ISSN 0252-1075

Research Report No.RR-060

Contributions from

Indian Institute of Tropical Meteorology

Signatures of a Universal Spectrum for Atmospheric Interannual Variability in COADS Temperature Time Series

By

A.M. Selvam, R.R. Joshi and R. Vijayakumar

PUNE-411 008
INDIA

OCTOBER 1994

Signatures of a Universal Spectrum for Atmospheric Interannual Variability in COADS Temperature Time Series

A.M.Selvam, R.R. Joshi and R. Vijayakumar
Indian Institute of Tropical Meteorology
Pune 411 008, India

Abstract

Continuous periodogram analyses of 28-years (1961-1988) seasonal (Sept.-Nov.) mean COADS surface (air and sea) temperature time series show that the power spectra follow the universal inverse power-law form of the statistical normal distribution. Such long-range temporal correlations are signatures of self-organized criticality. Identification of the universal quantification for self-organized criticality in the interannual variability of surface temperature implies predictability of the total pattern of fluctuations. The other important results of the study are as follows. (1) The power spectra are broadband implying an eddy continuum structure for atmospheric interannual variability. (2) The eddy continuum has embedded dominant wave-bands, the bandwidth increasing with period length. Further, there is a smooth rotation of the phase angle with period length within a wave-band and from one wave-band to the next, implying a spiral-like structure for the eddy continuum. (3) Periodicities up to 5 years contribute to as much as 50% of the total variance. (4) Dominant periodicities of 2-3 years and 3-7 years corresponding respectively to the high and low frequency components of El-Nino/Southern Oscillation (ENSO) cycle are present in almost all the data sets. The above results are consistent with a recently developed cell dynamical system model for atmospheric flows.

1. Introduction

The surface (air and sea) temperatures exhibit interannual variability of all time scales up the length of record investigated. Major quasiperiodic oscillations such as the QBO (quasi-biennial oscillation) and the 2-7 years ENSO (El-Nino/Southern Oscillation) cycle have been identified in surface temperature records (Ghil and Vautard, 1991; Tsonis and Elsener 1991, Cole et al., 1993). Such quasiperiodic dominant cycles characterising atmospheric flows are however superimposed on an appreciable "background noise" contributed by a continuum of eddies of all scales up to the period length investigated (Lorenz 1990; Tsonis and Elsner 1990). It is therefore important to identify the physics of multiple scale interactions (Barnett, 1991) and to quantify the total pattern of fluctuations. of atmospheric flows for predictability studies.

Deterministic chaos in computer realizations of traditional non-linear mathematical models of atmospheric flows impose a limit on realistic simulation of flow dynamics and prediction. Mary Selvam (1993b) has shown that round-off error of finite precision numerical computations approximately doubles for every iteration. Such round-off error enters the mainstream computation and gives unrealistic solutions in long-term numerical integration schemes such as that used in numerical weather prediction and climate models which incorporate several thousands of iterative computations.

In this paper, a recently developed non-deterministic cell dynamical system model (Mary Selvam, 1990; Mary Selvam et al., 1992; Mary Selvam, 1993a; Mary Selvam, 1994) concepts are applied to show that the temporal (years) fluctuations of surface (air and sea) temperatures self-organize to form a universal spectrum. Such a concept rules out linear secular trends in surface temperatures.

2. Cell Dynamical System Model

Model concepts have been described in earlier papers (Mary Selvam, 1990; Mary Selvam et al., 1992; Mary Selvam, 1993a; Selvam and Radhamani, 1993; Selvam and Joshi, 1994). The model predicts the following. (1) The power spectrum of temporal fluctuations follows the universal inverse power law form of the statistical normal distribution such that the variance represents the probability corresponding to the normalised standard deviation t given as

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

where L is the period (in years) and T_{50} the period up to which the cumulative percentage contribution to total variance is equal to 50. (2) Atmospheric flow structure follows an overall logarithmic spiral trajectory with the quasiperiodic Penrose tiling pattern for the internal structure giving rise to dominant wavebands of increasing bandwidth. The peak periodicities P_n in the dominant wavebands are given as

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

Where τ is the golden mean equal to $(1+\sqrt{5})/2 = 1.618$, T the primary perturbation time period (equal to the annual cycle of solar heating in the present study) and n ranges from negative to positive integer values including zero. (3) Spiral-like structure for flow pattern will be seen as a progressive increase in phase angle with increase in period length.

