ISSN 0252-1075
Research Report No. RR-063

Contributions from
Indian Institute of Tropical Meteorology

A UNIVERSAL SPECTRUM FOR FLUXES OF ENERGETIC CHARGED PARTICLES FROM THE EARTH'S MAGNETOSPHERE

by

A. M. SELVAM
and
M. RADHAMANI

PUNE - 411 008
INDIA

JUNE 1995

A UNIVERSAL SPECTRUM FOR FLUXES OF ENERGETIC CHARGED PARTICLES FROM THE EARTH'S MAGNETOSPHERE

A.M. Selvam and M. Radhamani

Indian Institute of Tropical Meteorology, Pune 411 008, India

ABSTRACT

Continuous periodogram analyses of energetic charged particles observed by Space Environment Monitor (Meteorological Satellite Center, Japan) follow the universal and unique inverse power law form of the statistical normal distribution. Inverse power law form for the power spectra of temporal fluctuations is ubiquitous to real world dynamical systems and is recently identified as a signature of self-organized criticality. The universal quantification for self-organized criticality in the temporal fluctuations of energetic charged particles from the earth's magnetosphere implies predictability of the total pattern of fluctuations and may help to identify the physics of solar-terrestrial relationship

1. INTRODUCTION

The magnetospheric plasma-wave particle processes carry the signatures of energy exchange between solar wind and the earth's magnetosphere which contribute to the solar-terrestrial coupling processes. The power spectra of the energetic charged particles of planetary magnetospheres and solar wind exhibit the inverse power law form (AGU, 1983). In general the power spectra of many geophysical phenomena are well approximated by a powerlaw dependence on frequency or wave number (Agnew, 1992). Such inverse powerlaw form for power spectra indicating long-range temporal correlations are ubiquitous to real world dynamical systems and are now identified as signatures of self-organized criticality (Bak, et al., 1988). The Physics of self-organized criticality is not yet identified. In this paper a cell dynamical system model for atmospheric flows (Selvam, 1990, Selvam, et al., 1992) applicable to magnetospheric plasma flows (Sikka et al., 1988) is summarised. The model enables universal quantification of the nonlinear variability of magnetospheric energetic charged particles. The important conclusion of this study is that the total pattern of fluctuations of energetic charged particles of magnetospheric origin is predictable and therefore prediction of major solar-terrestrial disturbances is possible.

2. CELL DYNAMICAL SYSTEM MODEL

The model (Mary Selvam, 1990; Mary Selvam et al., 1992; Selvam and Radhamani, 1994) is based on Townsend's (1956) concept that spatial integration of small scale fluctuations give rise to large eddy circulations in turbulent shear flows. In atmospheric flows there is an inherent net upward momentum flux of frictional origin at the planetary surface. This upward momentum flux is progressively amplified by the exponential decrease of atmospheric density with height coupled with buoyant energy generation during microscale fractional condensation by deliquescence on hygroscopic nuclei even in an unsaturated environment. This upward momentum flux generates helical vortex roll circulations manifested as cloud rows/streets in the global cloud cover pattern. Such vortex roll circulations are visualised to extend up to the magnetosphere (Sikka et al., 1988). Atmospheric flows extending up to the magnetosphere therefore consist of a continuum of eddies with two-way ordered energy feedback between the larger and smaller scales. Since successive large eddy circulations form as the spatial integration of enclosed turbulent eddies, the eddy energy (kinetic) spectrum follows normal distribution characteristics. Therefore, the square of the eddy amplitude represents the probability of occurrence. Such a result is similar to the observed sub-atomic dynamics of quantum systems and implies quantum-like mechanics for atmospheric flows. The model thus predicts the universal inverse power law form of the statistical normal distribution for the power spectrum of atmospheric eddy fluctuations. As mentioned earlier, inverse power law for power spectra imply long-range temporal correlations identified as self-organized criticality. Model concepts provide unique quantification for self-organized criticality in atmospheric flows.

