Portland, Oregon, USA

P1.12 SELF-ORGANIZED CRITICALITY IN ATMOSPHERIC FLOWS : IMPLICATIONS FOR PREDICTION

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1. INTRODUCTION

Numerical weather prediction (NWP) models in current use are based on Newtonian continuum dynamics and consist of nonlinear governing equations. Finite precision computer realizations of such NWP models are sensitively dependent on initial conditions and give chaotic solutions, now identified as deterministic chaos, an area of intensive research in all branches of science (Gleick 1987). The physics of deterministic chaos is not yet identified. Mary Selvam (1993) has shown that round-off error doubles on an average for each iteration of error sensitive dynamical systems such as $X_{n+1} = F(X_n)$ where, X_{n+1}, the value of the variable X at (n+1)th instant is a function F of X_n. Round-off error will enter the mainstream computation and give unrealistic solutions in NWP and climate models which incorporate thousands of such iterations in long-term numerical integration schemes. Realistic prediction therefore requires nondeterministic models which can satisfactorily explain the recently documented (Lovejoy and Schertzer 1986; Tesser et al 1993; Fritts and VanZandt 1993) long-range spatiotemporal correlations manifested as the self-similar fractal geometry to the global cloud cover pattern concomitant with inverse power law form for power spectra of temporal fluctuations. Such selfsimilar pattern formation by selfsimilar temporal fluctuations of all scales is generic to extended dynamical systems in nature and is recently identified as signature of self-organized criticality (Bak, Tang and Wiesenfeld 1988). The physics of self-organized criticality is not yet identified. In this paper, a recently developed cell dynamical system model for atmospheric flows (Mary Selvam 1990; Mary Selvam et al 1992) is summarized. The model predicts the observed self-organized criticality as intrinsic to quantum-like mechanics governing flow dynamics. The model predicts universal structure for atmospheric eddy energy spectrum which is independent of details of energy generation mechanisms in atmospheric flows, thereby avoiding arbitrary assumptions and approximations traditionally required for modelling studies.

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2. MODEL CONCEPTS

The model is based on Townsend's (1956) concept that large eddies form in turbulent shear flows as the spatial integration of enclosed turbulent eddies. The energy (kinetic) spectrum of atmospheric eddy continuum thus generated follow statistical normal distribution characteristics. The square of eddy space-time structure of atmospheric flows. In this paper a recently developed nondeterministic cell dynamical system model for atmospheric flows is summarised. The model predicts the observed self-organized criticality as intrinsic to quantum-like mechanics governing flow dynamics (Mary Selvam 1990; Mary Selvam et al 1992). Model predictions are in agreement with observations of surface (8 m) fluxes of momenta and sensible heat.

2. MODEL CONCEPTS

In summary, the model is based on Townsend's (1956) concept that large eddy circulations form in turbulent shear flows as the envelopes of enclosed turbulent eddy circulations. The energy (kinetic) of atmospheric eddy continuum will therefore follow normal distribution characteristics. The square of the eddy amplitude, i.e., the variance will then represent the probability of occurrence. Such a concept that the additive amplitudes of eddies, when squared, represent the probability densities is analogous to quantum mechanical laws governing subatomic dynamics of quantum systems such as electron or photon. Atmospheric flows therefore follow quantum-like mechanical laws with inherent long-range spatiotemporal correlations, i.e., self-organized criticality. The model provides universal quantification for self-organized criticality by predicting that the power spectra of temporal fluctuations follow the universal inverse power law form of the statistical normal distribution with the percentage contribution to total variance representing the percentage probability corresponding to normalised standard deviation t equal to $(\log L/\log T_{50})-1$ where L is the period (time) and T_{50} the period up to which the cumulative percentage contribution to total variance is equal to 50. Model prediction of unique scaling structure for atmospheric eddy continuum is independent of the details of the dynamics of energy generation mechanisms in atmospheric flows.

3. DATA AND ANALYSIS

High resolution (8 Hz) sonic wind (u,v,w) and temperature (T) measurements at 8 m above surface level at Kharagpur (23.3N, 87.2E, 83 m a.s.l) India for 10-minute time periods were used to compute the power spectra of vertical fluxes of momenta (wu, wv) and sensible heat (wT) using continuous periodogram (Jenkinson, 1977) analysis technique. Representative sample spectra are shown in Fig. 1 as cumulative percentage contribution to total variance versus the normalised standard deviation t. The statistical normal distribution is also plotted in Fig. 1. The flux spectra closely follow the statistical normal distribution in agreement with model prediction.

4. CONCLUSION

Universal spectrum for the nonlinear variability of vertical fluxes of momenta and sensible heat indicate predictability of total pattern of fluctuations independent of location, time and other details of energy generation mechanisms. Traditional parameterization schemes for boundary layer fluxes (Avissar et al 1993) incorporate ad hoc assumptions and approximations which can now be avoided with the present model concepts.

ACKNOWLEDGEMENT

The author is grateful to Dr. A.S.R. Murty for his keen interest and encouragement during the course of the study. Thanks are due to

Mr. M.I.R. Tinmaker for typing the manuscript.

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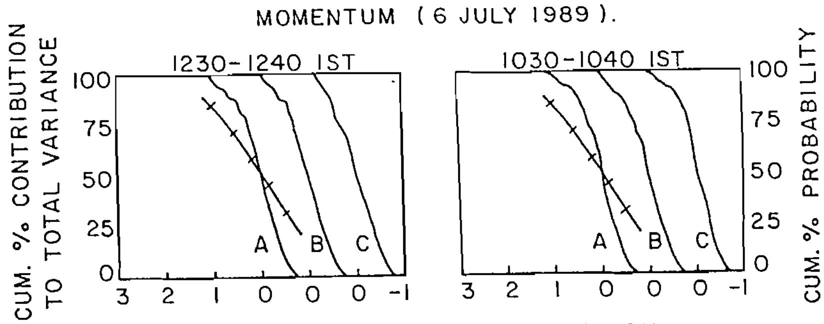
Figure 1

POWER SPECTRA : KHARAGPUR (23·3 N, 87·2 E, 83 m asl)

SURFACE FLUXES OF SENSIBLE HEAT AND MOMENTUM (6 JULY 1989).



NORMALISED STANDARD DEVIATION t

x—x—x—x—x NORMAL DISTRIBUTION

A : W·T B : W·U C : W·V