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Mathematics of Energy and Climate Change

International Conference and Advanced
School Planet Earth, Portugal,
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Foreword

Alberto Adrego Pinto, the president of the Centro Internacional de Matemática (CIM), has asked me to write a few words on the International Conference Planet Earth, Mathematics of Energy and Climate Change, MPE 2013. I am very happy to do so since I had a chance to participate in this extremely important event. I became a member of the CIM Scientific Council in 2009. Two years later Alberto Adrego Pinto took office as the new president and he started with a lot of enthusiasm and energy. The executive committee decided that the CIM should become a partner in the global program Mathematics of Planet Earth (MPE 2013). In addition it was decided to organize two conferences in 2013 with accompanying Advanced Schools. The present proceedings are the outcome of the conference MECC 2013, the International Conference and Advanced School Planet Earth, Mathematics of Energy and Climate Change, held between March 21 and 28. Clearly these two chosen topics fit extremely well to the problems our planet is currently facing. In addition one needs complex mathematical models to understand the processes. I was very much looking forward to being part of this event in Lisbon and to learning from the excellent plenary speakers about how mathematics can be used to understand energy issues and the climate. It was a great idea to actually do several video lectures. This not only allowed us to get the best speakers from remote locations, like Rio de Janeiro or Berkeley to name a few, but with this approach the conference also demonstrated how to save energy and reduce the production of CO₂. Alberto Adrego Pinto had two further excellent ideas. About a third of all plenary speakers volunteered to present two further lectures on the topic in the associated “Advanced School.” For example there was the public lecture by David Zilberman, who spoke on “Technology and the Future Bioeconomy.” He then also spoke on the “Economic Foundations of Climate Smart Agriculture” and “The Economics of Payment for Ecosystem Services.” These talks were supplemented by the plenaries, the “Advanced Schools” and seventeen “Thematic Sessions,” so that altogether it was a very intensive time. Thanks to the famous Calouste Gulbenkian Foundation, which hosted the event at their excellent conference facilities, all participants enjoyed the friendly and constructive atmosphere. I think it was actually a very good idea to hold the plenary lectures in an auditorium, which allowed

the delegates to participate in discussions. Finally I was extremely impressed by the contributions of our Portuguese colleagues, who organized nearly all of the Thematic Sessions. There is a large community of applied mathematicians who work on research concerning the mathematics of planet earth. Finally I would like to thank Alberto Adrego Pinto for organizing the conference and for his unbridled enthusiasm, which allowed him to motivate so many participants.

Zürich, Switzerland
28 November 2014

Rolf Jeltsch

Foreword

The stress placed on the dynamical system we call Planet Earth, owing to the activities of mankind, threatens mankind itself. It calls for an unprecedented response. This begins with an understanding of the problem. The sheer complexity of the system, and the consequential ease with which an unexpected consequence or an unanticipated bifurcation can occur, or an unjustified cause-and-effect relation can be inferred, calls for a careful mathematical analysis. Understanding is essential, but also creative solutions are urgently needed. Here again, mathematical theory will play an important role.

These papers comprise a snapshot of current mathematical work devoted to these problems. The topics coincide with the major themes of the International Conference and Advanced School.

An understanding of the problem begins a careful overall study of the energy flow to the earth. This includes work on the difficult-to-predict role, also in weather prediction, of clouds (Santos, chapter “The Role of Clouds, Aerosols and Galactic Cosmic Rays in Climate Change”), and climate and the ecology of polar regions (Xavier, Hill, Belchier, Bracegirdle, Murphy, and Lopes Dias, chapter “From Ice to Penguins: The Role of Mathematics in Antarctic Research”). Pereira’s article (chapter “Mathematics of Energy and Climate Change: From the Solar Radiation to the Impacts of Regional Projections”), encompassing all aspects of the energy flow to the earth, from the Stefan-Boltzmann law to the statistical treatment of fires to recommendations for future rain gutter sizes is a *tour de force* of climate change. It will be required reading for future mathematical climatologists.

