

## Contents

	Preface	page xiii
	Acknowledgments	xv
1	<b>Introduction</b>	1
1.1	What Is Complexity?	1
1.2	Criticality	2
1.3	Self-Organized Criticality	8
1.4	Fluctuations, Intermittency, and Multifractals	8
	1.4.1 Wavelet Transform	9
	1.4.2 Geometrical Interpretation of Intermittency	10
1.5	Dynamic Renormalization Group	11
1.6	Application to Space Plasmas	13
1.7	Outline of the Monograph	14
2	<b>Dynamical Criticality Far from Equilibrium and Associated Phenomena</b>	16
2.1	Introduction to Self-Organized Criticality	16
2.2	Flicker Noise and Running Avalanche Models	18
2.3	An Interlude – Mean Field Theory and Scaling Near Criticality	19
	2.3.1 Mean Field Theory	19
	2.3.2 Scaling Theory	22
2.4	Scaling Properties of Global Geomagnetic Fluctuations	24
	2.4.1 Introduction	24
	2.4.2 Global Auroral Images and Scaling	27

- 2.4.3 Spatiotemporal Avalanches and Their Scale-Free Statistics 31
- 2.4.4 Modeling Substorms by Running Sandpiles 36
- 2.4.5 Revised Forest-Fire Model 38
- 2.4.6 Running Coupled Maps Applied to Global Magnetotail Dynamics 43
- 2.4.7 The Magnetic Field Reversal Model 45
- 2.4.8 Closing Remarks on Critical Dynamics 51

### 3 **Physics of Complexity** 53

- 3.1 Introduction 53
- 3.2 Coherent Structures in Space Plasmas 54
- 3.3 Alfvénic Resonant Structures 54
- 3.4 Alfvénic Flux Tubes 58
- 3.5 Alfvénic (Solitary) Vortices 59
- 3.6 Coarse-Grained Dissipation and Stochastic Interaction of Coherent Structures 64
- 3.7 Complexity and Wavelet Transforms 68

### 4 **Probability Distribution and Structure Functions** 75

- 4.1 Probability Distribution Functions of Incremental Changes 75
- 4.2 Castaing Distributions 78
- 4.3 Kappa and Other Related Distributions 79
- 4.4 One-Parameter Scaling for Self-Similar PDFs 81
- 4.5 Fractals, Multifractals, and Structure Functions 83
  - 4.5.1 Fractals 83
  - 4.5.2 Structure Functions 84
  - 4.5.3 A Formal Structure Function Description of Multifractals 86
  - 4.5.4 Log-Poisson Model of Intermittency for the Structure Function Exponents 87

### 5 **Partition Functions, Generalized Dimensions, and Singularity Spectra** 89

- 5.1 Partition Function 89
- 5.2 Generalized Dimensions 92
- 5.3 The Singularity Spectrum  $f(\alpha)$  93
- 5.4 Wavelet Transform Modulus Maxima 96

### 6 **Rank Ordered Multifractal Analysis** 100

- 6.1 Introduction 100
- 6.2 Examples of ROMA Based on Numerical Simulations 103
  - 6.2.1 2D MHD Simulation 103
  - 6.2.2 Fluid Turbulence 104

- 6.3 Applications to Observations 107
  - 6.3.1 Solar Wind Turbulence 107
  - 6.3.2 The Auroral Electrojet Index 109
  - 6.3.3 Turbulent Fluctuations in the Magnetospheric Cusp 111
  - 6.3.4 Solar Extreme Ultraviolet Emissions 113
  - 6.3.5 Intermittency of Broad Band Turbulence in the Ionosphere 115

### 7 **Dynamic Renormalization Group and Connection between Criticality and Multifractals** 123

- 7.1 Introduction 123
- 7.2 An Illustrative Example – One-Dimensional Modified Forest Fire Model 127
- 7.3 Beyond Criticality 131
  - 7.3.1 Introduction 131
  - 7.3.2 Generalized Near Criticality and Finite-Size Scaling Laws, Complexity, and Multifractals 131
  - 7.3.3 A Toy Model of Global Crossover among Multiple Fixed Points 133

Finale 141

References 143

Index 157

*Color plates follow page xvi.*