Preface

Current concepts in meteorological theory and limitations are as follows. The nonequilibrium system of atmospheric flows is modeled with assumption of local thermodynamic equilibrium up to the stratopause at 50 km; molecular motion of atmospheric component gases is implicitly embodied in the gas constant. Nonequilibrium systems can be studied numerically, but despite decades of research, it is still very difficult to define the analytical functions from which to compute their statistics and have an intuition for how these systems behave. Realistic mathematical modeling for simulation and prediction of atmospheric flows requires alternative theoretical concepts and analytical or error-free numerical computational techniques and therefore comes under the field of “General Systems research” as explained in the following.

Space-time power law scaling and nonlocal connections exhibited by atmospheric flows have also been documented in other nonequilibrium dynamical systems, e.g. financial markets, neural network of brain, genetic networks, internet, road traffic, and flocking behavior of some animals and birds. Such universal behavior has been the subject of intensive study in recent years as “complex systems” under the subject headings self-organized criticality, nonlinear dynamics and chaos, network theory, pattern formation, information theory, cybernetics (communication, control, and adaptation). Complex system is a system composed of many interacting parts, such that the collective behavior or “emergent” behaviors of those parts together is more than the sum of their individual behaviors. Weather and climate are emergent properties of the complex adaptive system of atmospheric flows. Complex systems in different fields of study exhibit similar characteristics and therefore belong to the field of “General Systems.” The terms “general systems” and “general systems research (or general systems theory)” are due to Ludwig von Bertalanffy. According to Bertalanffy, general systems research is a discipline whose subject matter is “the formulation and derivation of those principles which are valid for ‘systems’ in general.”

Skyttner quotes basic ideas of general systems theory formulated by Fredrich Hegel (1770–1831) as follows:

1. The whole is more than the sum of the parts.
2. The whole defines the nature of the parts.

3. The parts cannot be understood by studying the whole.
4. The parts are dynamically interrelated or interdependent.

In cybernetics, a system is maintained in dynamic equilibrium by means of communication and control between the constituent parts and also between the system and its environment.

Chapter 1 gives applications of the concept of self-organized criticality to atmospheric flows. Atmospheric flows exhibit self-similar fractal fluctuations generic to dynamical systems in nature. Self-similarity implies long-range space-time correlations identified as self-organized criticality. It has been suggested that atmospheric convection could be an example of self–organized criticality. Atmospheric convection and precipitation have been hypothesized to be a real-world realization of self-organized criticality (SOC). The physics of self-organized criticality ubiquitous to dynamical systems in nature and in finite precision computer realizations of nonlinear numerical models of dynamical systems is not yet identified. Finite precision computer realizations of mathematical models (nonlinear) of dynamical systems do not give realistic solutions because of propagation of round off error into mainstream computation. During the past three decades, Lovejoy and his group have done extensive observational and theoretical studies of fractal nature of atmospheric flows and emphasize the urgent need to formulate and incorporate quantitative theoretical concepts of fractals in mainstream classical meteorological theory. The empirical analyses summarized by Lovejoy and Schertzer show that the statistical properties such as the mean and variance of atmospheric parameters (temperature, pressure, etc) are scale dependent and exhibit a power law relationship with a long fat tail over the space-time scales of measurement. The physics of the widely documented fractal fluctuations in dynamical systems is not yet identified. The traditional statistical normal (Gaussian) probability distribution is not applicable for statistical analysis of fractal space-time data sets because of the following reasons: (i) Gaussian distribution assumes independent (uncorrelated) data points while fractal fluctuations exhibit long-range correlations, (ii) the probability distribution of fractal fluctuations exhibit a long fat tail, i.e., extreme events are of more common occurrence than given by the classical theory.

A general systems theory model for fractal fluctuations proposed by the author predicts that the amplitude probability distribution as well as the power (variance) spectrum of fractal fluctuations follow the universal inverse power law $\tau^{-4\sigma}$ where τ is the golden mean (≈ 1.618) and σ the normalized standard deviation. The atmospheric aerosol size spectrum is derived in terms of the universal inverse power law characterizing atmospheric eddy energy spectrum. A universal (scale independent) spectrum is derived for homogeneous (same density) suspended atmospheric particulate size distribution expressed as a function of the golden mean τ (≈ 1.618), the total number concentration and the mean volume radius (or diameter) of the particulate size spectrum. Knowledge of the mean volume radius and total number concentration is sufficient to compute the total particulate size spectrum at any location. In summary, the model predictions are: (i) Fractal fluctuations can be resolved into an overall logarithmic spiral trajectory with the quasiperiodic Penrose tiling pattern for the internal structure. (ii) The probability distribution of fractal space-time fluctuations represents the power (variance) spectrum for fractal fluctuations and follows universal inverse power law form incorporating the golden mean. The result that the additive amplitudes of eddies when squared represent probability distribution is observed in the subatomic dynamics of quantum systems such as the electron or photon. Therefore, the irregular or unpredictable fractal fluctuations exhibit quantum-like chaos. (iii) Atmospheric aerosols are held in suspension by the vertical velocity distribution (spectrum). The normalized atmospheric aerosol size spectrum is derived in terms of the universal inverse power law characterizing atmospheric eddy energy spectrum. The model satisfies the maximum entropy principle.

