«Physics of the Auroral Phenomena», Proc. XXV Annual Seminar, Apatity, pp.29-32, 2003
©Kola Science Centre, Russian Academy of Science, 2003
Polar Geophysical Institute

FRACTAL ANALYSIS OF THE MAGNETIC FLUCTUATIONS NEAR LOCAL DIPOLARIZATION AT 5-7 Re

B.V. Kozelov and T.V. Kozelova *(Polar Geophysical Institute, Apatity)*

Abstract. The satellite observations show that the substorm onsets are accompanied by specific behaviors of the particle fluxes and fields. The short-time pseudo-periodic fluctuations of the magnetic field are observed by CRRES satellite in the night side of the Earth's magnetosphere near the moment of the local magnetic field dipolarizations at 5÷7 Re. The period and amplitude of these fluctuations are varying, so the usual Fourier analysis can not be used. Earlier the same substorm associated fluctuations at 7÷9 Re have been studied by (Ohtani et al., JGR, 1995,1998) by using the fractal analysis. Here we have made the same analysis of the CRRES observation data. The results of the fractal analysis we use to discuss the dynamical features of the particle fluxes and magnetic field.

1. Introduction

According to numerous satellite observations the disruption of cross-tail current (current disruption phenomenon) usually associated with substorm onset has complex temporal and spatial structure. Usually the structure is seen as the short-time pseudo-periodic fluctuations of the magnetic field. Such fluctuations have been extensively studied by several researchers. Holter et al. (1995) found the oscillations at low frequency with a period of 40-65 s on r = 6.6 Re. On r = 7÷9 Re, Ohtani et al (1995, 1998) obtained a characteristic frequency component of several times below ion cyclotron frequency. Lui et al (1992) obtained a low-frequency component with a period of 30÷45 s. Higher-frequency components with a period of near 15 s and with a period of 3-4 s are apparent also.

In our previous works (Kozelova et al., 1998, 1999) we also noted low frequency oscillations observed by CRRES satellite. Here we present the results of the fractal analysis of the magnetic fluctuations observed by CRRES near the moments of the local dipolarization.

2. Analytical method

The analytical method used for investigation of the scaling properties of magnetic fluctuations during current disruption in the near-Earth magnetotail was described by Ohtani et al. (1995) and Lui (2002). In the analysis for the scale of τ, where τ is a multiple of the time resolution Δt of the magnetic field data, the total data interval $(N\Delta t)$ is divided into k $(=\tau/\Delta t)$ data subsets with $B_{k,m}=\{B(\mathrm{m}\Delta t), B(\mathrm{m}\Delta t+\tau), B(\mathrm{m}\Delta t+2\tau),..., B(\mathrm{m}\Delta t+[(N-m)/k]\tau)\}$, where m = 1,2,...,k, and the square bracket $[n]$ indicates the largest integer not exceeding n. The length $L_m(\tau)$ of the subset $B_{k,m}$ is defined as

$$L_m(\tau) = \{(\Sigma_i |B(\mathrm{m}\Delta t+i\,\tau)-B(\mathrm{m}\Delta t+(i-1)\,\tau))\, A_m\}/\tau$$

The coefficient A_m, defined as $(N-1)/([(N-m)/k]k)$ (here the square bracket also has the special meaning as noted above), is a normalization factor to adjust the difference in the number of data points among the subsets. The length $L(\tau)$ is then the average of $L_m(\tau)$ over the k subsets. If $L(\tau) \propto \tau^{-d}$, then $B(t)$ is self-affine and d is the fractal dimension. The self-affine data have a power law spectrum $P(f) \propto f^{-s}$, with $s = 5 - 2d$ (Mandelbrot, 1977) when d is not close to either 1 or 2. In some cases the logarithmic plot of $L(\tau)$ versus τ has a kink at a certain value of $\tau = \tau_c$. That is, the plot has different slopes in $\tau \le \tau_c$ and $\tau \ge \tau_c$. This indicates that an associated physical process has a certain characteristic timescale T_c. The relationship of T_c and τ_c was numerical examined by Higuchi (1990). He obtained that $T_c = 3 \div 5\ \tau_c$. Two advantages of the fractal analysis over the traditional Fourier analysis were pointed out by Ohtani et al. (1995). The calculation of $L(\tau)$ is significantly more stable and localized in the time domain against abrupt phase changes of fluctuations than that of a power spectrum from Fourier analysis. Furthermore, the fractal analysis gives reliable results even for fluctuations with a characteristic time scale that is a significant fraction of the entire data interval. Here we use the same method for the study of the magnetic fluctuations observed by CRRES satellite.

