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SELF-ORGANIZED CRITICALITY IN CLIMATE DYNAMICS.

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1. INTRODUCTION

Atmospheric flows exhibit long-range spatiotemporal correlations manifested as selfsimilar fractal geometry to spatial pattern concomitant with inverse power law form for power spectra of temporal fluctuations documented and discussed by Lovejoy and his group (Tessier et.al. 1996) on all observed scales (space-time). Long-range spatiotemporal correlations are ubiquitous to dynamical systems in nature and are recently identified as signatures of *self-organized criticality* (Bak et al. 1988) , The physics of self-organized criticality is not yet identified. Standard meteorological theory cannot explain satisfactorily the observed self-organized criticality in atmospheric flows. Traditional models for climate variability, based on Newtonian continuum dynamics are nonlinear and require numerical solutions. Finite precision computer realizations of nonlinear climate models are subject to deterministic chaos, i.e. sensitive dependence on initial conditions. Mary Selvam (1993) has shown that round-off error of finite precision iterative computations doubles on an average for each iteration. Round-off error propagation into the main stream computation will give unrealistic solutions in numerical weather prediction (NWP) and climate models which incorporate thousands of iterative computations. Mary Selvam (1990) has developed an alternative nondeterministic cell dynamical system model for atmospheric flows which predicts the observed self-organized criticality as intrinsic to quantumlike mechanics governing flow dynamics. The model predicts the universal inverse power law form of the statistical normal distribution for the power spectrum of temporal fluctuations. Model predictions are in agreement with continuous periodogram power spectral analyses of TOGA upper air temperature, for 850mb, 500mb and 200mb. Model predicted universal spectrum for interannual variability was verified earlier for COADS surface temperature and pressure (Mary Selvam and. Joshi, 1995; Mary Selvam et al. 1996). The important conclusion is that universal spectrum for climate variability rules out linear trends. Model concepts predict propagation of energy to all scales with intensification as a result of man-made greenhouse gas atmospheric warming.

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2. MODEL CONCEPTS AND PREDICTION

In summary,the model (Mary Selvam,1990;Mary Selvam and Joshi,1995;Mary Selvam et.al. 1996;Pethkar and Selvam,1997) is based on the concept that large eddies can be visualized as envelopes of enclosed turbulent eddies in turbulent shear flows. The root mean square (r.m.s.) circulation speed W of large eddy of radius R is the integrated mean of the r.m.s. circulation speed w_* of enclosed turbulent eddies of radius r and is given as

$$W^2 = \frac{2}{\pi}\frac{r}{R} w_*^2 \qquad (1)$$

The eddy length scale ratio r/R is equal to the phase angle $d\theta$ between the eddies. Therefore the phase angle is directly proportional to the variance,i.e.,

$$W^2 \propto d\theta \qquad (2)$$

Since large eddy is the integrated mean of enclosed turbulent eddies,the energy(kinetic) of large eddies follow normal distribution characteristics according to the Central Limit Theorem in Statistics. The square of the eddy amplitude, namely, the variance,therefore, represents the probability of occurrence.The above result that the additive amplitudes of eddies, when squared,represent the probability density is observed in the subatomic dynamics of quantum systems such as the electron or photon. Atmospheric flows, therefore follow quantumlike mechanical laws.

The model also predicts the logarithmic wind profile relationship for atmospheric flows. The overall envelope of the large eddy traces a logarithmic spiral with the quasiperiodic Penrose tiling pattern for the internal structure. Atmospheric circulation structure therefore consists of a nested continuum of vortex roll circulations(vortices within vortices) with a two-way ordered energy flow between the larger and smaller scales.Such a concept is in agreement with the observed long-range spatiotemporal correlations in atmospheric flow pattern. Conventional power spectrum analysis of such logarithmic spiral circulation structure will reveal a continuum of eddies with progressive increase in phase. The conventional power spectrum plotted as the percentage contribution to total variance versus the logarithm of frequency(period) will now represent the eddy probability density versus the standard deviations of the eddy fluctuations since the logarithm of the eddy wavelength represents the standard deviation,i.e., the r.m.s value of eddy fluctuations.This follows from the concept of logarithmic wind profile and also that the r.m.s. value of eddy fluctuations at each stage form the mean level for the next stage of eddy growth. The r.m.s. value of eddy fluctuations can be represented in terms of 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 normalized standard deviation t is defined for the eddy energy spectrum as

