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IDENTIFICATION OF SELF-ORGANIZED CRITICALITY IN ATMOSPHERIC LOW FREQUENCY VARIABILITY

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Abstract

Atmospheric flows exhibit long-range spatiotemporal correlations manifested as self-similar fractal geometry to the global cloud cover pattern concomitant with inverse power law form f^B. Such non-local connections are ubiquitous to dynamical systems in nature and are identified as signatures of self-organized criticality. Standard models in meteorological theory cannot explain satisfactorily the observed self-organized criticality in atmospheric flows. A recently developed cell dynamical model for atmospheric flows predicts the observed self-organized criticality as a direct consequence of quantumlike mechanics governing flow dynamics. The model predictions are in agreement with continuous periodogram power spectral analyses of two-day mean TOGA temperature time-series. The application of model concepts for prediction of atmospheric low frequency variability is discussed.

1. INTRODUCTION

The cooperative existence of fluctuations ranging in size-duration from a few millimeters-seconds (turbulence scale) to thousands of kilometers-years (planetary scale) result in the observed long-range spatiotemporal correlations, namely, fractal geometry to the global cloud cover pattern concomitant with inverse power law form for power spectra of temporal fluctuations documented by Lovejoy and his group.[1] Long-range spatiotemporal correlations are ubiquitous to real world dynamical systems and are recently identified as signatures of self-organized criticality.[2] The physics of self-organized criticality is not yet identified. It is important to quantify the total pattern of fluctuations in atmospheric

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flows for predictability studies. Traditional numerical weather prediction models based on Newtonian continuum dynamics are nonlinear and require numerical solutions. Finite precision computer realizations of such nonlinear models are sensitively dependent on initial conditions, now identified as deterministic chaos[3] resulting in unrealistic solutions. Mary Selvam[4] has shown that round-off error approximately doubles on an average for each step of finite precision numerical iteration. Such round-off error doubling results in unrealistic solutions for numerical weather prediction and climate models which incorporate long-term numerical integration schemes with thousands of such iterations. Realistic modeling of atmospheric flows therefore requires alternative concepts for fluid flows and robust computational techniques which do not require round-off error prone calculus-based long-term numerical integration schemes. In this paper, a recently developed non-deterministic cell dynamical system model for atmospheric flows[5–8] is summarized. The model predicts the observed self-organized criticality, i.e. long-range spatiotemporal correlations as intrinsic to quantumlike mechanics governing atmospheric flow dynamics. Further, the model concepts enable to show that the temporal fluctuations self-organize to form power spectra with universal inverse power law form of the statistical normal distribution. Power spectra of global upper air TOGA (Tropical Ocean Global Atmosphere) temperature data are consistent with model predictions. Atmospheric low frequency variability documented by Madden and Julian (1994)[9] is shown to be intrinsic to atmospheric flows powered by the diurnal cycle of solar heating.

2. CELL DYNAMICAL SYSTEM MODEL FOR ATMOSPHERIC FLOWS

In summary, the model is based on Townsend's[10] concept that large eddies can be visualized as envelopes of enclosed turbulent eddies in turbulent shear flows. Model predictions are as follows:

(1) Atmospheric flows follow quantumlike mechanical laws.

(2) The overall envelope of the large eddy traces a logarithmic spiral with the quasiperiodic Penrose tiling pattern for the internal structure. Conventional power spectrum analysis of such logarithmic spiral circulation structure will reveal a continuum of eddies with progressive increase in phase.

(3) The phase angle is directly proportional to the variance.

(4) The power spectrum follows the universal inverse power law form of the statistical normal distribution such that the square of the eddy amplitude represents the eddy probability density corresponding to normalized standard deviation t equal to $(\log L/\log T_{50}) - 1$ where T_{50} is the period up to which the cumulative percentage contribution to total variance is equal to 50.

(5) The eddy continuum has embedded dominant wavebands, the bandwidth increasing with period length. The dominant peak periodicities P_n are given as

$$P_n = \tau^n (2 + \tau)^T \qquad (1)$$

where τ is the golden mean equal to $(1 + \sqrt{5})/2 = 1.618$, T is the primary perturbation time period equal to the diurnal (day to night) cycle of solar heating in the present study and n is an integer ranging from negative to positive values including zero.

3. DATA AND ANALYSIS

Global 850, 500, and 200 mb 00GMT two-day mean upper air temperature data for the period in days for MAM, JJA (92 days), SON (91 days), DFJ (90/91 days) respectively for the 1986–1990 was taken from TOGA (Tropical Ocean Global Atmosphere) data sets.[11] Data was available at 5° latitude and longitude intervals. Data for latitude belts from 50°N to 50°S was considered for the study. The broadband power spectrum of temperature time-series was computed accurately by an elementary, but very powerful method of analysis developed by Jenkinson.[12] The cumulative percentage contribution to total variance, the cumulative percentage normalized phase (normalized with respect to the total phase rotation) and the corresponding t values were computed for all grid points. The mean power (variance) and phase spectra were computed respectively as cumulative percentage contribution to total variance and percentage of total rotation for each latitude belt from 50°N to 50°S at latitude intervals of 5°. A majority of the mean variance and phase spectra follow each other closely and also the

