured X ray flux for all energy channels. Shading denotes PSD levels in 1.5-dB steps. The principal region of pulsation activity is evident in the 30-50 keV energy range, centered roughly about 0553 LT. In this region the highest PSD levels are reached. It is worth mentioning that the AE index shows the occurrence of a substorm starting at 0530 LT reaching a maximum intensity of about 500 γ.

Before proceeding to speculate on a possible mechanism for the observed temporal variations, we should be able to rule out circumstantial effects inherent in the experiment. The most obvious of these undesirable effects would be associated with a change in the altitude of the balloon. However, we can argue that in order to have flux variations of the order of those observed, the balloon altitude should undergo changes of the order of 400 m (or approximately

0.5 g cm^{-2} at 35 km) continuously in lapses of about 1 min. These changes should be easily observed by the pressure sensor on board the balloon, which was not the case.

Some further effects are worth reporting. One of them refers to movements of the payload in the atmosphere in association with the balloon. Considering that the X ray detector was semiomnidirectional, changes in the orientation would not be able to cause such variations. Another effect could be thought to result from some modulation of the loss cone angle. Considering the auroral region as an example, there are two possibilities. One is associated with a modulation of the loss cone angle by changes in the equatorial magnetic field intensity due to a hydromagnetic wave or magnetic pulsation. Such a process was suggested by Barcus and Christensen [1965]. In contrast to the auroral region, at low L values of the SAMA region the equatorial magnetic field intensity, around 2 x 10^4 nT, is much higher than those expected for magnetic pulsations, around 1 nT [Jacobs, 1970], so that this process should not operate. The modulation in $\sin^2 \alpha_c$, where α_c is the loss cone angle, is of the order of 10^{-4}. Hence no variation in the electron precipitation should be expected. Another effect is associated with a modulation of the loss cone angle by density fluctuations, or atmospheric waves, in the neutral atmosphere around 100 km altitude. Such a process was first suggested to operate in the auroral region by Luhmann [1979]. In this context, the periodicity around 108 s shown in Figure 2 would be in the limit of the acoustic and gravity wave domains. Independently of the existence or not of these waves at low L values of the SAMA region, such a process must be disregarded in the present case, since the horizontal wavelengths of these waves at 100 km altitude have values of about 10 km. These values are much smaller than the radius of the region at about 100 km altitude that is expected to influence a balloon-borne X ray detector [Lazutin, 1986]. However, when considering collimated detectors with an angular opening $\leq 40^o$, such a process must be taken into account [Gal'per et al., 1980].

Discussion

After we have disregarded several possible explanations for the periodicity shown in Figure 2, we can look for possible mechanisms that could be responsible for it. These mechanisms could result from the modulation of the physical process or processes responsible for the precipitation itself. At the present time, the causes of the intensification at the energetic electron precipitation at the SAMA region during magnetically disturbed periods, such as that reported in paper 1, are not known (see, for a review, Pinto and Gonzalez [1989]). However, some evidence that reports an intensification in the plasmaspheric ELF hiss at low L values during magnetically disturbed periods [Smith et al., 1974; Tsurutani et al., 1975; Larkina and Likhter, 1982] seems to indicate that at these times wave-particle resonant interactions could be intensified. Considering that such interactions actually occur, the above mentioned periodicity can be due to a wave-wave interaction process operating in a similar way as that suggested by Coroniti and Kennel [1970] for the auroral region. In fact, there are several evidences giving support to the idea of a wave-wave-electron interaction occurring in the magnetosphere [Kitamura et al., 1969; Kimura, 1974; Sato et al., 1974; Korotova et al., 1975; Olson et al., 1980; Lanzerotti et al., 1980, 1985], some of them showing a correlation with the substorm activity. According to Coroniti and Kennel [1970], such a process could be seen as modulations of the averaged quasi-linear pitch angle diffusion throughout the plasmasphere, due to a modulation by magnetic pulsation of the instability giving rise to the plasmaspheric hiss around the plasmapause. This region is known to be a possible source for magnetic pulsations [Lanzerotti et al., 1985; Lin et al., 1986; Odera and Stuart, 1986] in addition to the magnetopause [Odera, 1986]. In this sense, the weak pitch angle diffusion rate expected in the SAMA region is favorable for the production of precipitation pulsations. Another important characteristic obtained from Figure 1 is that the precipitation pulsations observed (that fall in the range of Pc 4 magnetic pulsations) are superimposed onto an already enhanced precipitation background (at quiet times, the flux between 30 keV and 50 keV is approximately 1500 counts min^{-1} [Pinto and Gonzalez, 1986a]). This fact was pointed out by Coroniti and Kennel [1970] to be a necessary condition for the modulation process to occur. The resonance periods of these magnetic pulsations, supposing a toroidal mode, depend on the length of the geomagnetic field line and the Alfvén velocity along the field line. The Alfvén velocity, in turn, is a function of the magnitude of the local magnetic field and the plasma mass density, both of which vary with the position along the field line. A simple calculation, using a dipole magnetic field model and an average Alfvén velocity [Volland, 1984], gives for the plasmapause a period of about 100 s. This value is sufficiently close to that of the observed periodicity (for a more detailed calculation see, for example, Orr and Matthew [1971]).