$$t = (\log L / \log T_{50}) - 1 \quad (3)$$

where L is the period in days and T_{50} is the period upto which the cumulative percentage contribution to total variance is equal to *50* and $t = 0$. Further, $\log T_{50}$ also 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. Power spectral analysis will show that the eddy continuum has embedded dominant wavebands, the bandwidth increasing with period length. The dominant peak periodicities P_n are given as

$$P_n = \tau^n(2+\tau)T \quad (4)$$

where τ is the golden mean equal to $(1+\sqrt{5})/2 \cong 1.618$, 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(50N to 50S, 5-degree grid resolution) 850mb,500mb and 200mb, 00gmt,2-day mean upper air temperature data for the four seasons ,JJA(June-august),SON(September-November),DJF(December-February) and MAM(March-May) for the five years 1986 to 1990 was taken from TOGA(Tropical Ocean Global Atmosphere)data sets.Continuous periodogram power spectral analysis (Jenkinson,1977) was used for the study.The cumulative percentage contribution to total variance was computed starting from the high frequency side of the spectrum.The cumulative percentage contribution to total variance, the cumulative percentage normalized phase (normalized with respect to total phase rotation) and the corresponding t values(Eq.3) were computed for all grid points where data was available.Statistical details of data and periodogram estimates as percentages of total number of grid points for each latitude belt are given in Figures 1 - 3 as follows: (1) Variance spectra follow normal distribution. (2) Variance and phase spectra are the same. (3) Data series follow normal distribution characteristics. (4) Spectra where T_{50} is less than 20 days.(5) Spectra which exhibit dominant peak periodicities in wavebands 4-8,8-12,12-18,18-30 days. These wavebands include model predicted(Eq.4) dominant periodicities (days) 5.8,9.5,15.3,24.8 for values of n equal to 1,2,3,4 respectively.

4. DISCUSSION AND CONCLUSION

A majority of spectra(Figs. 1-3) for all the seasons,particularly in the Southern Hemisphere follow the universal inverse power law form of the statistical normal distribution consistent with model prediction of quantumlike mechanics in atmospheric flows. Inverse powerlaw form for power spectra of temporal fluctuations is a signature of self-organized criticality(Bak et.al. 1988) in the nonlinear variability of temperature at all pressure levels in this study.The unique quantification for self-organized criticality presented in his paper implies predictability of the total pattern of fluctuations. The contribution to temperature fluctuations by shorter periodicities is larger in the Southern Hemisphere as compared to the Northern Hemisphere.

