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Understanding Complex Systems

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Understanding Complex Systems

Future scientific and technological developments in many fields will necessarily depend upon coming to grips with complex systems. Such systems are complex in both their composition (typically many different kinds of components interacting with each other and their environments on multiple levels) and in the rich diversity of behavior of which they are capable. The Springer Series in Understanding Complex Systems series (UCS) promotes new strategies and paradigms for understanding and realizing applications of complex systems research in a wide variety of fields and endeavors. UCS is explicitly transdisciplinary. It has three main goals: First, to elaborate the concepts, methods and tools of self-organizing dynamical systems at all levels of description and in all scientific fields, especially newly emerging areas within the Life, Social, Behavioral, Economic, Neuro- and Cognitive Sciences (and derivatives thereof); second, to encourage novel applications of these ideas in various fields of Engineering and Computation such as robotics, nanotechnology and informatics, third, to provide a single forum within which commonalities and differences in the workings of complex systems may be discerned, hence leading to deeper insight and understanding. UCS will publish monographs and selected edited contributions from specialized conferences and workshops aimed at communicating new findings to a large multidisciplinary audience.
Non-equilibrium Thermodynamics and the Production of Entropy

Life, Earth, and Beyond

With a Foreword by Hartmut Grassl

Springer
For many millions of years the Earth has been a life-supporting planet with on average increasing biodiversity and its mean near surface air temperature varying only by a few percent (± 5 Kelvin) around the present mean of about 288K. However, despite this comparably small temperature change, the concentration of a major radiatively active gas, carbon dioxide, was more than double the present anthropogenically enhanced value before glaciation set in and only slightly above half the present value during maximum glaciation, the continents have changed shape and have moved to different geographical latitudes, and the luminosity of the sun has increased substantially.

Which processes have guaranteed this impressive temperature stability? A first candidate with the buffering capacity needed is planetary shortwave albedo, which – by decreasing only from 30 to 29 percent – could cause a radiative forcing of the same magnitude but with opposite sign as a drop in carbon dioxide concentration from its value in an interglacial, like our Holocene, to a typical maximum glaciation value of slightly less than 200 part per million by volume. As the maximum contribution to planetary albedo stems from tropospheric clouds both in the tropics and mid-latitudes, their change could be the key stabilizing agent. But why should cloud cover and/or cloud optical depth increase in an interglacial as compared to the glacial? At present we do not know. Because clouds are the expression of an important diabatic process – phase fluxes of water – these fluxes contribute strongly to entropy production in the atmosphere, second only to longwave radiative flux divergence, which is again strongly modulated by clouds.

For me this book is an exceptional one, as it offers a way forward, maybe the solution. It gives as strong hope that an integral principle, maximum entropy production (MEP), is at work in all open systems with large distance to thermodynamic equilibrium, i.e. those governed by non-linear thermodynamics like the Earth. The low import of entropy, expressed as net shortwave flux density divided by the sun’s blackbody radiation (∼6000 K) and the high export of entropy, expressed as the net longwave flux density at the top of the atmosphere divided by a typical terrestrial temperature (250 to 300 K), point to strong entropy production within the Earth system. It is largely due to the well-known diabatic processes radiative flux divergence, phase changes of water, turbulent sensible heat flux, and dissipation of turbulent kinetic energy.
This book contains, in addition to these purely physical processes, attempts to integrate life as it enhances diabatic processes through evapotranspiration, higher surface roughness and higher emissivity. Life intensifies the global cycles of water, carbon and nitrogen. If all thermodynamic systems far from equilibrium are subject to MEP, life on Earth included, it would also be a governing principle for the evolution of the Earth system. There would no longer be the need for ad-hoc assumptions, like the Gaia hypothesis. On the contrary, we would have a powerful tool to ask climate and Earth system models – the latter just emerging – what kind of human behaviour would lead to which state as we would be able to add MEP as a constraint in addition to the well-known physical laws and boundary conditions (dynamical, thermodynamical and radiation principles; spectral solar irradiance). These models would then search for the most probable future state which will be attained with very high probability. We could for example also see the consequences of land use changes, including the redistribution of water, which strongly impact biodiversity and the carbon cycle, as well as those changes caused by an enhanced greenhouse effect. This would help us to find a sustainable development path. Additionally, the regional, and perhaps global, consequences of air pollution would become visible.