Besides the Coroniti and Kennel model, other different models can be invoked to explain the modulation in the electron precipitation. Chen [1974] considered the modulation as a result of a nonlinear interaction between the waves. Davidson [1979, 1986] and Sazhin [1987] have pointed out that there exists a periodic solution of the system of equations describing a wave field and particle dynamics, analogous to a highly nonlinear relaxation oscillator. Based on these models, the irregular periodicity in Figure 3 would be a consequence of the nonlinearity of the wave-particle system. Another possibility is that the irregular nature of the periodicity is due to the complex characteristic of the magnetic pulsations [e.g., Cahill et al., 1984; Lanzerotti et al., 1985; Menk, 1988]. However, the ultimate origin of this phenomenon requires a study of simultaneous ELF wave data with hydromagnetic wave data and precipitating particle data, which is out of the scope of this work.

Another possible process that could be investigated is related to a local resonant process. Local resonances may be associated with field line resonances resulting from effects of a global magnetospheric compressional wave, which is capable of propagating up to low latitudes mainly near the noon meridian [Yumoto et al., 1985; Ansari and Fraser, 1986]. The modulation of quasi-trapped electrons into the drift loss cone could then transmit such information for all longitudes. However, as pointed out by Yumoto [1986], at the low latitude of the observations reported here the magnetic field lines are practically entirely in the ionosphere, where larger ion-neutral particle collisions occur, and thus a standing field line oscillation is difficult. Finally, another local process that has been suggested may develop at the SAMA region, mainly at disturbed periods, and that could be associated with the evidences reported here, is related to some current-driven plasma instabilities [Prange and Bruston, 1980]. However, at the present time, such a process remains poorly known.

Conclusions

An analysis of the time variations of the X ray flux measured at the South Atlantic Magnetic Anomaly during a strong geomagnetic storm was carried out. Two main conclusions were achieved. First, time variations with amplitudes greater than 3 around the mean value were observed. Second, a periodicity with a period of about 108 s was found to exist. It is suggested that such periodicity is possibly caused by wave-particle or wave-modulated wave-particle interactions taking place at L values inside or just at the plasmapause. Nevertheless, we believe that only after a large statistical study of such periodicities will the relative importance of the suggested processes be evaluated.

It is important to mention that astrophysical X ray observations at the SAMA region during magnetically disturbed periods could be seriously affected by the background variability introduced by the type of time variations in the X ray fluxes, due to electron precipitation, discussed in this work.

Acknowledgments. This work was partially supported by the Fundo Nacional de Desenvolvimento Científico e Tecnológico (FNDCT) and the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). The authors would like to thank D. J. Thomson for valuable suggestions concerning the statistical analysis and T. J. Birmingham for his constant assistance.

The Editor thanks three referees for their assistance in evaluating this paper.

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(Received October 6, 1987;
revised August 1, 1989;
accepted August 1, 1989.)

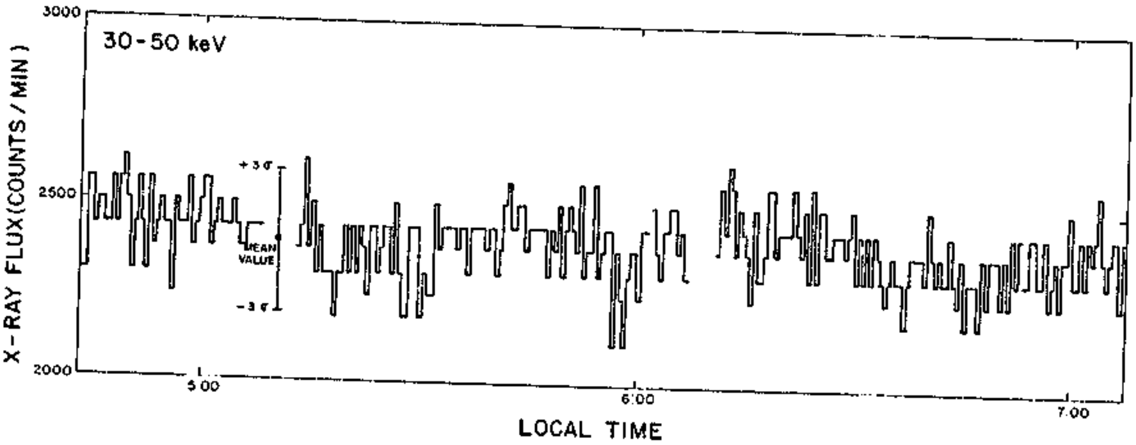
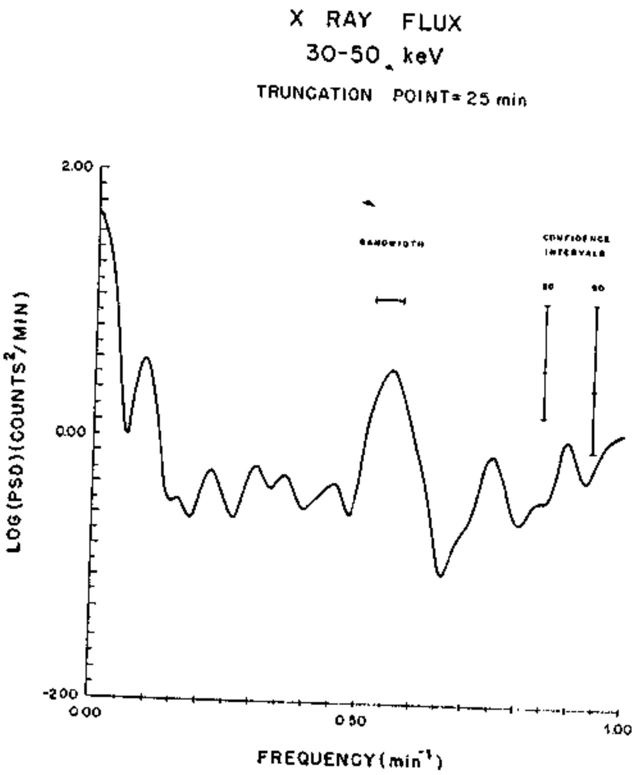