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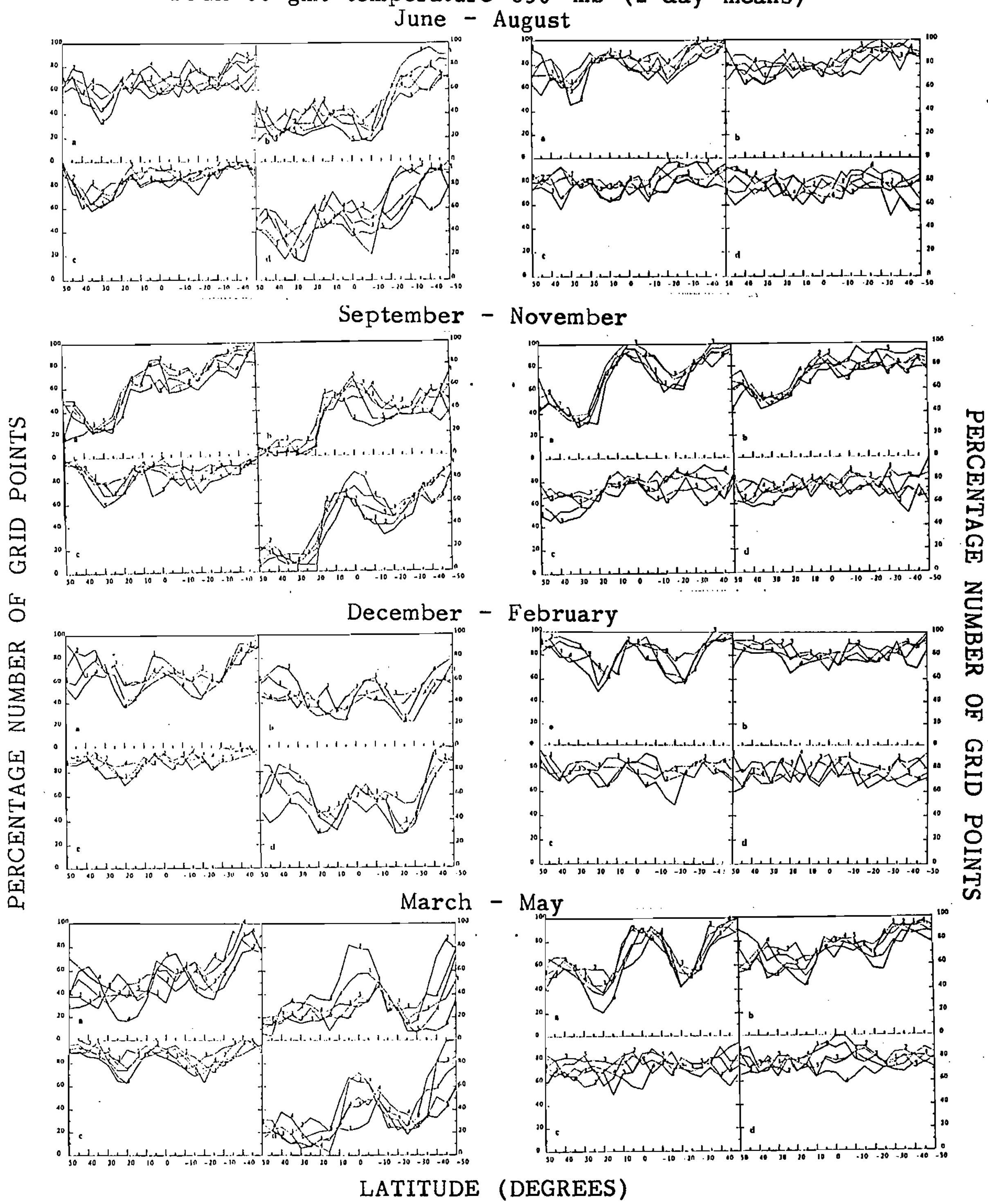
PERIODOGRAM ESTIMATES (LATITUDINAL MEANS 50°N TO 50°S)
TOGA 00 gmt temperature 850 mb (2-day means)



a:Var. spectra follow normal distr.
b:Variance and phase spectra same
c:Time series follow normal dist.
d:T_{50} < 20 days

a to d - Dominant wavebands (days)

