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Identification of a Universal Spectrum for Nonlinear Variability of Solar-Geophysical Parameters

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IDENTIFICATION OF A UNIVERSAL SPECTRUM FOR NONLINEAR VARIABILITY OF SOLAR-GEOPHYSICAL PARAMETERS

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ABSTRACT. The power spectra of time series of fourteen different solar-geophysical parameters of different time scales and time periods are shown to follow the universal inverse power law form of the statistical normal distribution. Inverse power law form for the power spectra of temporal fluctuations are ubiquitous to real world dynamical systems and are recently identified as the temporal signature of self-organized criticality. The unique quantification for the inverse power law form for power spectra implies predictability of the total pattern of non-linear variability in time evolution of solar geophysical parameters.

1. Introduction

Long-range temporal correlations manifested as the inverse power law for the power spectra of temporal fluctuations are ubiquitous to real world dynamical systems and are recently identified as the temporal signatures of self-organized criticality (Bak, Tang and Wiesenfeld, 1988). Computations of power spectra have become standard in the analysis of time series data (MacDonald 1989), in particular, of solar-geophysical parameters for the identification of dominant periodicities for predictability studies. Conventional power spectrum analysis shows in general that dominant periodicities coexist with a broadband continuum spectrum for the temporal fluctuations, e.g., the 11-year and 22-year periodicities in sunspot numbers and the ENSO (El-Nino-Southern Oscillation) cycle in weather patterns. Geophysical phenomena in general exhibit the inverse power law form for the power spectrum of temporal fluctuations (Agnew, 1992). Identification of the universal inverse power law form for the power spectrum, namely "self-organized criticality" mentioned earlier implies ordered 'coexistence' of a continuum of fluctuations. Though the universal inverse power law form, namely v^{-B} where v is the frequency and B the exponent has been identified for the shape of the power spectrum of temporal fluctuations, the magnitude of B varies with time scales of parameters investigated. A universal quantification for the self-organized critical state, namely, the inverse power law form for the power spectra will enable prediction of the total pattern of fluctuations of all scales. In this paper it is shown that the power spectra of the temporal fluctuations of solar-geophysical parameters

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can be quantified in terms of the universal and unique characteristics of the statistical normal distribution.

2. Data and Analysis

The following 14 sets of solar-geophysical parameters of different time-scales and time periods are used for the study.

1. 300 daily A_p index, Nov. 89-Sept.90
   (Solar-geophysical data prompt reports. Dec. 1990, No.556- Part I, National geophysical data center, Boulder, Colorado, USA).

2. 20 3-year means of annual sunspot number, 1793-1852. (Solar-terrestrial physics and meteorology : a working document, 1975, SCOSTEP, Washington, D.C., USA)

3. 24 6-hour means of surface atmospheric electric field at Pensacola, Florida, USA, 19-22 June 1960.
   (Trent and Anderson, 1965).

4. 20 6-day means of total columnar ozone for Cairo, March-June 1990
   (Ozone data for the world, March-June 1990, Atmospheric environment service, Department of the environment, Canada)

5. 50 24-hour means of hourly equatorial DST values Jan.-Feb.1989.
   (Solar-geophysical data prompt reports, November 1990, No.555-Part I, National geophysical data center, Boulder, Colorado, USA).

6. 20 6-hour means of air temperature at ground level, Bombay, India, 1-4 Jan. 1966 (Magnetic, meteorological and atmospheric electric observations made at government observatories at Bombay, Alibag, Annamalainagar and Trivandrum in the year 1966, India Meteorological Department, Delhi, India).

7. 30 3-day means of vorticity area index (northern hemisphere), Jan.-Mar. 1946.
   (Solar-terrestrial physics and meteorology : working document II, 1977, SCOSTEP, Washington, D.C., USA).

8. 36 10-day means of daily sunspot number 1 Jan. - 26 Dec. 1989
   (Solar-geophysical data prompt reports.January 1990, No.545-Part I, National geophysical data center, Boulder, Colorado, USA).

