Contents

1 Entropy Production by Earth System Processes

Axel Kleidon, Ralph Lorenz ............................................. 1
1.1 Introduction ..................................................... 1
1.2 Entropy Production of Climate Systems ...................... 2
  1.2.1 Earth’s Climate System ................................. 3
  1.2.2 Other Planetary Climate Systems ...................... 4
1.3 The Principles of Minimum and Maximum Entropy Production .................................. 5
  1.3.1 Heat Transport and Minimum Entropy Production ..... 6
  1.3.2 Heat Transport and Maximum Entropy Production ..... 7
  1.3.3 Maximum Entropy Production in a Planetary Context ... 10
  1.3.4 Minimization Versus Maximization of Entropy Production .................................. 11
1.4 Entropy Production and Life on Earth ....................... 12
  1.4.1 Environmental Effects of Biotic Activity .......... 12
  1.4.2 The Gaia Hypothesis ................................ 14
  1.4.3 Optimization and Entropy Production Within the Biosphere .................................. 14
1.5 Structure of This Book ..................................... 16

2 Non-equilibrium Thermodynamics in an Energy-Rich Universe

Eric J. Chaisson ..................................................... 21
2.1 Introduction ..................................................... 21
2.2 Time’s Arrow ................................................... 22
2.3 Cosmological Setting .......................................... 24
2.4 Complexity Rising ............................................ 26

3 Stumbling into the MEP Racket: An Historical Perspective

Garth W. Paltridge .................................................. 33

4 Maximum Entropy Production and Non-equilibrium Statistical Mechanics

Roderick C. Dewar .................................................. 41
4.1 Introduction ..................................................... 42
4.2 Boltzmann, Gibbs, Shannon, Jaynes ......................... 43
4.3 Macroscopic Reproducibility ................................................. 45
4.4 The Concept of Caliber ...................................................... 47
4.5 Path Information Formalism of NSEM .................................. 47
4.6 New Results Far from Equilibrium ...................................... 49
  4.6.1 Maximum Entropy Production (MEP) ............................. 50
  4.6.2 The Fluctuation Theorem (FT) ................................. 51
  4.6.3 Self-Organized Criticality (SOC) .............................. 52
4.7 Thermodynamics of Life ................................................. 53
4.8 Further Prospects .......................................................... 53

5 Using Ecology to Quantify Organization in Fluid Flows
Robert E. Ulanowicz, Michael J. Zickel ................................... 57
  5.1 Introduction .............................................................. 57
  5.2 Constraint Among Biotic Processes .................................. 58
  5.3 Quantifying Constraint in Fluid Flow .............................. 61
  5.4 Identifying Flow Bottlenecks ........................................ 64
  5.5 Conclusion ............................................................... 64

6 Cosmological and Biological Reproducibility: Limits on the
Maximum Entropy Production Principle
Charles H. Lineweaver .......................................................... 67
  6.1 Maximum Entropy Production and Reproducibility .............. 67
    6.1.1 Cosmological Reproducibility ................................ 68
    6.1.2 The Entropy of an Observable Universe Must Start Low .... 68
    6.1.3 Expansion Does Not Increase the Entropy of the Universe .... 70
    6.1.4 Return of the Heat Death ..................................... 71
  6.2 Biological Reproducibility ............................................ 73
    6.2.1 Does Life Increase the Total Entropy Growth over What It Would Be Without Life? 73
  6.3 Applying the Maximum Entropy Principle to Biological Evolution ........................................ 75
  6.4 Does the MEP Imply That Life Is Common in the Universe? ........................................................................................................ 76

7 Entropy Production in Turbulent Mixing
Joël Sommeria ................................................................. 79
  7.1 Introduction .............................................................. 79
  7.2 MEP in Classical Thermodynamics ................................. 82
  7.3 MEP in Two-Dimensional Turbulence ............................. 84
  7.4 Application to Stellar Systems ...................................... 88
  7.5 Conclusions ............................................................... 89
8 Entropy Production of Atmospheric Heat Transport
Takamitsu Ito, Axel Kleidon .............................................. 93
8.1 Introduction .......................................................... 93
8.2 Entropy Production in an Idealized Dry Atmosphere .......... 95
  8.2.1 Global Budget of Energy and Entropy .................... 96
  8.2.2 Sources of Entropy Production .............................. 96
  8.2.3 Theoretical Upper Bound of Entropy Production .......... 97
8.3 Testing Maximum Entropy Production with Atmospheric General
  Circulation Models .................................................. 98
  8.3.1 Simulated Entropy Production in the Climatological Mean . 98
  8.3.2 Comparing the Analytic MEP Solution to the Simulated
       Atmosphere ...................................................... 99
  8.3.3 Sensitivity of Entropy Production to Internal Parameters ... 101
8.4 Climatological Implications ....................................... 103