3. Data

We analyze the 2-s data of the magnetic field observations by CRRES satellite at orbits 445, 494, 497, 527, 540, 545, 560, and 577. For 484 orbit we have 5-s data only. We used the total value B_t and the magnetic field components in SM system. Several time intervals with different types of fluctuations were selected near the moments of the local dipolarization at 5÷7 Re. In Section 3.1 we present one example from the list of the substorms that were considered.

3.1. Substorm on 24 January 1991

The onset of the substorm on 24 January 1991 took place at 1649 (Maynard et al., 1996). The CRRES (Orb 445) was located near the current sheet equatorial plane (at L = 6, mlat = -0.9 degree and 2335 MLT, Kp = 4) when the substorm onset occurred. The particle injections and the magnetic field variations at the CRRES started with a five minutes delay from the substorm onset at about 1654 UT . Fig. 1 presents the total magnetic field Bt on the CRRES, the inclination angle relative to the XY plane, the electron flux intensity in several channels (21.5-31.5, 49.5-59, 69-81, 94.5-112 and 129.5-151 keV) and the ion flux intensity in four channels (37-54, 69-85, 147-193 and 335-447 keV).

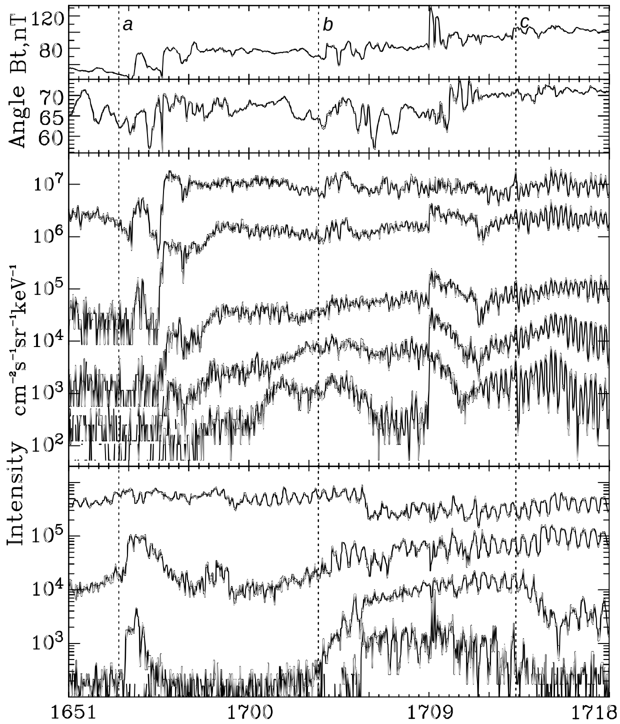

Fig.1. CRRES satellite observations, orbit 445, from top to bottom: magnetic field, inclination angle, electron flux in 5 channels, proton flux in 4 channels (see text).

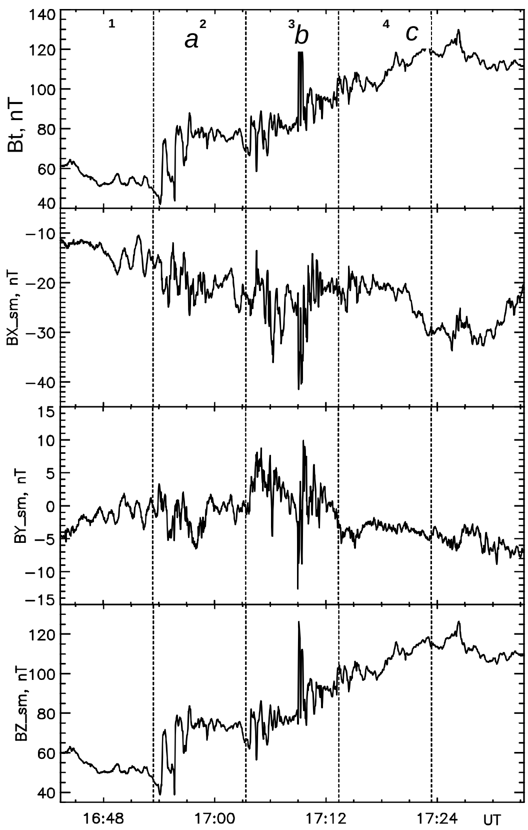

Fig.2. Magnetic field observations on CRRES satellite, orbit 445.