In the following section it is shown that continuous periodogram analyses of seasonal (Sept.-Nov.) mean surface temperature for the 28-year period 1961-1988 agree with model predictions.

3. Data and Analysis

The seasonal mean SON (Sept.-Nov.) surface air temperature and sea surface temperature for available grid points numbering 1716 and 1641 respectively for the 28-year period (1961-1988) was taken from the Comprehensive Ocean Atmospheric Data Set (COADS, 1985). Figures 1 and 2 show respectively the location of grid points for which unbroken data is available for surface air temperature and sea surface temperature for the period under study.

The broadband power spectrum of the surface temperature time series can be computed accurately by an elementary but very powerful method of analysis developed by Jenkinson (1977) which provides a quasi-continuous form of the classical periodogram allowing systematic allocation of the total variance and degrees of freedom of the data series to logarithmically spaced elements of the frequency range (0.5, 0). The cumulative percentage contribution to total variance was computed starting from the high frequency side of the spectrum. The period T_{50} at which 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 cumulative percentage contribution to total variance and the corresponding t values were computed for surface air temperature and sea surface temperature respectively for all the grid points (Figures 1 and 2) for the 28-year period 1961-1988. The cumulative percentage contribution to total variance was found to closely follow the cumulative normal probability density distribution. The "goodness of fit" with normal distribution at 95% confidence level was tested using the standard statistical chi-square test (Spiegel 1961). Almost all the spectra follow normal distribution.

Sets of 26 grid points contained within about 10-degree Latitude-Longitude boxes were grouped together and the mean and standard deviation of cumulative percentage contribution to total variance corresponding to normalised standard deviation t values were computed. Representative mean and standard deviation spectra thus computed for grid points within 10-degree boxes are shown in Figure 3 and Figure 4 respectively for surface air temperature and sea surface temperature for the northern hemisphere. The location of the 10-degree boxes and the number of grid points contained therein are given in the inset to figures 3-4. The cumulative normal probability density distribution is also shown in Figures 3-4. It is seen that the mean spectra closely follow the statistical normal distribution.

Table 1, summarises for northern hemisphere and southern hemisphere, in terms of the number of grid points, the following results of continuous periodogram spectral analyses for sea air temperature and sea surface temperature.

(1) The total number of grid points for which unbroken data is available. (2) time series data which follow normal distribution characteristics. (3) Spectra which follow normal distribution characteristics (4) Spectra for which T_{50} is less than 5-years, T_{50} being the period up to which the cumulative percentage contribution to total variance is equal to 50. (5) Spectra which exhibit dominant (normalised variance greater than one) periodicities in the wavebands, 2-3, 3-4, 4-8, 12-20 and 20-28 years. The above period ranges were chosen with reference to model predicted intrinsic periodicities 2.2, 3.6, 5.8, 9.5, 15.3 and 24.8 years for values of n ranging from -1 to 4 (Eq.2).

The smooth rotation of the phase angle with increase in period is shown in Fig. 5 for air and sea temperatures for one representative grid point each.

4. Discussion and Conclusion

From Figs 3-4 and Table 1 it is seen that the spectra of temporal (years) fluctuations of surface (air and sea) temperature follow the universal and unique inverse power law form of the statistical normal distribution such that the square of the eddy amplitude represents the eddy probability density corresponding to the normalised standard deviation t equal to $(\log L_m/\log T_{50})-1$ where L_m is the period in years and T_{50} refers to the period up to which the cumulative percentage contribution to total variance is equal to 50. Inverse power law form for the power spectra of temporal fluctuations is a signature of self-organized criticality in the non-linear variability of surface temperature. The unique quantification for self-organized criticality in terms of the statistical normal distribution presented in this paper implies predictability of the total pattern of fluctuations in the atmospheric surface temperature over a period of time, 28-years in the present study. It may therefore be possible to predict future trends in atmospheric surface temperature. Fig. 5 shows that there is a continuous smooth rotation of phase angle with period in the spectra of surface temperatures consistent with model prediction of spiral like structure for the atmospheric eddy continuum.