In Chap. 2, the complete theory relating to the formation of warm cumulus clouds and their responses to the hygroscopic particle seeding are presented. It is shown that warm rain formation can occur within a time period of 30 min as observed in practice. Traditional cloud physical concepts for rain development requires over an hour for a full-sized raindrop to form.

Knowledge of the cloud dynamical, microphysical, and electrical parameters and their interactions are essential for the understanding of the formation of rain in warm clouds and their modification. Extensive aircraft observations of cloud dynamical, microphysical, and electrical parameters have been made in more than 2000 isolated warm cumulus clouds forming during the summer-monsoon seasons (June–September) in Pune (18° 32′N, 73° 51′E, 559 m asl), India. The observations were made during aircraft traverses at about 300 m above the cloud base. These observations have provided new evidence relating to the dynamics of monsoon clouds. The observed dynamical and physical characteristics of monsoon clouds cannot be explained by simple entraining cloud models. A simple cumulus cloud model which can explain the observed cloud characteristics has been developed. The relevant physical concept and theory relating to dynamics of atmospheric planetary boundary layer (PBL), formation of warm cumulus clouds, and their modification through hygroscopic particle seeding are presented.

The mechanism of large eddy growth discussed in the atmospheric ABL can be applied to the formulation of the governing equations for cumulus cloud growth. Based on the above theory equations are derived for the in-cloud vertical profiles of (i) ratio of actual cloud liquid water content (q) to the adiabatic liquid water content (qa) (ii) vertical velocity (iii) temperature excess (iv) temperature lapse rate (v) total liquid water content (qt) (vi) cloud growth time (vii) cloud drop size spectrum (viii) rain drop size spectrum. The equations are derived starting from the microscale fractional condensation (MFC) process at cloud base levels. This provides the basic energy input for the total cloud growth.

Chapter 3 discusses the importance of information on the size distribution of atmospheric suspended particulates (aerosols, cloud drops, raindrops) for the understanding of the physical processes relating to the studies in weather, climate, atmospheric electricity, air pollution, and aerosol physics. Atmospheric suspended particulates affect the radiative balance of the Earth/atmosphere system via the direct effect whereby they scatter and absorb solar and terrestrial radiation, and via the indirect effect whereby they modify the microphysical properties of clouds thereby affecting the radiative properties and lifetime of clouds. At present empirical models for the size distribution of atmospheric suspended particulates is used for the quantitative estimation of earth-atmosphere radiation budget related to climate warming/cooling trends. The empirical models for different locations at different atmospheric conditions, however, exhibit similarity in shape implying a common universal physical mechanism governing the organization of the shape of the size spectrum. The pioneering studies during the last three decades by Lovejoy and his group show that the particulates are held in suspension in turbulent atmospheric flows which exhibit self-similar fractal fluctuations on all scales ranging from turbulence (mm-s) to climate (km-years). Lovejoy and Schertzer have shown that the rain drop size distribution should show a universal scale invariant shape.

The general systems theory for fractal space-time fluctuations developed by the author predicts (Chap. 1) a universal (scale independent) spectrum for suspended atmospheric particulate size distribution expressed as a function of the golden mean τ (≈ 1.618), the total number concentration and the mean volume radius (or diameter) of the particulate size spectrum. Knowledge of the mean volume radius and total number concentration is sufficient to compute the total particulate size spectrum at any location. The model-predicted spectrum is in agreement with the following four experimentally determined data sets: (i) CIRPAS mission TARFOX_WALLOPS_SMPS aerosol size distributions, (ii) CIRPAS mission ARM-IOP (Ponca City, OK) aerosol size distributions, (iii) SAFARI 2000 CV-580 (CARG Aerosol and Cloud Data) cloud drop size distributions, and (iv) TWP-ICE (Darwin, Australia) rain drop size distributions.

In Chap. 4 it is shown that the model-predicted suspended particulate (aerosol) size spectrum is in agreement with observations using VOCALS 2008 PCASP data.

In Chap. 5, the model-predicted spectrum is compared with the total averaged radius size spectra for the AERONET (aerosol inversions) stations Davos and Mauna Loa for the year 2010 and Izana for the year 2009.

In Chap. 6 it is shown that model-predicted spectrum is in agreement with the following two experimentally determined atmospheric aerosol data sets, (i) SAFARI 2000 CV-580 Aerosol Data, Dry Season 2000 (CARG) (ii) World Data Centre Aerosols data sets for the three stations Ny Ålesund, Pallas and Hohenpeissenberg.

There is close agreement between the model-predicted and the observed aerosol spectra at different locations. The proposed model for universal aerosol size spectrum will have applications in computations of radiation balance of earth–atmosphere system in climate models.

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