a: 4-8 b:8-12 c:12-18 d:18-30

1 : 1986 2 : 1987 3 : 1988 4 : 1989 5 : 1990

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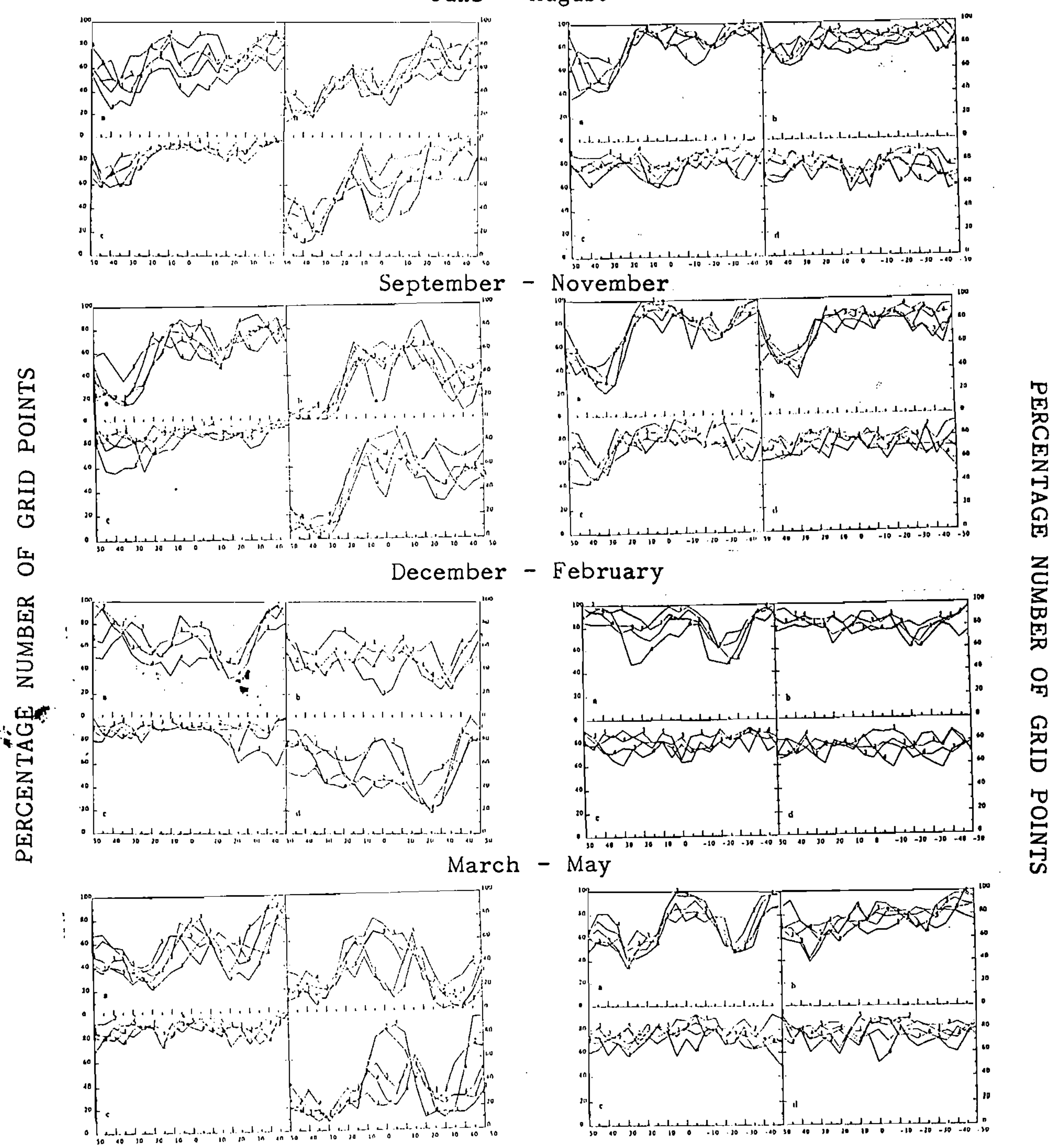