The model further predicts logarithmic wind profile relationship for atmospheric flows. The conventional power spectrum plotted as the variance versus the frequency in log-log scale will now represent the eddy probability density on logarithmic scale versus the standard deviation of the eddy fluctuations on linear scale since the logarithm of the eddy wavelength represents the standard deviation, i.e., the r.m.s. value of the eddy fluctuations.

The r.m.s. value of the eddy fluctations can be represented in terms of the statistical normal distribution as follows: A normalized standard deviation t=0 corresponds to cumulative percentage probability density equal to 50 for the mean value of the distribution. Since the logarithm of the wavelength represents the r.m.s. value of eddy fluctuations the normalised standard deviation t is defined for the eddy energy distribution as $t = (\log L/\log T_{50})-1$ where L is the period and T_{50} is the period up to which the cumulative percentage contribution to total variance is equal to 50 and t=0. Log T_{50} represents the mean value for the r.m.s. eddy fluctuations and is consistent with the concept of the mean level represented by r.m.s. eddy fluctuations.

In the following it is shown that power spectra of temporal (hours to days) fluctuations of magnetospheric energetic particles follow the universal inverse power law form of the statistical normal distribution consistent with model predictions.

3. DATA AND ANALYSES

The energetic charged particles during the period August to November 1990 as observed by the Space Environment Monitor (SEM) of the Geostationary Meteorological Statellite (GMS) of Japan (Monthly Report of Meteorological Satellite Center, August-November, 1990) is used for this study. Details of the 22 sets of time series used are given in Table 1.

The broadband power spectra of the magnetospheric energetic charged particles are computed by the simple but powerful method of continuous periodogram analysis of Jenkinson (1977). This method provides a quasi-continuous form of classical periodogram allowing systematic allocation of the total variance and degrees of freedom of the data series to logarithmically space elements of the frequency range (0.5, 0). The cumulative percentage contribution to total variance is computed from high frequency side of the spectrum. The period T_{50} at which the 50% contribution to total variance occurs is taken as reference and the normalised standard deviation t_m values are computed as:

$$t_m = (\log L_m/\log T_{50}) - 1$$

The power spectra are plotted as cumulative percentage contribution to total variance versus the normalised standard deviation t. The statistical normal distribution is also plotted as crosses in Fig.1 and represent the cumulative percentage probability for the normalised standard deviation t. The short horizontal lines in the lower part of the spectra indicate the lower limit above which the spectra are the same as the normal distribution determined by the statistical Chi-square test for "goodness of fit" at 95% confidence level. It is seen from Fig.1 that the power spectra of magnetospheric energetic charged particles are the same as the statistical normal distribution when plotted in this manner. Table 1 gives the mean and standard deviation of the data, the periodicities T_{50}, T_{75}, T_{90} up to which the cumulative percentage contribution to total variance is equal to 50, 75 and 90 respectively and the peak periodicities for dominant wave-bands for which the normalised variance is equal to or more than 1.

4. DISCUSSION AND CONCLUSION

The power spectra of energetic charged particles of magnetospheric origin closely follow the universal inverse power law form of the statistical normal distribution (Fig.1) when plotted in the manner described above. The result implies that the square of the eddy amplitude represents the eddy probability density and is consistent with the cell dynamical system model prediction of quantum-like mechanics for atmospheric flows (Mary Selvam, 1990; Mary Selvam, et al., 1992) and also magnetospheric plasma flows (Sikka et al., 1988). The apparently chaotic temporal fluctuations of magnetospheric energetic charged particles therefore exhibit self-organized criticality, namely long-range temporal correlations. Such sensitive dependence on initial conditions (temporal) is a signature of deterministic chaos. Deterministic chaos has been identified in magnetospheric plasma fluctuations (Ashour - Abdalla, 1991).

The cell dynamical system model summarised in section 2 identifies quantum-like mechanics governing atmospheric flow dynamics as the physical basis for the observed self-organized criticality or deterministic chaos in magnetospheric particle density variability. The unique quantification for self-organized criticality implies predictability of the total pattern of charged particle fluctuations over a period of time.