3000
30-50 keV
+3σ
MEAN VALUE
-3σ
2500
2000
X-RAY FLUX (COUNTS / MIN)
5:00
6:00
7:00
LOCAL TIME

Fig. 1



X RAY FLUX
30-50 keV
TRUNCATION POINT = 25 min
2.00
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0.00
0.50
1.00
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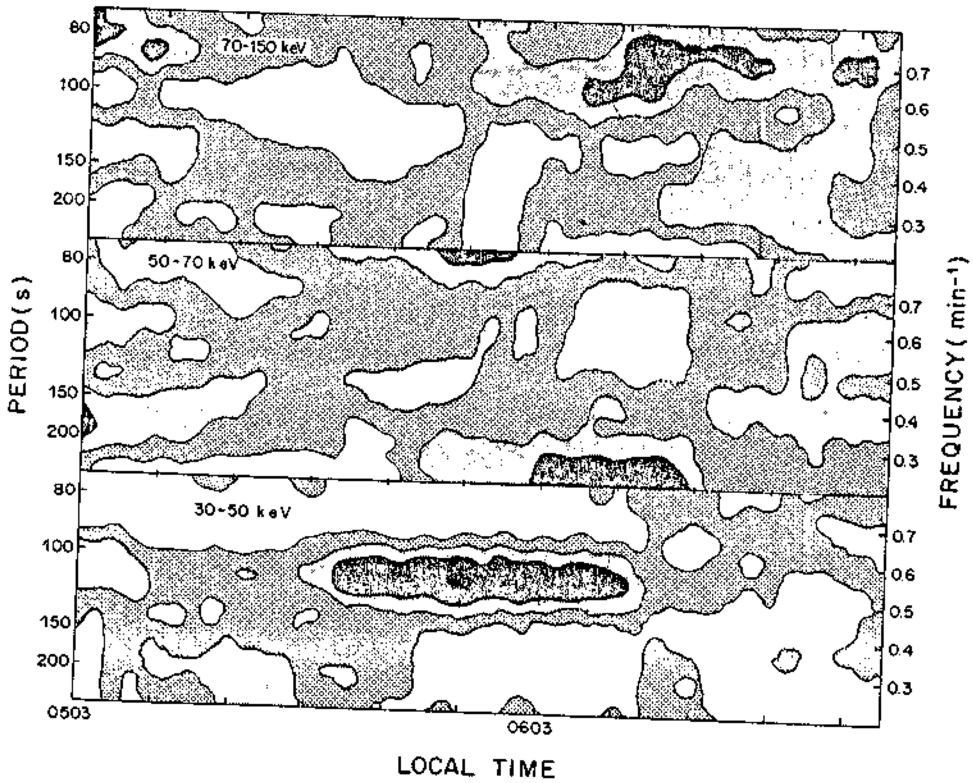
Fig. 2


70-150 keV
50-70 keV
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PERIOD (s)
FREQUENCY (min-1)
80
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0.7
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LOCAL TIME

Fig. 3

Paper number 89JA01603.
0148-0227/89/89JA-01603$02.00

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Fig. 1. X ray flux between 30 keV and 50 keV measured on April 14, 1981, as a function of local time. The mean value and the 30σ bar are indicated.

Fig. 2. PSD in a logarithmic scale for the 30-50 keV X ray flux. The truncation points is equal to 25 min. the 80% and 90% confidence intervals and the bandwidth are also indicated.

Fig. 3. Dynamic power spectrum of all energy channels for the measurements on April 14, 1981. Shading denotes PSD levels in 1.5-dB steps.

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Chefe do Departamento de Geofísica
e Aeronomia-DGA

APÓS A PUBLICAÇÃO, ESTA FICHA SERÁ ARQUIVADA JUNTAMENTE COM A VERSÃO ORIGINAL

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