The spectra exhibit dominant periodicities (Table 1) which correspond to the model predicted time periods of the internal circulations of the quasi-periodic Penrose tiling pattern equal to 2.2, 3.6, 5.8, 9.5, 15.3 and 24.8 years (see section 2 above). Periodicities of 2-3 years and 3-7 years have been widely documented in meteorological time series data and refer respecting to the high and low frequency components of the El-Nino/Southern Oscillation (ENSO) cycle. The dominant periodicities in the atmospheric surface temperatured time series may therefore be expressed as functions of the golden mean and these periodicities are intrinsic to atmospheric flows powered by the annual cycle of solar heating.

Most of the spectra show (Table 1) that periodicities up to 5.5years contribute as much as 50% of the total variance and therefore near future flow pattern trends may be estimated by high frequency periodicities up to 5-years.

The present study shows that atmospheric flows self-organize to form a universal eddy continuum. Such a concept rules out indefinite linear secular trends in surface (air and sea) temperatues. Ghil and Vautard (1991) also conclude that warming signals may not be detectable in the near future in the presence of bidecadal and other oscillatory modes in surface air temperature.

Acknowledgements

The authors wish to express their grateful thanks to Director for encouragement and providing facilities. The authors express their gratitude to Dr. A.S.R. Murty for his keen interest and encouragement during the course of this study. Thanks are due to Mrs. A.A. Ursekar for typing this manuscript.

References

Bak, P.C., C. Tang and K. Wiesenfeld, 1988: Self-organized criticality. *Phys.Rev.* **A 38**, 364-374.

Barnett, T.P., 1991: The interaction of multiple time scales in the tropical climate system. *J.Climate.* **4**, 267-285.

Coads, 1985 : *Comprehensive Ocean Atmosphere Data Set Release 1*. NOAA-ERL Boulder, Co., USA.

Cole, J.E., R.C. Fairbanks and G.T. Shen, 1993 : Recent variability in the southern oscillation : Isotopic results from a Tarawa Atoll Coral. *Science* **260**, 1790-1793.

Elsner, J.B. and A.A. Tsonis, 1991 : Do bidecadal oscillations exist in the global temperature record? *Nature* **353**, 551-553.

Ghil, M. and R.Vautard, 1991: Interdecadal oscillations and the warming trend in global temperature time series. *Nature* **350**, 324-327.

Jenkinson, A.A., 1977: *A powerful elementary method of spectral analysis for use with monthly, seasonal or annual meteorological time series*. Met. O 13 Branch Memorandum No.57 pp.23.

Lorenz, E.N., 1990 : Can chaos and intransitivity lead to interannual variability ? *Tellus* **42A**, 378-389.

Mary Selvam, A., 1990 : Deterministic chaos, fractals and quantum-like mechanics in atmospheric flows. *Can.J.Phys.*, **68**, 831-841.

Mary Selvam, A., J.S. Pethkar and M.K.Kulkarni., 1992 : Signatures of a universal spectrum for atmospheric interannual variability in rainfall time series over the Indian region. Int'l. J. Climatology **12**, 137-152.

Mary Selvam, A., 1993a: A universal spectrum for interannual *Adv.Atmos.Sci*. **10(2)**, 221-226.

Mary Selvam, A., 1993b: Universal quantification for deterministic chaos in dynamical systems.*Applied Mathematical Modelling* **17**, 642-649.

Selvam, A.M. and M. Radhamani, 1993: *Identification of self-organized criticality in atmospheric total ozone variability*. IITM Research Report No. RR-057, 1993, pp.16.

Selvam, A.M. and M.Radhamani, 1994: Signatures of a universal spectrum for nonlinear variability in daily colunar total ozone content. *Adv.Atmos.Sci* **11(3)**, 335-342.

Selvam, A.M. and R.R. Joshi, 1994: Universal spectrum for interannual variability in COADS global air and sea surface temperatures. *Int'l.J.Climatol*. (Accepted).

Spigel, M.R., 1956. *Statistics*. (McGraw-Hill Book Co., N.Y.) pp.359.