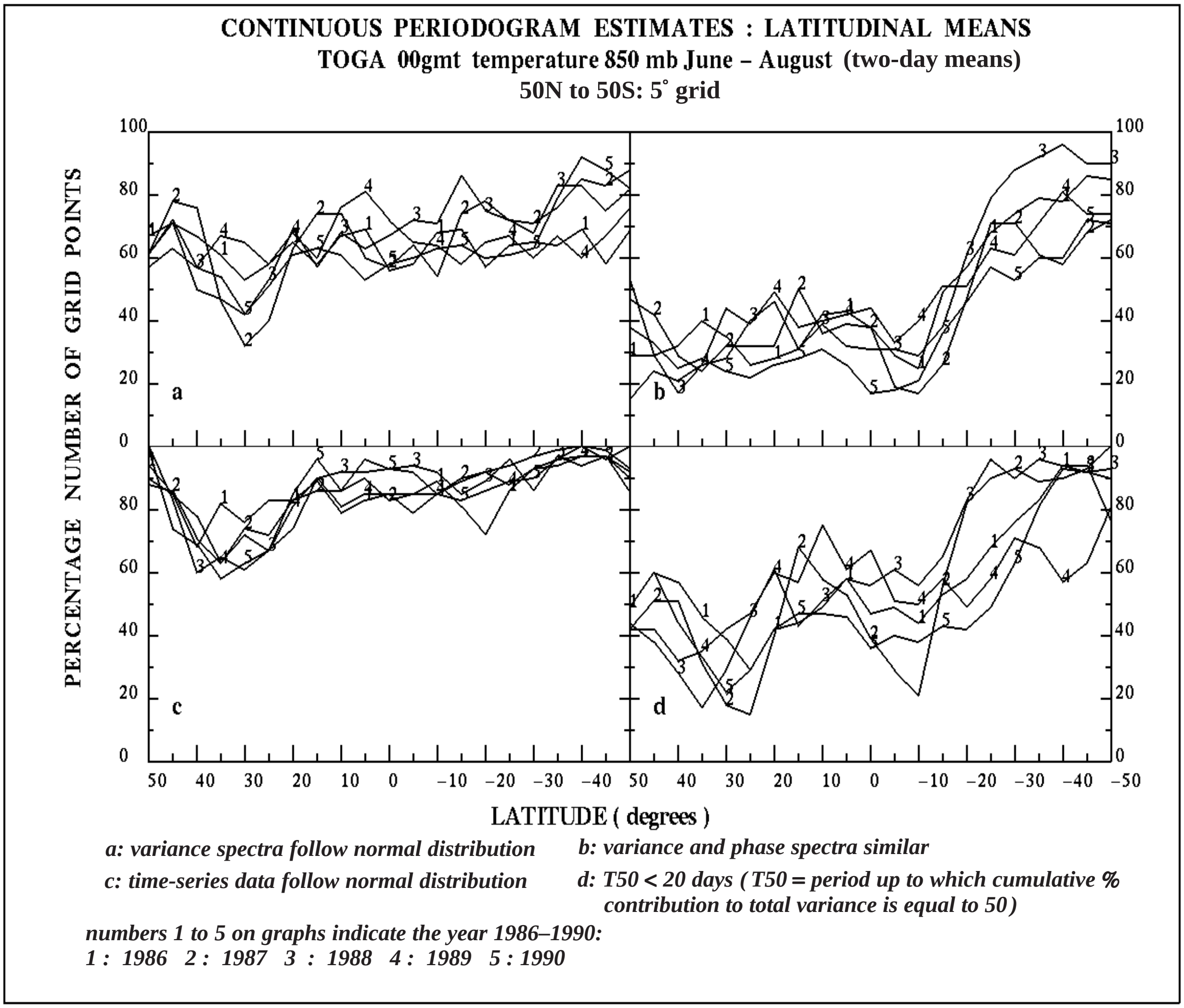

Fig. 1 Continuous periodogram estimates: Latitudinal means TOGA 00gmt temperature 850 mb June–August (two-day means).

statistical normal distribution. The "goodness of fit" with normal distribution was tested using the standard statistical chi-square test. Statistical details of data and periodogram estimates as percentages of total number of grid points for each latitude belt are given as follows:

(1) Variance spectra follow normal distribution [Fig. 1(a)].
(2) Variance and phase spectra are similar [Fig. 1(b)].
(3) Data series follow normal distribution characteristics [Fig. 1(c)].
(4) Spectra where T_{50} is less than 20 days [Fig. 1(d)].
(5) Spectra which exhibit dominant peak periodicities in wavebands 4–8, 8–12, 12–18, 18–30, 30–50 and 50–90 days (Fig. 2). These wavebands include model-predicted dominant periodicities (days) 5.8, 9.5, 15.3, 24.8 and 40.1 for values of n equal to 1, 2, 3, 4 and 5, respectively (see Sec. 2).