A particular consequence of climate change is the increased frequency of rare, sometimes disastrous, events. Fundamental work on the mathematical theory of extreme values is needed, such as the theory of max-stability distributions (Fraga Alves, chapter “Max-Stability at Work (or Not): Estimating Return Levels for Daily Rainfall Data”), and resampling methodologies (Gomes, Henriques-Rodrigues, and Figueiredo, chapter “Resampling-Based Methodologies in Statistics of Extremes: Environmental and Financial Applications”), and methods to reveal additive outliers in time series (Eduarda Silva and Pereira, chapter “Detection of Additive Outliers in Poisson INAR(1) Time Series”). Application of these and related methods to

the occurrence of extremal earthquakes is presented by Brito, Cavalcante, and Moreira Freitas (chapter “Modeling of Extremal Earthquakes”). Manuela Neves’ overview of geostatistical methods (chapter “Geostatistical Analysis in Extremes: An Overview”) contains also a brief but useful historical perspective.

Solutions to problems of climate change and its effect on human populations may involve optimal control theory. This is useful in physical systems (Grilo, Gama, and Lobo Pereira, chapter “On the Optimal Control of Flow Driven Dynamic Systems”) and also in epidemiology (Aweke and Kassa, chapter “Impacts of Vaccination and Behavior Change in the Optimal Intervention Strategy for Controlling the Transmission of Tuberculosis”).

The chemical physics of climate change involves especially the careful study of the chemical kinetics of environmental processes. This is known to be a challenging problem, and improvement of the associated mathematical theories is needed. The state-of-the-art is here presented by Carvalho, Silva, and Soares (chapter “Detonation Wave Solutions and Linear Stability in a Four Component Gas with Bimolecular Chemical Reaction”), da Costa (chapter “Mathematical Aspects of Coagulation-Fragmentation Equations”), and Sasportes (chapter “Long Time Behaviour and Self-similarity in an Addition Model with Slow Input of Monomers”). Silva and Rodrigues (chapter “Modelling the Fixed Bed Adsorption Dynamics of CO_2 / CH_4 in 13X Zeolite for Biogas Upgrading and CO_2 Sequestration”) analyze a possible solution: the use of zeolites to catalyze the sequestration of CO_2 .

Human communication will be an inextricable consequence of climate change, particularly in the context of such major potential societal disruptions as the shifting of populations to the north. Salvador, Nogueira, and Rocha (chapter “Multiscale Internet Statistics: Unveiling the Hidden Behavior”) analyze the statistics of internet traffic.

Implementation of solutions will inevitably involve policy decisions, which in turn drive a politico-economic dynamical system. The politico-economics of ethanol production is treated by Moss, Schmitz, and Schmitz (chapter “The Economics of Ethanol: Use of Indirect Policy Instruments”).

The authors in this volume have made a tremendous effort to explain the overall context of their work, which makes these diverse presentations approachable for a broad scientific audience. This approachability speaks to the unity and universality of mathematics in the sciences, and underlies its essential value in approaching the pressing problems facing Planet Earth.

On behalf of the participants and authors, I would warmly like to thank Alberto Adrego Pinto. Conference participants were never more inspired, nor treated more warmly than by Alberto in the context of the magnificent venue of the Calouste Gulbenkian Foundation. The Fado was truly delightful.

Minneapolis, MN, USA
17 March 2015

Richard D. James

Preface

As the International Center for Mathematics (CIM) celebrated its 20th anniversary on the 3rd of December 2013, it is the perfect opportunity to look back on this past year, which has undoubtedly been one of the most ambitious and eventful ones in its history. With the support of our associates from 13 leading Portuguese universities, our partners at the University of Macau, and member institutions such as the Portuguese Mathematical Society, in 2013 the CIM showed yet again the importance of a forum such as this for bringing together leading Portuguese-speaking scientists and researchers from around the world.