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

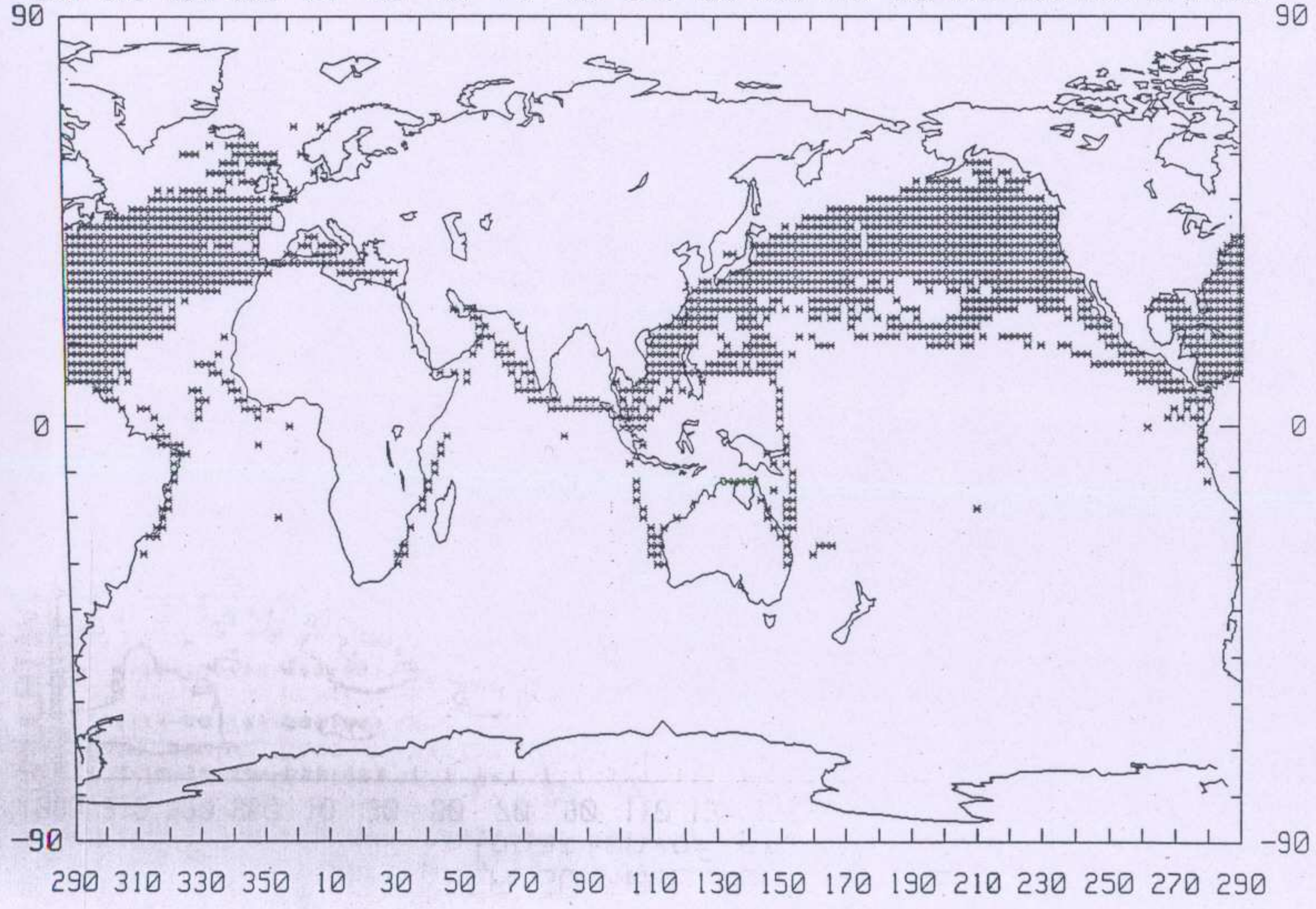
Tsonis, A.A. and J.B. Elsner, 1990 : Multiple attractors, fractal basins and long-term climate dynamics. *Beitr.Phys.Atmosp.* **63(3,4)** , 171-176.