Table 1 shows that eddies of periods from 6 to 25 days contribute to up to 50% of the total variance. The dominant periodicities are in agreement with model predicted periodicities of $T(2+\tau)\,\tau^n$ where τ is the golden mean [$= (1+\sqrt{5})/2 = 1.618$] , the exponent n ranges from negative to positive integer values and T, the primary perturbation time period of the diurnal cycle of solar heating and is consistent with the observations that geomagnetic activity as seen in the power spectrum of hourly averages of the AE index exhibit peak at 24-hour period (Shan, *et al., 1991)* consistent with the inferred primary perturbation cycle of diurnal heating. For values of n ranging from -1 to 5 the model predicted dominant periodicities are 2.2, 3.6, 5.8, 9.5, 15.3, 24.8 and 40.1 days and are in agreement with those in Table 1.

Earlier .studies have identified the existence of self-organized criticality in temporal flucutations of different time scales in the following meteorological parameters: (1) Rainfall (summer monsoon) over the Indian region (Mary Selvam *et al.,* 1992, Mary Selvam, 1993), COADS surface (air and sea) temperatures (seasonal mean) (Selvam and Joshi 1995) (2) Atmospheric columnar total ozone content (daily) (Selvam and Radhamani, 1994). The present study has identified the existence of self-organized criticality in magnetospheric plasma fluctuations.

Acknowledgements -- The authors are grateful to Dr. A.S.R. Murty for his keen interest and encouragement during the course of this study.

REFERENCES

Agnew, D.C. (1992) The time-domain behaviour of power-law noises. *Geophys. Res. Lett.*, **19(4),** 333

AGU (1983) Contributions in Solar-Planetary relationships. U.S. National report to International Union of Geodesy and Geophysics 1979-1982. American Geophysical Union, U.S.A.

Bak, P.C. Tang, C., and Wiesenfeld, K., (1988) Self-organized criticality. *Phys. Rev.* A **38,** 364.

Jenkinson, A.F. (1977) *A powerful elementary method of spectral analysis for use with monthly, seasonal or annual meteorological time series,* Met. O 13 Branch Memorandum, **57,** pp. 1-23.

Maha Ashour-Abdalla (1991) Chaos and stochasticity in space plasmas. *Geophys. Res. Lett.*, **18(8)**, 1573.

Monthly report of Meteorological Satellite Centre, August-November (1990) Meteorological Satellite Centre, Tokyo, Japan.

Selvam, A.M. (1990) Deterministic chaos, fractals and quantum-like mechanics in atmospheric flows, *Can. J. Phys.*,**68,** 831

Selvam, A.M., Pethkar, J.S. and Kulkarni, M.K. (1992) Signatures of a universal spectrum for atmospheric interannual variability in rainfall time series over the Indian region. *Int'l. J. of Climatol.,* **12(2),** 137.

Selvam, A.M. and Radhamani, M. (1994) Signatures of a Universal spectrum for nonlinear variability in daily columnar total ozone content, *Adv. Atmos. Sci.*,**11(3),** 335.

Selvam, A.M. and Joshi, R.R. (1995) Universal spectrum for interannual variability in COADS global air and sea surface temperature, *Int'l. J. Climatol.,* **15,** 1995.

Shan, L.H., Goertz, G.K. and Smith, R.A. (1991) On the embedding-dimension analysis of AE and AL time series, *Geophys. Resi. Lett.,* **18(8),** 1647.

Sikka, P., Mary Selvam, A. and Ramachandra Murty, A.S. (1988) Possible solar influence on atmospheric electric field, *Adv. Atmos. Sci.,* **5(2),** 217.

Townsend, A.A. (1956) The structure of turbulent shear flow. Cambridge University Press, U.K., pp. 130.

