

## SIAM Minisymposium: From Global Predictions to Local Action

Organized by Inez Fung, Chris Jones and Mary Lou Zeeman

### Room 11A

Monday January 7, 2008: I: 8:00-11:00AM, II: 1:00-4:15PM, Room 11A

Tuesday January 8, 2008: III: 8:00-11:00AM, IV: 1:00-5:00PM, Room 11A

There is widespread agreement in the scientific community that the climate is warming. The prediction of specific events, however, raises many mathematical questions including the effect of sensitivity in the system, multiple scales and the quantification of uncertainty. This series of minisymposia will bring these issues into the open and initiate a discussion as to how the mathematics community can get involved and contribute to this critical area.

### Session I: Dynamical Systems Challenges in Climate Change

**Monday January 7, 2008: 8:00-11:00AM, Room 11A**

8:00-8:10AM	Welcome remarks and symposium goals
8:10-8:35AM	Emily Shuckburgh (1035-37-1423) <i>Addressing the key climate questions of the next few decades to inform adaptation strategies and policy.</i>
8:40-9:05AM	Amala Mahadevan (1035-00-2015) <i>Coupling between the carbon cycle and physical processes on multiple scales in the past and present.</i>
9:10-9:35AM	Gordon Swaters (1035-86-727) <i>Dynamics of grounded meridional abyssal flow.</i>
9:40-10:05AM	William Collins (1035-60-1976) <i>Scaling laws, scale invariance, and climate prediction.</i>
10:10-10:35AM	Eric Kostelich (1035-37-746) <i>A dynamical systems approach to weather forecasting and climate prediction.</i>
10:40-11:00AM	Round table discussion on outstanding problems in the field.

**SIAM Invited Address by Inez Fung, Monday January 7, 2008: 11:10-12:00PM, Room 6AB**

*From global predictions to local action: Mathematical challenges in global warming.*

### Session II: Mathematics of Social and Economic Feedback in Climate Change

**Monday January 7, 2008: 1:00-4:15PM, Room 11A**

The goal of this session is to begin a discussion between climate scientists, economists, and mathematicians to define a path towards the development of integrated economic and climate models. Please do come and join the discussion.

1:00-1:05PM	Welcome remarks.
1:05-1:30PM	Dave Stainforth <i>Climate Science for Decision Support</i>
1:30-1:50PM	Questions and Discussion

1:50-2:15PM	Max Auffhammer (1035-00-1677) <i>The Challenge of Measuring and Modeling the Economic Impacts of Climate Change.</i>
2:15-2:35PM	Questions and Discussion
2:35-3:00PM	Roy Radner (1035-91-1516) <i>Self-Enforcing Climate-Change Treaties.</i>
3:00-3:20PM	Questions and Discussion
3:20-3:45PM	Graciela Chichilnisky (1035-91-2021) <i>The Mathematics of Climate Change</i>
3:45-4:15PM	Questions and Discussion

**Session III: Working Groups and Round Table Discussion  
Tuesday January 8, 2008: 8:00-11:00AM, Room 11A**

This minisymposium follows on from Sessions I and II on Monday Jan. 7.

8:00-8:10AM	Welcome remarks.
8:10-8:35AM	Richard McGehee <i>The 2007 IPCC Report: A 20th Century Mathematician Ponders the 21st Century Predictions.</i>
8:45-11:00AM	We will summarize the outstanding problems in modeling climate change identified in the sessions so far, and form interdisciplinary break out groups to define steps on a path toward the development of integrated economic and climate models. We will conclude with a round table discussion of the ideas generated. A summary report will be produced. Please join us in this important task.

**Session IV: Working Groups and Panel Discussion  
Tuesday January 8, 2008: 1:00-5:00PM, Room 11A**

This minisymposium follows on from Sessions I, II and III.