Three vertical lines "a"-"c" denote the transitions between different states of the magnetic field and the intensities of the particles. The first transition (line "a") was near the "local dipolarization" of the magnetic field. The injection of the electrons and the bursts of energetic ions are observed simultaneously with this dipolarization. Further one can see the subsequent development of this substorm. The line "b" on the Fig.1 denotes second substorm intensification (Lazutin et al., 1998). The injection of the energetic ions and the bursts of energetic electrons are observed in the interval between the line "b" and "c". The line "c" denotes the exit out of the disturbance region and the transition toward the final state of the plasma sheet and the magnetic field.

Fig. 2 presents the total magnetic field on the CRRES, and its components in SM system. Selected time intervals 1-4 are separated by above-mentioned lines "a"-"c" (vertical dashed lines). In this intervals we use the fractal analysis to study the fluctuations of the magnetic field components. The interval 1 is before the local dipolari-zation onset. Each magnetic component started to change irregularly at the moment “a”. The highly irregular fluctuations continued during the intervals 2 and 3.

4. Results

Fig.3 presents the correspondent results of the fractal analysis: $L(\tau)$ versus τ in the logarithmic scale and slope of the dependence, $d(\tau)$, versus τ. Note that $L(\tau)$ is an increasing function of the number of data points; therefore it must be normalized to a certain interval when compared between intervals with different numbers of data points. In this study, $L(\tau)$ is normalized to 1 s, and $L(\tau)$ is given in units of nT/s^2.

In Fig.3 one can see that the kink of the $L(\tau)$ plot is not evident only in the total field B_t and B_z component and only in the interval 1. However sharp increase of the slope, $d(\tau)$, (or an appearance of a kink of $L(\tau)$ plot) is observed during the intervals 2 and 3 for each magnetic component and B_t. For example, for B_z component during the interval 2, from Fig.3 (right column) one can see that the slope of the line $L(\tau)$, which corresponds to the fractal dimension, sharp increases from 1.2÷1.4 to 1.6÷2 near τ_c = 20 s. Thus the characteristic time scale of the B_z component fluctuations is 60 s < T_c < 100 s during the interval 2. Note that these B_z fluctuations are not observed in the interval 1. The comparison between the intervals 2 and 3 for the B_z magnetic component indicates that $L(\tau)$ increased primarily in more short timescale range near τ_c = 4 s or 12 s < T_c < 20 s. Thus, the magnetic fluctuations of the B_z component have two oscillation regimes: 1 - with a characteristic timescales T_c = 60÷100 s, and 2 - timescales T_c = 12÷20 s.

Two oscillation regimes are observed also in the other magnetic components. The fluctuations of the B_x and B_y components have more large time scale (near τ_c

= 20 s) during the interval 1. For these components the sharp increase of $d(\tau)$ is observed near τ_c= 4 s or 12 s < T_c< 20 s during the intervals 2 and 3.