Table 1 : Periodogram estimates of energetic charged particles from the earth's magnetosphere

Sr. No.	No. of days	Averages of hourly values for (Days)	duration (Hrs. UT)	Mean (No. conc.)	Std. Dev. (No. conc.)	T_{50} (Days)	T_{75} (Days)	T_{90} (Days)	Peak Periodicities (days) contributing to maximum normalised variance (H) in the wave band H>=1					
	ELECTRON: >2 MeV.													
1.	120 (1 Aug-28 Nov)*	6	1-24	427.45	311.34	27.9	70.2	98.2	18.0	27.0	81.4	-	-	-
2.	60 (1 Aug-29 Sep)	4	4-18	299.91	172.69	15.4	37.4	57.7	9.9	12.9	18.1	51.5	-	-
3.	120 (1 Aug-28 Nov)*	6	14-24	345.50	273.39	27.1	33.3	95.0	17.8	27.1	53.7	-	-	-
4.	120 (1 Aug-28 Nov)*	4	3-12	435.29	291.57	28.6	74.8	101.0	18.3	26.4	81.3	-	-	-
5.	75 (1 Aug-14 Oct)*	3	10-19	257.87	215.51	13.3	19.9	79.5	6.3	6.9	9.7	13.5	17.5	-
6.	119 (1 Aug-27 Nov)	7	18-22	384.52	250.16	28.5	71.3	103.2	15.3	18.6	26.7	80.5	-	-
7.	60 (1 Aug-29 Sep)	3	5-7	447.98	260.25	14.0	36.3	55.9	6.9	10.3	13.2	18.5	49.1	-
8.	60 (1 Aug-29 Sep)	3	18-20	292.64	196.45	13.5	33.8	53.1	6.0	6.8	10.1	13.1	18.3	47.0
9.	60 (1 Aug-29 Sep)	4	12-13	180.42	131.08	7.0	13.7	31.2	5.0	6.5	8.9	29.1	-	-
	PROTON: 15-36 MeV.													
10.	120 (1 Aug-28 Nov)*	6	1-24	0.51	1.41	24.2	48.4	121.3	12.0	13.4	15.0	17.3	20.4	25.0
									31.5	42.7	68.6	-	-	-
11.	40 (1 Aug-9 Sep)*	2	1-24	1.16	3.88	8.8	18.3	46.1	8.8	8.2	10.5	14.2	22.7	40.0
12.	80 (1 Aug-19 Oct)*	4	1-12	0.54	1.54	16.3	17.5	85.9	10.1	11.6	13.6	16.4	20.9	28.4
13.	40 (10 Sep-19 Oct)	2	13-24	0.17	0.015	10.7	39.4	67.1	4.0	4.9	6.0	10.2	14.4	-

PROTON: 200-500 MeV													
14. 50 (1 Aug-19 Sep)	2	1-3	1.01	0.045	7.2	17.8	35.6	4.7	5.1	7.1	13.2	20.3	-
15. 80 (1 Aug-19 Oct)*	4	1-5	1.10	0.16	25.6	79.8	136.5	14.1	17.3	28.3	-	-	-
16. 80 (1 Aug-19 Oct)*	6	20-24	1.08	0.12	27.7	88.4	144.7	11.4	14.1	19.2	27.4	-	-
ALPHA: 325-390 MeV.													
17. 100 (1 Aug-8 Nov)	4	1-24	0.05	0.002	16.1	45.9	72.8	9.0	13.6	18.1	65.2	-	-
18. 120 (1 Aug-28 Nov)	6	6-11	0.05	0.004	18.2	43.2	52.5	15.1	47.3	-	-	-	-
ALPHA: 148-244 MEV													
19. 60 (1 Aug-29 Sep)	3	1-24	0.04	0.003	9.8	19.9	47.0	8.8	11.3	26.4	-	-	-
20. 50 (1 Aug-19 Sep)	2	1-3	0.04	0.008	5.6	10.7	19.7	4.5	5.7	6.7	17.6	-	-
21. 50 (1 Aug-19 Sep)	2	11-13	0.04	0.009	6.3	15.5	26.2	4.3	4.8	6.2	7.3	8.8	24.1
22. 60 (1 Aug-29 Sep)	3	22-24	0.04	0.006	10.9	19.3	72.6	7.9	9.9	19.1	-	-	-

Std. dev. : Standard deviation of the time series.
* denotes the data series is not distributed normally.