Table 1 : Results of periodogram estimate

Parameter/ Total no. of grid points	Data follow normal distri.	Variance spectra follow normal distri.	Spectra with T50<5.5 years	Spectra with dominant peak periodicities (years) in the range					
				2-3	3-4	4-8	8-12	12-20	20-28
			Percentages of total number of grid number)						
			Northern Hemisphere						
AIR/1616	92	90	76	96	74	88	50	39	15
SST/1520	95	91	74	95	77	90	50	39	23
			Southern Hemisphere						
AIR/100	94	87	49	97	77	84	37	62	8
SST/121	94	90	80	95	79	95	36	51	9

Figure 1

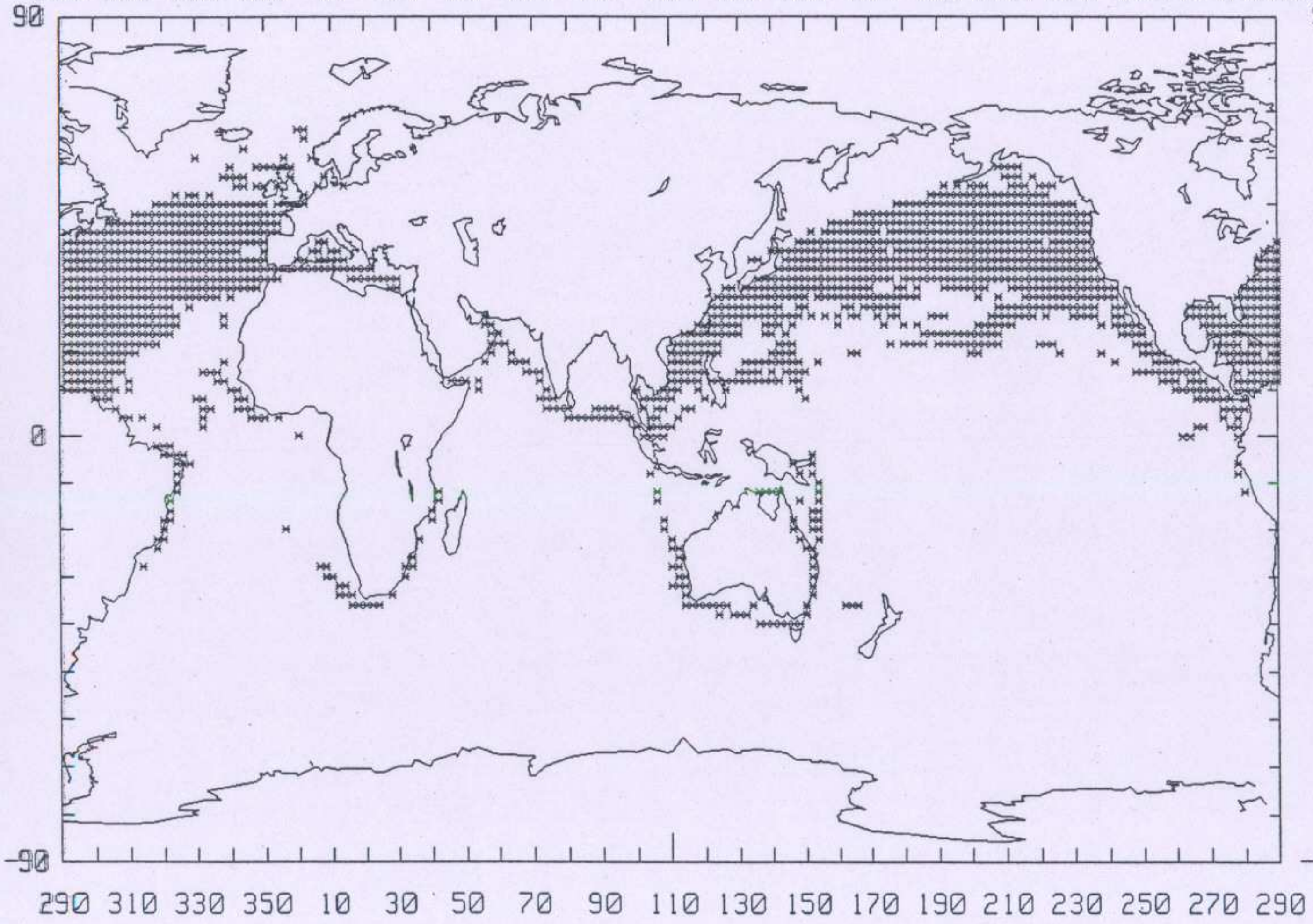
SURFACE AIR TEMPERATURE
location of grid points