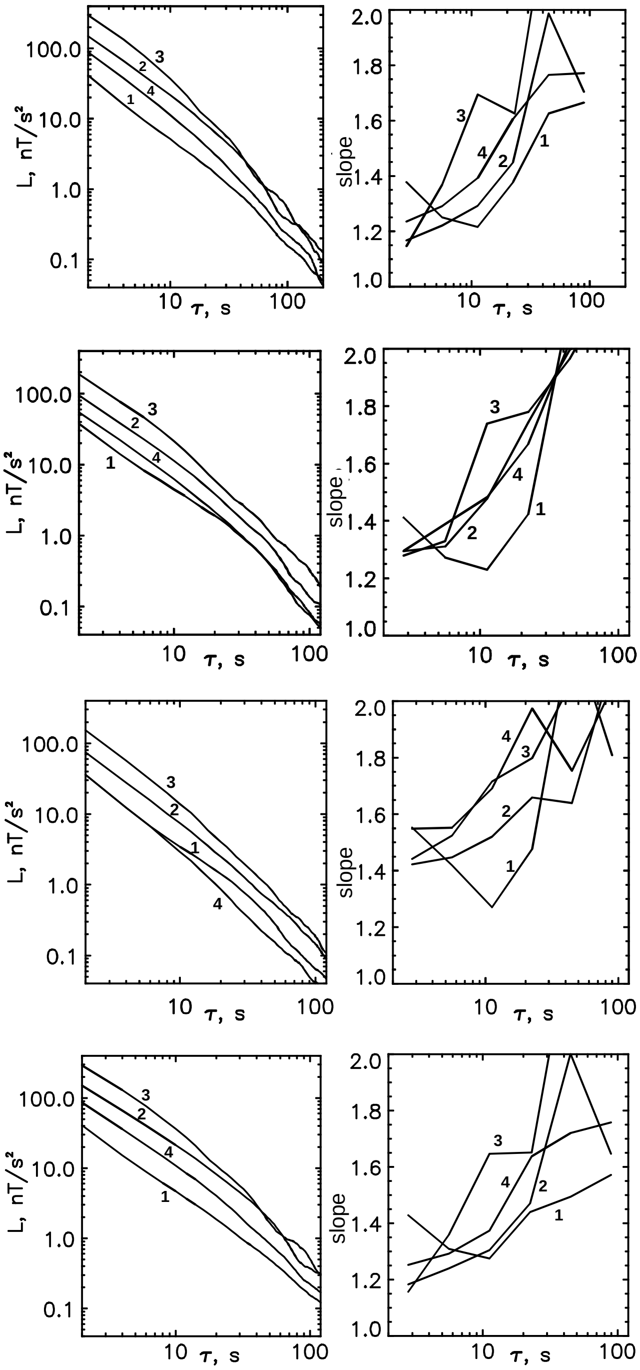

Fig.3. Results of the fractal analysis. Rows correspond to the magnetic field data shown in Fig.2. The lines are numbered according to intervals in Fig.2.

From Fig.3 one can see the difference in τ_c among the components during the same time interval. The more large scale oscillations are observed in the B_x and B_y components in the interval before the local dipolarization and particle injection (interval 1). Then in the interval after local dipolarization (interval 2) these oscillations appear also in the B_z component. Simultaneously in this interval 2 the oscillations with more short time scale begin in the B_x and B_y components. Further (in the interval 3 when the subsequent dipolarization and the injection of more energetic particles occurred) the oscillations with more short time scale begin in the B_z component. Thus, the appearance (enhancement) of the oscillations with more short time scale coincides with the energetic particle injection. In the interval 4, when the changes both in the magnetic field and particle fluxes are caused by effects occurring far away from the CRRES, the amplitude of oscillations decreases and characteristic timescale increases.

The difference of the time scale for the different magnetic components may reflect different kinds of the electric currents (cross-tail and field-aligned currents), which flow in the different directions and have different spatial scales.

This is true also for the magnetic components during other substorms which we analyzed.

5. Discussion

The fluctuations associated with the current disruption (and the magnetic field dipolarization) have been studied several researchers. Holter et al (1995) obtained the magnetic oscillations with a period of 40÷65 s. Roux et al (1991) observed similar oscillations in the electric field. They related these oscillations with the ballooning waves. Erickson et al (2000) obtained that the magnetic field oscillations with a period of 30 s appear near the local dipolarization onset. Besides, higher frequency components of magnetic fluctuations are observed also in the agreement with the cross-field current instability (Lui et al., 1991). Cheng and Lui (1998) consider the kinetic ballooning instability and suggest that a resonance “the ballooning wave – magnetic drifting energetic ions” is possible. Then these ions may lead to the generation of higher-frequency cross-field current-driven instability.

6. Conclusions

We examine the variations of the characteristics ($L(\tau)$ and $d(\tau)$) of the magnetic field fluctuations in the course of the several substorms on the CRRES at 5÷7 Re. Main results are following.

1). The magnetic fluctuations have two oscillation regimes: 1- with a characteristic timescales T_c = 60÷100 s and 2 - timescales T_c = 12÷20 s.