1:00-1:05PM	Welcome remarks.
1:05-1:20PM	<b><i>NEW!!! Guest talk by California Congressman Jerry McNerney.</i></b> Dr. McNerney has a mathematics PhD, and is an expert in alternative energy engineering.
1:30-3:30PM	Questions and discussion, and continue to flesh out ideas generated in the previous sessions.
3:30-5:00PM	<i>Interdisciplinary Training.</i> Panel discussion with E. Kostelich, T. Pfaff, E. Shuckburgh, K.K. Tung and M.L. Zeeman on how to develop the interdisciplinary training required (at a variety of levels, from the undergraduate curriculum to established researchers) to tackle the wide variety of mathematical challenges in modeling climate change.

**Abstracts**  
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**Max Auffhammer:** *The Challenge of Measuring and Modeling the Economic Impacts of Climate Change.* The economic impacts of climate change are the net costs or benefits from such climatic change on the global economy relative to a world with constant climate. Economic impacts are usually measured relative to a "pre-industrial" average climate (1750-1850). Due to the lack of controlled experiments, economists employ statistical models on historically observed weather and climate in order to extract the climate response of e.g. agricultural yields, mortality rates and energy demand. These response functions are linked with global circulation models in order to simulate future values of these variables. In order to calculate impacts, one compares the observed outcomes to the simulated outcomes. The use of weather station data in estimation and climate model output in simulation creates potential biases in the estimated impacts. Further, predicted impacts suffer from potential overestimation, since they do not take into account agents' ability to adapt to a changed climate. In addition, existing simulation models only allow for very simplistic feedback mechanisms between the economy and future climate via emissions. Impacts of societal changes on other relevant physical aspects (e.g. albedo changes) are currently not taken into account.

**Graciela Chichilnisky:** *The Mathematics of Climate Change.* How to evaluate the risks of Climate Change, and more generally, how to plan and make sensible decisions for our long term future? The standard approach relies on three axioms and a representation theorem of Von Neumann, Morgenstern and Milnor that is widely used today. We show however that this approach ignores catastrophic risks in the long term future, such as the risks of global warming, and may be responsible for the inaction that led to the current environmental crisis. We update the classic axioms with more sensible axioms - and provide a new representation theorem that is sensitive to catastrophic risks in the long run future. We show that this approach can resolve the current global warming situation. In mathematical terms, we obtain a new type of functional not previously used in the calculus of variations, consisting of a convex combination of countable and purely finitely additive measures, and explore its practical consequences for making sensible decisions for our long run future.

**William Collins:** *Scaling laws, scale invariance, and climate prediction.* Climate models are based upon a discretization of the Navier Stokes equations. In the design of these models, one usually assumes that the physical processes are uniquely determined by and in statistical quasi-equilibrium with the fluid motion resolved by the model. This assumption was justifiable for previous generations of models with relatively coarse spatial and temporal resolution. However, the assumption is demonstrably incorrect for current and future climate codes. Although climate predictions should be invariant to the truncation scale of the underlying model, in fact the predictions may depend strongly on its spatial and temporal resolution. These results demonstrate the need for a fundamental change in the representation of physical processes in climate models. Future models should be based upon stochastic and auto-regressive formulations of physics that satisfy the basic scaling laws of the atmospheric and oceanic fluids.

**Eric Kostelich:** *A dynamical systems approach to weather forecasting and climate prediction.* This talk gives a survey of a model-independent approach to estimate initial conditions and parameters in chaotic spatiotemporal dynamical systems. This work, done in collaboration with researchers at the University of Maryland and elsewhere, has been applied successfully to state-of-the-art global weather forecast models and to models of coastal ocean flows. Work on applications to climate models is beginning. The talk will also describe an initiative at Arizona State University to provide advanced undergraduate and beginning graduate students in mathematics with experience using some of the computational tools that are necessary for research work involving geophysical modeling.

**Amala Mahadevan:** *Coupling between the carbon cycle and physical processes on multiple scales in the past and present.* The carbon cycle, an intrinsic part of the climate system, is driven and affected by physical and biological processes on a variety of space and time scales. Using examples from our climatic history, as well as our present understanding of the ocean, I will examine physical-biological coupling and climatic feedbacks on various scales. Problems arising due to multiple scales will be identified and modeling approaches will be discussed.