The MEP principle is also connected to self-organized criticality. It could thus become a tool to better understand the abrupt changes of thermohaline circulation and also local-scale phenomena like avalanches. Besides answers to questions raised earlier, it may even offer means to determine bounds for the best place of a planet with respect to its sun and the composition of its crust best suited for the development of life.

If discrepancies emerge between observations and such diverse modeling for recent history, this tells us about either the lack of information to describe the system or insufficient, maybe incorrect constraints or deficiencies in the handling of diabatic processes.

Earth system or climate models applying or exploring the MEP principle will be extremely demanding of computer time. Thus simplified models will be useful tools in the near future as also demonstrated in this book. Their results, although promising, are still not the real test that MEP governs climate and the Earth system. However, a joint activity of high performance computing centres working with Earth system and climate models could rapidly bring us closer to reality if the global observing system is adequate for a real check. I propose an international basic research project devoted to MEP and Climate, initiated by the group that has been gathered to write the chapters of this book, and which could form the nucleus for basic research with immediate repercussions for the global society. I recommend besides individual research projects a joint action by the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP) through the Working Group on Coupled Modelling (WGCM) and the Global Analysis, Integration and Modelling (GAIM) element, respectively; because this kind of research needs global data sets from several disciplines, access to largest...
computers and best models. At the same time the MEP principle will facilitate the search for better parameterizations as all processes in open systems would also obey it.

It was a great pleasure for me to read all the chapters. I hope that scientists from many different disciplines pick up the chapters most relevant for their future work.

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Hartmut Grassl

Director
Preface

“A theory is more impressive the greater the simplicity of its premises, the more different are the kinds of things it relates, and the more extended its range of applicability. Therefore, the deep impression which classical thermodynamics made on me. It is the only physical theory of universal content, which I am convinced, that within the framework of applicability of its basic concepts will never be overthrown.”

Albert Einstein (1879-1955)

This book arose from an encounter between the two editors, a Geography professor and a planetary scientist, two people who might otherwise have little in common. Both of us had independently, along with many of the contributors to this volume, grown aware of the profound importance of nonequilibrium thermodynamics and the potential utility of the principle of Maximum Entropy Production. The possible applications span a bewildering diversity of fields, and thus we felt it useful to all of us to draw some of these threads together in a reference volume that captures the ‘state of the art’.

But our encounter at the American Geophysical Union meeting in San Francisco in December 2002 would not have led to our undertaking this book were it not for a growing informal network of researchers in MEP – many of us each feeling alone in the wilderness of our own fields. This network has grown, and many of the ideas in the chapters of this book have been developed at informal workshops, notably a workshop on Maximum Entropy Production at INRA in Bordeaux in April 2003 organized by Roderick Dewar and a series of ‘Beyond Daisyworld’ workshops organized by Tim Lenton and Inman Harvey. These workshops take considerable time and effort to organize, and the editors therefore are most grateful to these ‘unsung heroes’ of the field, who as well as bringing MEP researchers together play a vital role in exposing others to the idea.

We thank Christian Caron at Springer Verlag for his encouragement and assistance with this project. We are also most grateful to the contributors to this volume, for their patient hard work in dealing with the editing pro-

cess and the frustrations of document templates. Last, but not least, we are grateful to Ma-Li Kleidon for her help with editing the book chapters.

We hope that with this book we demonstrate the wide potential applicability of thermodynamic concepts, and the principle of Maximum Entropy Production in particular, ranging from the evolution of the Universe, planetary climate systems, life on Earth, and the economic activity of humans and its interaction with the environment.

College Park, Tucson
April 2004

Axel Kleidon
Ralph Lorenz
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