* gives location of grid points

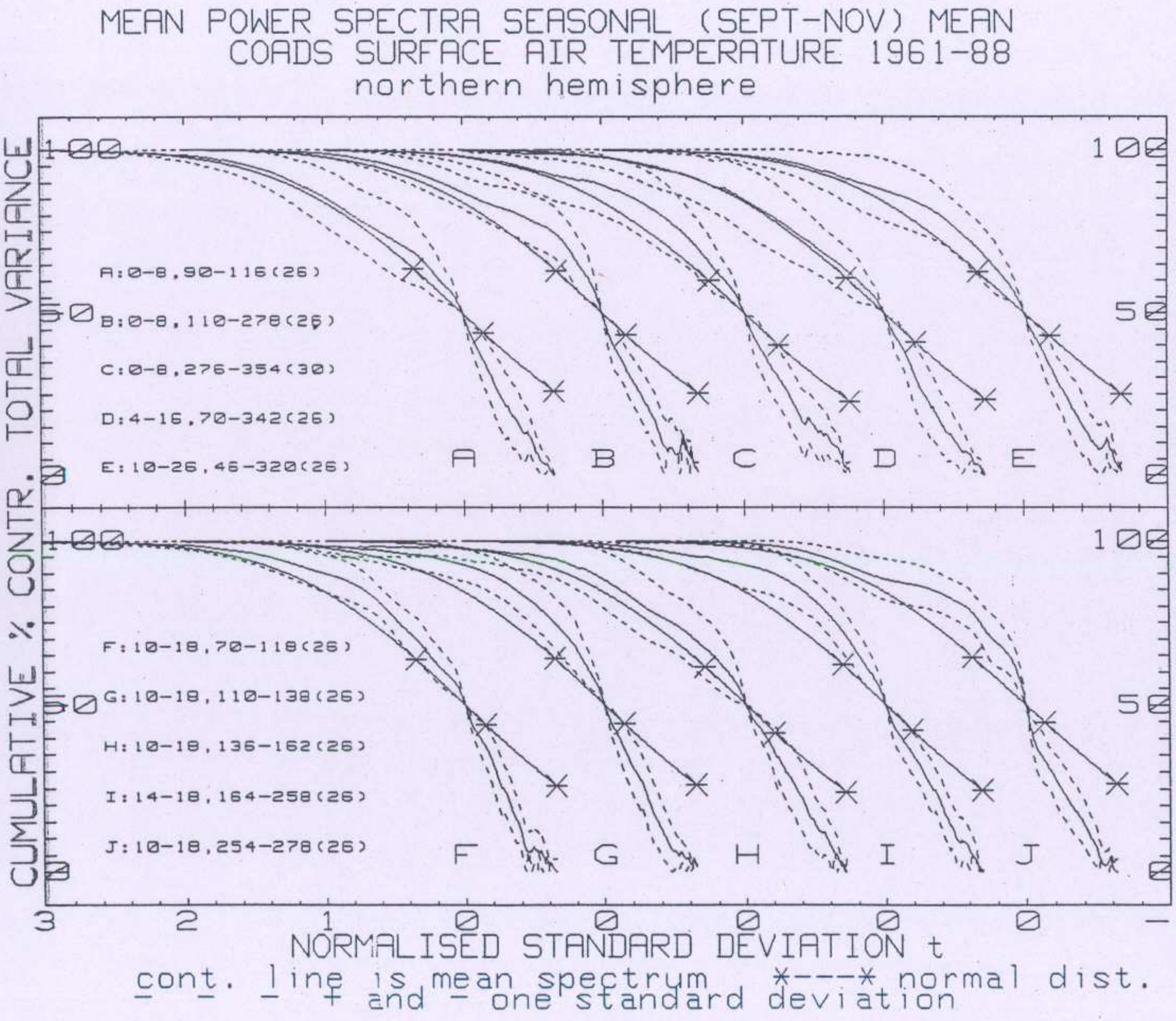
Figure 2

SEA SURFACE TEMPERATURE
location of grid points



* gives location of grid points