9 Water Vapor and Entropy Production in the Earth’s Atmosphere
Olivier M. Pauluis ....................................................... 107
9.1 Introduction .......................................................... 107
9.2 Idealized Cycles ..................................................... 110
  9.2.1 Cycle A: Pure Dehumidifier .................................. 110
  9.2.2 Cycle B: Atmospheric Dehumidifier and Water Vapor
       Expansion ......................................................... 112
  9.2.3 Cycle C: Sensible Heat Transport ......................... 114
9.3 Dehumidifier Versus Heat Engine .................................. 115
9.4 Frictional Dissipation in Falling Precipitation ................... 116
9.5 Entropy Budget of the Earth’s Atmosphere ....................... 117

10 Thermodynamics of the Ocean Circulation: A Global Perspective
    on the Ocean System and Living Systems
Shinya Shimokawa, Hisashi Ozawa ..................................... 121
10.1 Introduction .......................................................... 121
10.2 Calculation of Entropy Production ................................ 123
10.3 Model Description and Experimental Method ..................... 124
10.4 Entropy Production in a Steady State ............................ 126
10.5 Entropy Production During Transition Among Multiple
    Steady States ....................................................... 127
10.6 Entropy Production During Evolution of Structure ............... 128
10.7 Analogy Between Ocean System and Living System ............... 130

11 Entropy and the Shaping of the Landscape by Water
Hideaki Miyamoto, Victor R. Baker, Ralph D. Lorenz ................. 135
11.1 Introduction .......................................................... 135
11.2 Early Work by Leopold and Langbein ............................ 136
11.3 Scaling Laws in Hydrology .................................. 138
11.4 Thermodynamics of Fractal Networks ........................ 141
11.5 Entropy and Shoreline Profiles .............................. 144
11.6 Concluding Remarks ....................................... 145

12 Entropy Production in the Planetary Context
Ralph D. Lorenz ................................................ 147

12.1 Equator-Pole Temperature Gradients of Planetary Atmospheres ........................................ 147
12.1.1 Earth .............................................. 148
12.1.2 Titan .............................................. 148
12.1.3 Mars ............................................. 149
12.1.4 Venus .............................................. 150
12.1.5 Other Planets ....................................... 150
12.1.6 Other Processes in Planetary Atmospheres ............. 150
12.2 A Probabilistic Explanation for MEP ........................ 151
12.3 Dissipation and Heat Transport ............................. 152
12.4 Geomorphology and Dissipative Structures .................... 154
12.5 The Yarkovsky Effect – Migration of Meteorites via a Photon Heat Engine .......................... 155
12.6 Dyson Sphere – The Ultimate Stage in Planetary Evolution ........................................ 157
12.7 Concluding Remarks ....................................... 158

13 The Free-Energy Transduction and Entropy Production in Initial Photosynthetic Reactions
Davor Juretić, Paško Županović .................................. 161

13.1 Introduction ............................................. 161
13.2 The Two-State Kinetic Model ................................ 162
13.3 The Five State Model for Chlorophyll Based Photoconversion .................................. 164
13.4 Slip Coefficients and Forward Static Head State .......... 167
13.5 Conclusions .............................................. 168

14 Biotic Entropy Production and Global Atmosphere-Biosphere Interactions
Axel Kleidon, Klaus Fraedrich .................................... 173