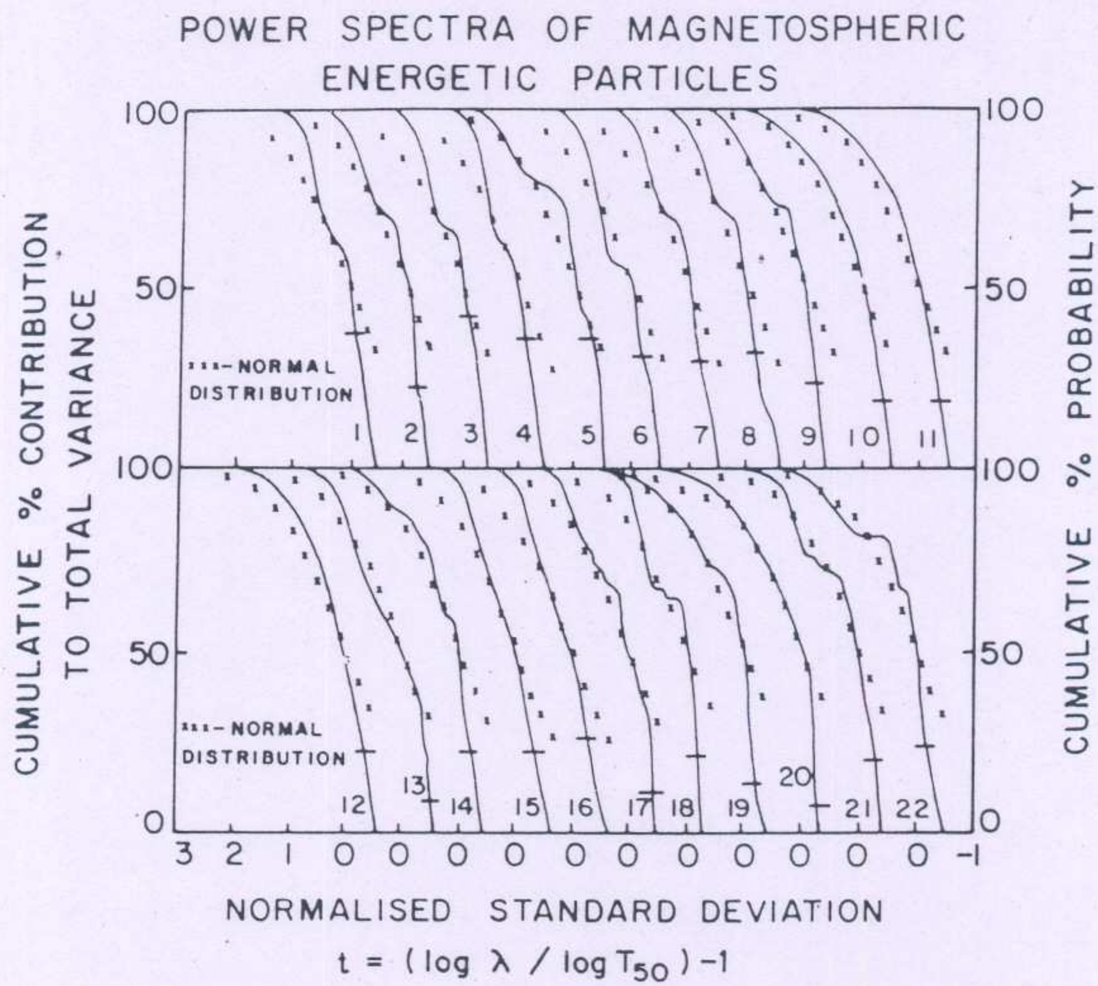

Figure 1: Power spectra of Energetic Charged Particles.