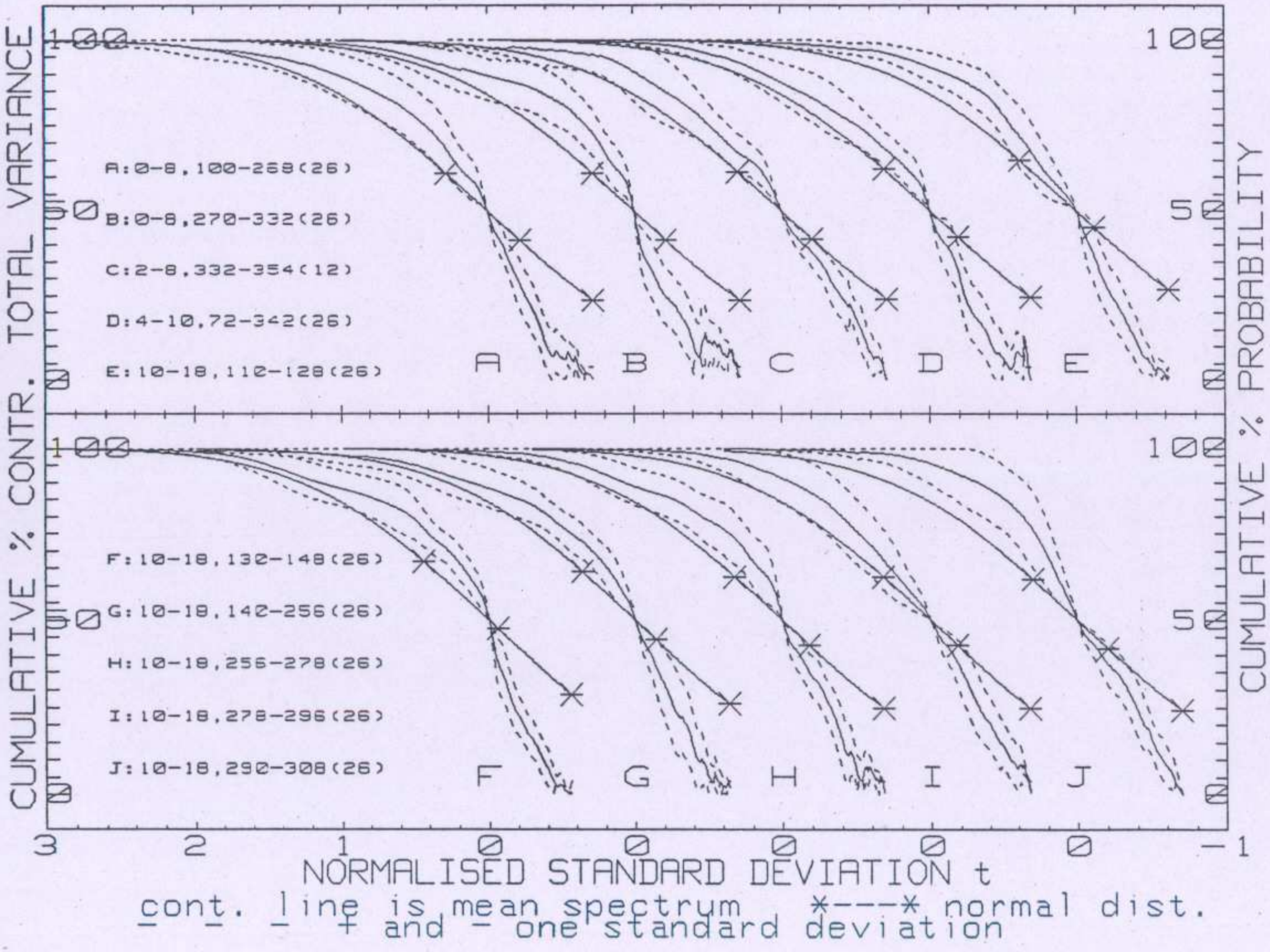
Figure 3



The location of 10-degree boxes corresponding to the mean spectra and the number of grid points in each box are given in the inset.