9. 25 Seasonal mean (September-November) southern oscillation index, 1961-1985. These are homogenized Darwin

pressure anomaly minus Tahiti pressure anomaly calculated monthly and averaged over 3-month season (Wright 1989).

10. 25 6-year means of horizontal intensity of geomagnetic field at Alibag (18.6°N, 72.9°E), India 1-7 Jan. 1966. (Data source same as for item 6 above).

11. 40 3-hour means of surface relative humidity at Bombay (18.9°N, 72.5°E), India 1-5 Jan. 1966. (Data source same as for item 6 above).

12. 28 Annual mean surface pressure for block No. 5831227 (24°N, 138°E) from COADS, 1961-1988. (Comprehensive Ocean-Atmosphere Data Set (COADS). Release 1, 1986, Climate research program, ERL, Boulder, Colorado, USA).

13. 30 7-day means of 10.7 cm solar flux at Algonquin radio observatory, Ottawa, Canada, Jan.- July 1987. (Solar-geophysical data prompt reports. January 1988, No 521-Part I, National geophysical data center, Boulder, Colorado, USA).

14. 115 Summer monsoon rainfall for meteorological subdivision 26, India 1851-1985. (Parthasarathy et. al., 1987).

The data sets were subjected to a quasi-continuous periodogram spectral analysis (Jenkinson 1977) as described briefly in the following. The periodogram is constructed for a fixed set of 10000 (m) wavelength (periods) L_m = 2 exp (cm) where c = 0.001 and m = 0,1,2 ...m. The data series y_t for the period N years was used. Details of methodology are given in Selvam and Radhamani (1993)

The cumulative percentage contribution P to total variance and the corresponding t values as given as

$$t= (\text{Log } L/\text{Log } T_{50})-1$$

where L is the period (time units) and T_{50} the period up to which the cumulative percentage contribution to total variance is equal to 50, are plotted for the 14 solar-geophysical parameters (Figure 1). The cumulative normal probability density distributions corresponding to the normalised standard deviation t values are also plotted in the figure. It is seen that the cumulative percentage contribution to total variance closely follows the cumulative normal probability density distribution. The "goodness of fit" was tested using the chi-square test (Spiegel 1961). The horizontal lines in the figure indicate the values of P above which the fit is good at 95% level at significance.

The normal probability and the cumulative normal probability density distributions follows the inverse power law form t^{-B} where B, the exponent approaches 1 for small values of t. It is therefore consistent that the observed eddy energy spectra for the 14 solar-geophysical parameters follow t^{-B} power law which is identified as a signature of self-organized criticality.

The non-linear variability of solar-geophysical parameters can therefore be resolved into a continuum of periodicities which contribute to form a universal power spectrum, namely, that of the normal distributin.

3. Conclusion

The present study arrives at the important conclusion that the non-linear variability of solar-geophysical parameters can be quantified in terms of the universal distribution characteristics of the normal distribution. It may therefore, be possible to estimate the future evolution of the parameters in terms of component periodicities and their phases of the unified eddy continuum.

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Legend

Figure 1 : Results of continuous periodogram analysis of the 14 solar-geophysical parameters listed in the text and indicated by corresponding numbers for each spectrum. The crosses refer to the cumulative normal probability density distribution. The horizontal short lines indicate the lower limit above which the spectrum is the same as the cumulative normal probability density distribution at 95% confidence level.