4. DISCUSSION AND CONCLUSION

A majority of spectra follow the universal and unique inverse power law form of the statistical normal distribution. Inverse power law form for power spectra of temporal fluctuations is a signature of self-organized criticality. The concept of self-organized criticality, namely, long-range spatial and temporal correlations intrinsic to atmospheric flow patterns forms the basis for statistical

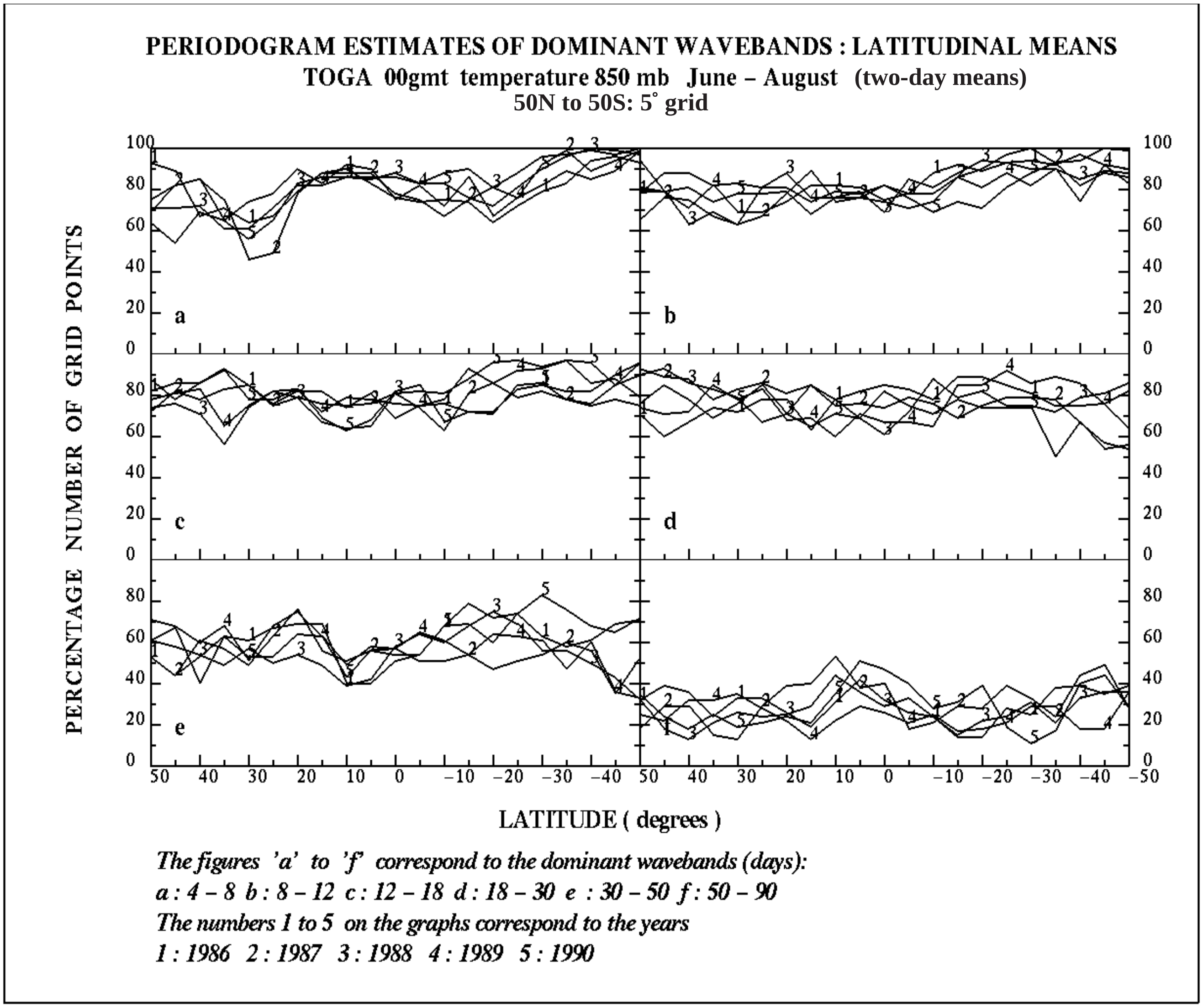

Fig. 2 Periodogram estimates of dominant wavebands: Latitudinal means TOGA 00gmt temperature 850 mb June–August (two-day means).

prediction models such as the 16-parameter long-range monsoon prediction model of Gowarikar et al. (1989).[13] Observed dominant cycles corresponding to model-predicted periodicities (days) 5.8, 9.5, 15.3, 24.8, 40.1 etc. can also be used for prediction purposes. The effect on intraseasonal variability, of climate change related to man-made greenhouse gas warming, can be qualitatively estimated as follows. Universal spectrum for intraseasonal variability rules out linear secular trends. Energy input into the atmosphere due to greenhouse gas warming will result in intensification of intraseasonal variability which can be seen immediately in the high frequency fluctuations, i.e. intensification of small scale, short period fluctuations. Incidently, high frequency fluctuations (less than 20 days) are more intense in the southern hemisphere [Fig. 1(d)].

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