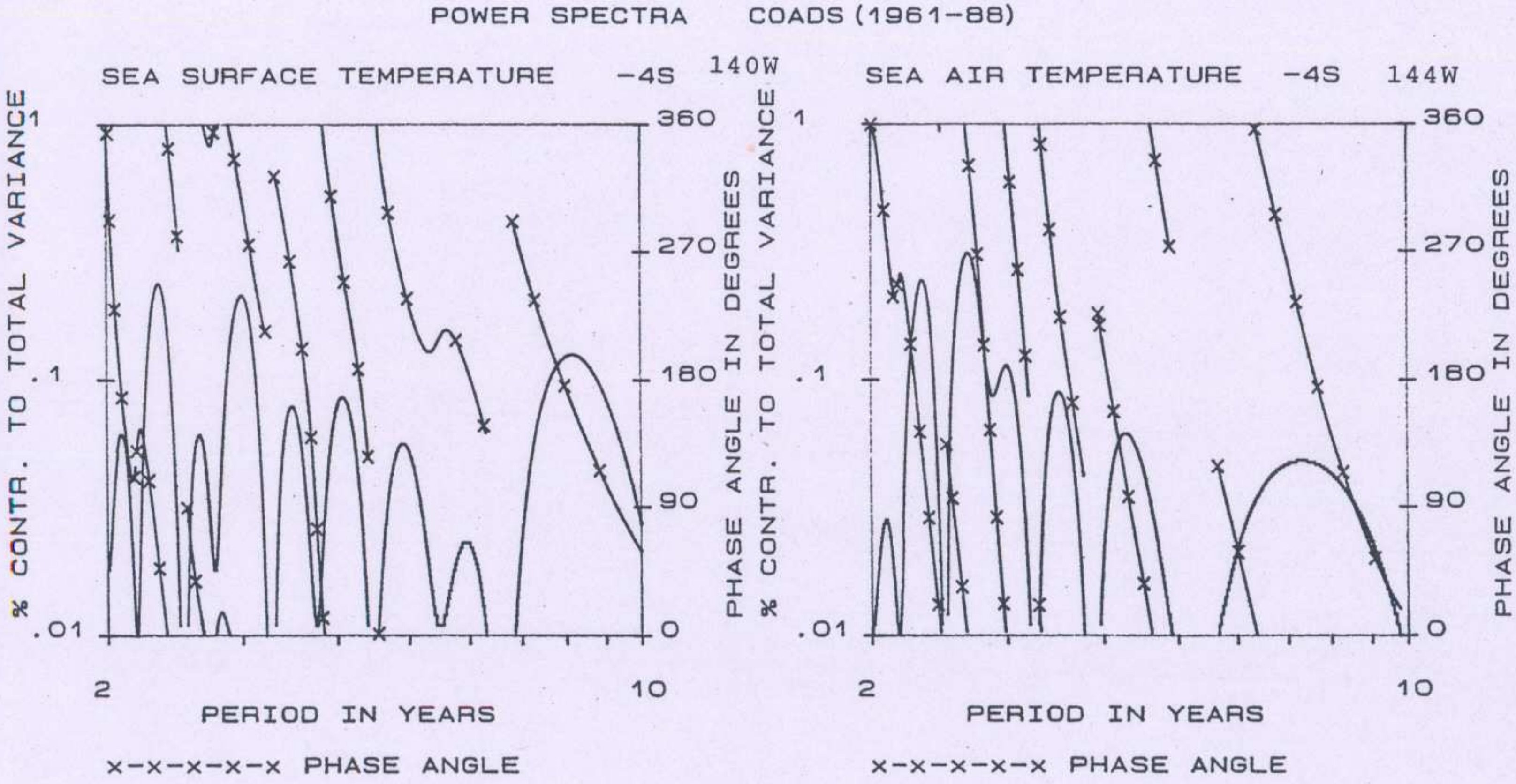
Figure 4

MEAN POWER SPECTRA SEASONAL (SEPT-NOV) MEAN
COADS SEA SURFACE TEMPERATURE 1961-88
northern hemisphere



The location of 10-degree boxes corresponding to the mean spectra and the number of grid points in each box are given in the inset.

Figure 5


POWER SPECTRA COADS (1961-88)
SEA SURFACE TEMPERATURE -4S 140W
SEA AIR TEMPERATURE -4S 144W
% CONTR. TO TOTAL VARIANCE
1
.1
.01
PHASE ANGLE IN DEGREES
360
270
180
90
0
2
10
PERIOD IN YEARS
x-x-x-x-x PHASE ANGLE