LATITUDE (DEGREES)

a:Var. spectra follow normal distr.
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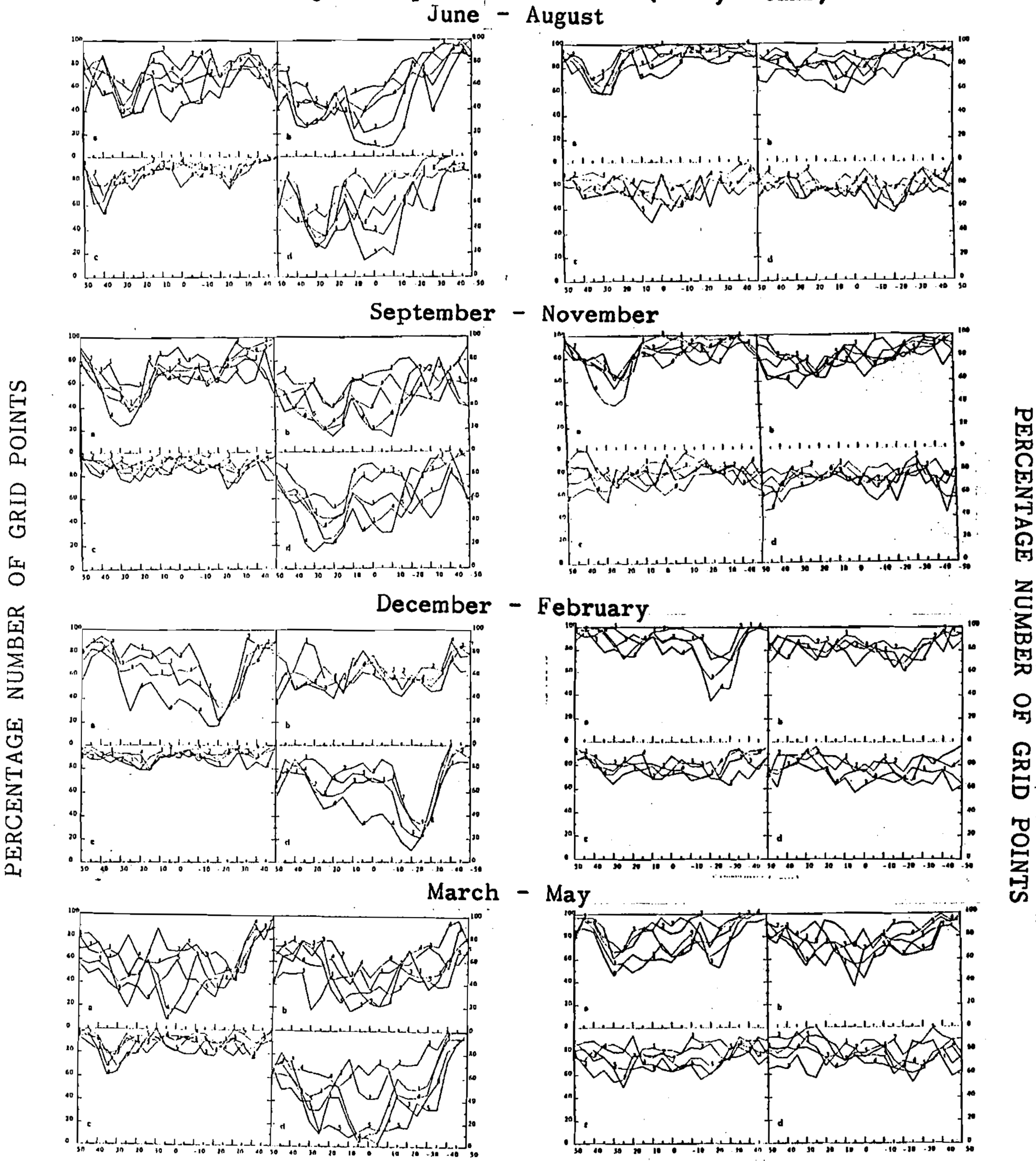
PERIODOGRAM ESTIMATES (LATITUDINAL MEANS 50°N TO 50°S)
TOGA 00 gmt temperature 200 mb (2-day means)



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