2). Oscillations in the different magnetic field components may be different (in different regimes) during the same time interval. After the local dipolarization onset the more large scale oscillations are observed in the B_z component and more short time scale oscillations in the B_x and B_y components.

3). Changes in the oscillation regime usually associated with the changes in the particle fluxes. The appearance (enhancement) of the oscillations with more short time scale coincides with the energetic particle injection during substorm expansion.

Acknowledgements. The work is supported by grant RFBR-01-05-64827.

References

Cheng, C. Z., and A. T. Y. Lui, Kinetic ballooning instability for substorm onset and current disruption observed by AMPTE/CCE, *Geophys. Res. Lett., 25*, 4091, 1998.

Erickson, G.M., N. C. Maynard, G. R. Wilson, and W. J. Burke, Electromagnetics of substorm onset in the near-geosynchronous plasma sheet, *Proc. Fifth International Conference on Substorms, St. Petersburg. Russia.16-20 May 2000. ESA SP-443(July, 2000),* 385, 2000.

Higuchi T. Relationship between the fractal dimension and the power law index for a time series: A numerical investigation, Physica D, 46, P. 254, 1990.

Holter, O., Altman C., Roux A., Perraut S., Pedersen A., Pecseli H., Lybekk B., Trulsen J., Korth A., Kremser G., Characterization of low frequency oscillations at substorm breakup, J. Geophys. Res., V.100, P.19109, 1995.

Kozelova T. V., Lazutin L. L., Kozelov B. V., Dipolarization and Disturbance Currents in the Magnetosphere as Observed by the CRRES Satellite, Geomagnetizm i aeronomy (English translation), V. 39, No. 1, p. 13-23, 1999.

Kozelova T.V., Kozelov B.V., Lazutin L.L. Changes in the magnetospheric cross-field current during substorm expansion phase as observed by CRRES, Proceedings of SUBSTORMS-4, Edited by S.Kokubun and Y.Kamide, p.393-396, 1998.

Lazutin L., T. Kozelova, R. Rasinkangas, A. Korth, H. Singer, J. Stadsness, S. Ullaland and K. Torkar. Radiation belt proton contribution to substorm structure and dynamics, SUBSTORM-4, Edited by S. Kokubun and Y. Kamide, 1998, P. 547-550.

Lui A.T.Y. Multiscale phenomena in the near-Earth magnetosphere, J. Atm. Sol.-Terr.Phys., V.64, P.125-143, 2002.

Lui A.T.Y., R. E. Lopez, B. J. Anderson, K. Takahashi, L. J. Zanetti, R. W. McEntire, T. A. Potemra, D. M. Klumpar, E. M. Greene, and R. Strangeway, Current disruptions in the near-Earth neutral sheet region, J. Geophys. Res., V.97, P.1461, 1992.

Lui, A. T. Y., C.-L. Chang, A. Mankofsky, H.-K. Wong, and D. Winske, A cross-field current instability for substorm expansion, *J. Geophys. Res., 96.*, 11389, 1991.

Mandelbrot B. Fractals: form, chance and dimension, Freeman, New York, 1977.

Maynard, N.C., W. J. Burke, E. M. Basinska, G. M. Erickson, W. J. Hughes, H. J. Singer, A. G. Yahnin, H. J. Hardy, and F. S. Mozer, Dynamics of the inner magnetosphere near times of substorm onsets *J. Geophys. Res.*, *101*, N. A4, P. 7705-7736, 1996.

Ohtani S., Higuchi, T., Lui, A.T.Y., Takahashi, K., Magnetic fluctuations associated with tail current disruption: fractal analysis, J. Geophys. Res. V.100, P. 19135-19145, 1995.

Ohtani S., Takahashi K., Higuchi T., Lui, A.T.Y., Spence, H.E., AMPTE/CCE-CATHA simultaneous observations of substorm-associated magnetic fluctuations. J. Geophys. Res. V.103, P.4671-4682, 1998.

Roux, A., S. Perraut, P. Robert, A. Morane, A. Pedersen, A. Korth, G. Kremser, B. Aparicio, D. Rodger, and R. Pellinen, Plasma sheet instability related to the westward traveling surge, *J. Geophys. Res., 96*, 17697, 1991.