**Richard McGehee:** *The 2007 IPCC Report: A 20th Century Mathematician Ponders the 21st Century Predictions.* The Intergovernmental Panel on Climate Change (IPCC) issued its Fourth Assessment Report in the spring. Among its many pages are predictions for climate change during the 21st century, based on a variety of models of varying complexity. We examine these predictions, asking whether simpler models can be effective in predicting global variables.

**Roy Radner:** *Self-Enforcing Climate-Change Treaties.* In the absence of world government, a treaty to control the emissions of greenhouse gases should be self-enforcing. A self-enforcing treaty (SET) has the property that, if a country expects other countries to abide by the treaty, then it will be in its self-interest to abide by the treaty, too. (One objection to the Kyoto Protocol is that it does not appear to lay the groundwork for a SET.) A SET can be modeled as a Nash equilibrium of a suitably defined dynamic game. The game analyzed here represents the strategic interactions among a large number of sovereign countries of diverse sizes and economic capabilities. We describe a methodology for identifying the equilibria of such a game (typically there are many), as well as the global-Pareto-optimal trajectories (GPOs). We identify one of the equilibria, "Business as Usual" (BAU), with the current situation. The multiplicity of equilibria provides an opportunity to move from the inefficient BAU to one or more equilibria that are Pareto superior. Using a calibrated model with 184 countries, we give numerical illustrations of BAU and GPO trajectories, and estimate the potential welfare gains from a SET. We also describe the mathematical and computational difficulties in extending the model to be more realistic.

**Emily Shuckburgh:** *Addressing the key climate questions of the next few decades to inform adaptation strategies and policy.* As the reality of future climate change becomes more accepted, stakeholders (be they governments, special-interest groups, businesses or individuals) are starting to ask detailed questions about climate change predictions to inform their adaptation strategies, as well as policy. These questions, which are necessarily location and weather-variable specific, push at the limits of our prediction capabilities. There is an increasing pressure on climate scientists to provide ever more detailed regional-scale predictions, to couple climate models with socio-economic and/or ecosystem models, and to provide quantification of the uncertainty of the predictions. In this talk I will review some of the current developments in climate modeling, focusing on predictions of the next few decades. I will highlight some of the challenges to providing answers to the questions outlined above, and indicate where lessons from dynamical systems research may provide useful input.

**Dave Stainforth:** *Climate Science for Decision Support.* The widespread acceptance of anthropogenic climate change as a serious global problem has led to significant interest and investment in adaptation strategies. Governments, businesses and individuals all look to climate science to provide predictions of the future on which to base their plans. In this context I will discuss some of the following questions: What are the significant sources of uncertainty in model based forecasts? How do we judge the relevance of model based, extrapolatory forecasts for decision support? How can we optimize modeling experiments for decision support and/or physical understanding and/or model development? How should we interpret multi-model ensembles? How can we optimize the exploration of model/parameter space given constraints on computational capacity? Given the current limited exploration of uncertainty in model based predictions, how can we communicate today's results in such a way that tomorrow's are accepted as a valuable advance?

**Gordon Swaters:** *Dynamics of grounded meridional abyssal flow.* On the planetary scale, Earth's ocean circulation is composed of the wind-driven surface intensified currents that transport warm equatorial water toward the Polar Regions and the buoyancy-driven deep or abyssal currents that transport cold/dense water produced by atmospheric cooling in the high latitudes back toward the equator and beyond. This circulation pattern corresponds to the global scale convective overturning of the oceans. From the perspective of climate dynamics, this large scale flow plays an important role in how equatorial heat is transported poleward. In this talk I will try to explain the underlying dynamical balances at play in the meridional flow of grounded abyssal currents including source-driven equatorward flow (Stommel-Arons dynamics), topographic-steered geostrophic flow (Nof dynamics), baroclinic instability and western intensification (planetary shock-wave balance) within the context of multilayer shallow water theory.