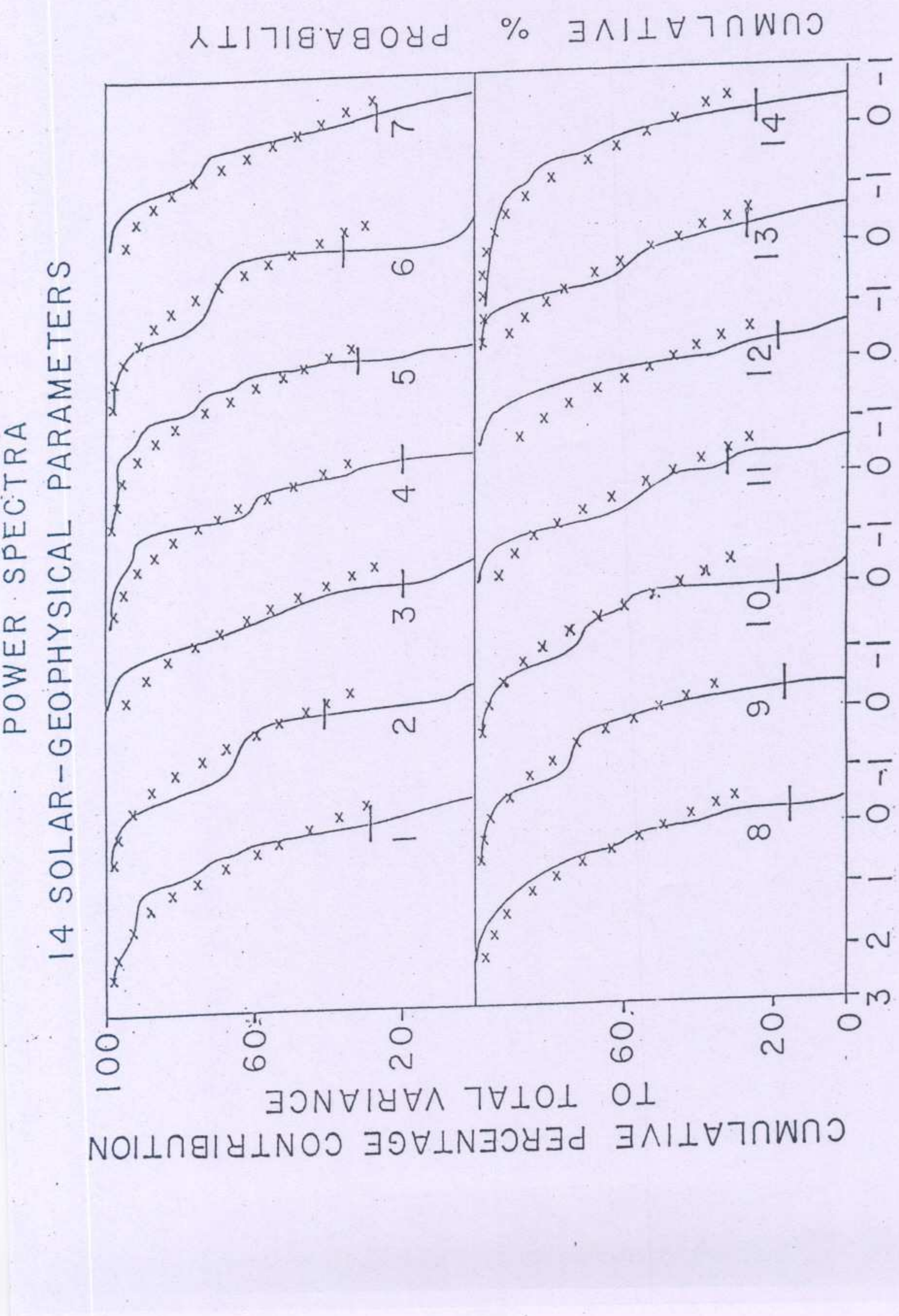
POWER SPECTRA
14 SOLAR-GEOPHYSICAL PARAMETERS
CUMULATIVE % PROBABILITY
CUMULATIVE PERCENTAGE CONTRIBUTION TO TOTAL VARIANCE
NORMALIZED STANDARD DEVIATION t
100
60
20
0
3
2
1
0
-1
1
2
3
4
5
6
7
8
9
10
11
12
13
14

FIGURE 1