The hallmark project of the year was the UNESCO-backed International Program Mathematics of Planet Earth (MPE) 2013, which the CIM participated in as a partner institution. This ambitious and global program was tasked with exploring the dynamic processes underpinning our planet's climate and man-made societies, and with laying the groundwork for the kind of mathematical and interdisciplinary collaborations that will be pivotal to addressing the myriad issues and challenges facing our planet now and in the future. The CIM heeded the MPE's call to action by organizing two headline conferences in March and September of 2013: the "Mathematics of Energy and Climate Change" conference in Lisbon in the spring, and the conference "Dynamics, Games, and Science II" in the fall. Both were held at the world-renowned Calouste Gulbenkian Foundation in Lisbon, one of more than 15 respected Portuguese foundations and organizations that enthusiastically supported the CIM conferences. As well as the conferences themselves, well attended "advanced schools" were held before and after each event: at the Universidade de Lisboa in the spring, and at the Universidade Técnica de Lisboa in the fall.

These conferences succeeded in bringing together some of the most accomplished mathematical and scientific minds from across the Portuguese-speaking world and beyond, while also serving as a launch pad for one of the CIM's most exciting endeavors in years: the new CIM Series in Mathematical Sciences, which will include lecture notes and research monographs and be published by Springer-Verlag. "The collaboration with Springer will bring mathematics developed in Portugal to a global audience," CIM President Alberto Adrego Pinto said at the time

of the announcement, “and will help strengthen our contacts with the international mathematics community.”

These first two volumes in the series, consisting of review articles selected from work presented at the “Mathematics of Energy and Climate Change” and “Dynamics, Games, and Science” conferences, reflect the CIM’s international reach and standing. Firstly, they are characterized by an impressive roster of mathematicians and researchers from across the United States, Brazil, Portugal, and several other countries whose work will be included in the volumes.

The authors are complemented by the editorial board responsible for this first installment, a world-renowned “quartet” consisting of: president of the European Research Council Jean-Pierre Bourguignon from the École Polytechnique; former Société Mathématique Suisse and European Mathematical Society president Rolf Jeltsch from the ETH Zurich; current Sociedade Brasileira de Matemática president Marcelo Viana from Brazil’s Instituto Nacional de Matemática Pura e Aplicada; and CIM president Alberto Adrego Pinto from the Universidade do Porto.

While the MPE program was a major focus of the CIM’s activities in 2013, the center also organized a number of further events aimed at fostering closer ties and collaboration between mathematicians and other scientists, mainly in Portugal and other Portuguese-speaking countries. In this context the CIM held the 92nd European Study Group with Industry meeting, part of a vital series held throughout Europe to encourage and strengthen the connections between mathematics and industry. As the MPE program made clear, humanity faces all manner of challenges, both man-made and natural, and though industry is attempting to overcome them, in many cases mathematics and science are far better suited to the task. Yet it is often industry that delivers the kinds of innovative ideas that will launch the next great scientific and technological revolutions, and which academia must adapt to. The potential for dialogue and cooperation between academia and industry is in fact so great that I have now made it one of the core initiatives in my presidency of the US-based Society for Industrial and Applied Mathematics (SIAM).

As we look back at the successful year the CIM had in 2013, we should also bear in mind the dramatic changes currently taking place in the world, changes that above all the mathematical sciences—including statistics, operational research, and computer science—will be called upon to address. Foremost among them is the rise of Big Data, especially as it relates to national security, finance, medicine, and the Internet (among other fields), which has come to dominate research in many scientific sectors and requires new analytical tools, which mathematics can provide. This new landscape will require an unparalleled level of partnership between science and industry, and is what prompted the European Commission to recently announce its Europe 2020 Growth Strategy, which calls for investment in groundbreaking research, innovation in industry, and the cultivation of a new generation of scientists. It is no coincidence that these three pillars are at the core of the CIM’s own mission, and the CIM series in Mathematical Sciences will provide the ideal platform for

communicating and broadening the impact of the CIM's activities with regard to these global challenges.

President of CIM Scientific Council

Irene Fonseca

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Bures-sur-Yvette, France
Zürich, Switzerland
Porto, Portugal
Rio de Janeiro, Brazil

Jean-Pierre Bourguignon
Rolf Jeltsch
Alberto Adrego Pinto
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