14.1 Introduction ............................................. 173
14.2 Photosynthetic Activity and Climatic Constraints .......... 175
14.2.1 Climatic Constraints on Biotic Productivity .......... 175
14.2.2 Dynamic Constraints of Terrestrial Energy- and Water Exchange .................. 177
14.3 Biogeophysical Effects and Feedbacks ....................... 178
14.3.1 Vegetation Effects on Land Surface Characteristics .... 178
14.3.2 Climate Feedbacks of Terrestrial Vegetation .......... 179
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.4 Biotic Entropy Production and MEP</td>
<td>181</td>
</tr>
<tr>
<td>14.4.1 Conditions for Biotic MEP States</td>
<td>182</td>
</tr>
<tr>
<td>14.4.2 Biotic States of MEP</td>
<td>183</td>
</tr>
<tr>
<td>14.4.3 Biotic MEP and Gaia</td>
<td>186</td>
</tr>
<tr>
<td>14.5 Conclusions</td>
<td>187</td>
</tr>
<tr>
<td>15 Coupled Evolution of Earth’s Atmosphere and Biosphere</td>
<td>191</td>
</tr>
<tr>
<td>15.1 Introduction</td>
<td>191</td>
</tr>
<tr>
<td>15.2 The Earliest Earth: Its Atmosphere and Biosphere</td>
<td>192</td>
</tr>
<tr>
<td>15.2.1 What Was the Composition of the Prebiotic Atmosphere?</td>
<td>192</td>
</tr>
<tr>
<td>15.2.2 When Did Earth Acquire a Biosphere?</td>
<td>192</td>
</tr>
<tr>
<td>15.2.3 What Effect Did Primitive Life Have on the Early Atmosphere?</td>
<td>193</td>
</tr>
<tr>
<td>15.3 Long-Term Climate Evolution and the Biosphere</td>
<td>195</td>
</tr>
<tr>
<td>15.4 Atmospheric Redox Change: The Rise of Oxygen</td>
<td>197</td>
</tr>
<tr>
<td>15.5 Oxygen, Energy, and Life</td>
<td>199</td>
</tr>
<tr>
<td>15.5.1 Aerobic Versus Anaerobic Energetics</td>
<td>199</td>
</tr>
<tr>
<td>15.5.2 Why Complex Life Anywhere in the Universe Will Likely Use Oxygen</td>
<td>200</td>
</tr>
<tr>
<td>15.6 The Anomalous Nature of Earth’s Current Atmosphere</td>
<td>202</td>
</tr>
<tr>
<td>16 Temperature, Biogenesis, and Biospheric Self-Organization</td>
<td>207</td>
</tr>
<tr>
<td>16.1 Introduction</td>
<td>207</td>
</tr>
<tr>
<td>16.1.1 Cosmology and Temperature</td>
<td>208</td>
</tr>
<tr>
<td>16.2 Biogenesis at Life’s Upper Temperature Limit: A Hyperthermophilic Origin of Life</td>
<td>208</td>
</tr>
<tr>
<td>16.3 The Temperature Constraint on Biologic Evolution</td>
<td>212</td>
</tr>
<tr>
<td>16.4 Future Directions</td>
<td>217</td>
</tr>
<tr>
<td>17 Entropy and Gaia: Is There a Link Between MEP and Self-Regulation in the Climate System?</td>
<td>223</td>
</tr>
<tr>
<td>17.1 Introduction</td>
<td>223</td>
</tr>
<tr>
<td>17.2 Daisyworld</td>
<td>224</td>
</tr>
<tr>
<td>17.3 Model Formulation</td>
<td>226</td>
</tr>
<tr>
<td>17.4 Two-Component System</td>
<td>229</td>
</tr>
<tr>
<td>17.5 Multi-component System</td>
<td>231</td>
</tr>
<tr>
<td>17.6 Saturated Growth</td>
<td>231</td>
</tr>
<tr>
<td>17.7 A Two-Box Model</td>
<td>233</td>
</tr>
</tbody>
</table>
17.8 Slow Daisies .............................................. 234
17.9 Discussion ............................................... 239

18 Insights from Thermodynamics
for the Analysis of Economic Processes
Matthias Ruth ........................................... 243
18.1 Introduction ............................................. 243
18.2 Thermodynamic Constraints
on Production and Consumption ..................... 245
18.3 Constraints at Macroeconomic Levels .............. 246
18.4 Thermodynamics and the “Evolution”
of Economic Processes ................................ 248
18.5 Information and Knowledge ........................ 249
18.6 Conclusion ................................................ 251

Index .......................................................... 255
Non-equilibrium Thermodynamics and the Production of Entropy
Life, Earth, and Beyond
Kleidon, A.; Lorenz, R.D. (Eds.)
2005, XX, 264 p., Hardcover
ISBN: 978-3-540-22495-2