

# Final Program



**SEPTEMBER 13–15, 2018**

**DoubleTree by Hilton Hotel  
Philadelphia Center City  
Philadelphia, Pennsylvania, USA**

*Sponsored by the SIAM Activity Group on Mathematics of Planet Earth.*

Climate change, biodiversity, infectious diseases, sustainability, energy, food, and water are among the areas of greatest global concern. The SIAM Activity Group on Mathematics of Planet Earth (SIAG/MPE) provides a forum for mathematicians and computational scientists engaged in these critical priority areas. The interests of SIAG/MPE span the range from developing quantitative techniques to providing policy makers with tools for qualitative decision support.

**siam** | Society for Industrial and  
Applied Mathematics

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## Organizing Committee

### Co-Chairs

#### Hans Engler

Georgetown University, USA

#### Eleanor Jenkins

Clemson University, USA

## Organizing Committee

#### Emil Constantinescu

Argonne National Laboratory, USA

#### Pedro Gajardo

Universidad Técnica Federico Santa María,  
Chile

#### Kathleen Kavanagh

Clarkson University, USA

## Conference Themes

Planet Earth as a physical system:  
climate dynamics, oceans, atmosphere,  
cryosphere, earth and space

Planet Earth as a system supporting life:  
mathematical ecology, carbon cycle, food  
systems, natural resources, sustainability

Planet Earth as a system organized by  
humans: land use, energy, communication,  
transportation, socio-economics

Planet Earth as a system at risk: global  
change, biodiversity, water, food security,  
epidemics, extreme events

## SIAM Registration Desk

The SIAM registration desk is located in the Aria B Room on the 3rd Floor. It is open during the following hours:

Wednesday, September 12

5:30 PM - 8:00 PM

Thursday, September 13

7:45 AM - 4:30 PM

Friday, September 14

8:15 AM - 4:30 PM

Saturday, September 15

8:00 AM - 10:30 AM

## Hotel Address

### DoubleTree by Hilton Hotel

Philadelphia Center City  
237 South Broad Street  
Philadelphia, PA 19107-5686

## Hotel Telephone Number

To reach an attendee or leave a message, call +1-215-893-1600. If the attendee is a hotel guest, the hotel operator can connect you with the attendee's room.

## Hotel Check-in and Check-out Times

Check-in time is 4:00 PM.  
Check-out time is 11:00 PM.

## Child Care

Attendees are responsible for making their own child care arrangements.

The Philadelphia Nanny Network  
<http://www.nannyagency.com/>

Your Other Hands  
(215) 790-0990

Kindercare Learning Centers  
[www.kindercare.com](http://www.kindercare.com)

Gills Babysitting Agency  
(215) 533-5366

Sitter City  
<https://www.sittercity.com/babysitters/pa/philadelphia.html>

## Corporate Members and Affiliates

SIAM corporate members provide their employees with knowledge about, access to, and contacts in the applied mathematics and computational sciences community through their membership benefits. Corporate membership is more than just a bundle of tangible products and services; it is an expression of support for SIAM and its programs. SIAM is pleased to acknowledge its corporate members and sponsors. In recognition of their support, non-member attendees who are employed by the following organizations are entitled to the SIAM member registration rate.

## Corporate/Institutional Members

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Bechtel Marine Propulsion Laboratory

The Boeing Company

CEA/DAM

Department of National Defence (DND/CSEC)

DSTO- Defence Science and Technology Organisation

Exxon Mobil

Hewlett-Packard

Huawei FRC French R&D Center

IBM Corporation

IDA Center for Communications Research, La Jolla

IDA Center for Communications Research, Princeton

IFP Energies nouvelles

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Lawrence Berkeley National Laboratory  
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 Los Alamos National Laboratory  
 Max-Planck-Institute for Dynamics of  
 Complex Technical Systems  
 Mentor Graphics  
 National Institute of Standards and  
 Technology (NIST)  
 National Security Agency (DIRNSA)  
 Naval PostGrad  
 Oak Ridge National Laboratory,  
 managed by UT-Battelle for the  
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 Sandia National Laboratories  
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 US Naval Research Labs  
*List current July 2018.*

## Join SIAM and save!

### ***Leading the applied mathematics community . . .***

SIAM members save up to \$140 on full registration for the 2018 SIAM Conference on Mathematics of Planet Earth! Join your peers in supporting the premier professional society for applied mathematicians and computational scientists. SIAM members receive subscriptions to *SIAM Review*, *SIAM News* and *SIAM Unwrapped*, and enjoy substantial discounts on SIAM books, journal subscriptions, and conference registrations.

If you are not a SIAM member and paid the *Non-Member* or *Non-Member Mini Speaker/Organizer* rate to attend the conference, you can apply the difference between what you paid and what a member would have paid (\$140 for a *Non-Member* and \$70 for a *Non-Member Mini Speaker/Organizer*)

towards a SIAM membership. Contact SIAM Customer Service for details or join at the conference registration desk.

If you are a SIAM member, it only costs \$15 to join the SIAM Activity Group on Mathematics of Planet Earth (SIAG/MPE). As a SIAG/MPE member, you are eligible for an additional \$15 discount on this conference, so if you paid the SIAM member rate to attend the conference, you might be eligible for a free SIAG/MPE membership. Check at the registration desk.

Free Student Memberships are available to students who attend an institution that is an Academic Member of SIAM, are members of Student Chapters of SIAM, or are nominated by a Regular Member of SIAM.

Join onsite at the registration desk, go to <https://www.siam.org/Membership/Join-SIAM> to join online or download an application form, or contact SIAM Customer Service:

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## Standard Audio-Visual Set-Up in Meeting Rooms

SIAM does not provide computers for any speaker. When giving an electronic presentation, speakers must provide their own computers. SIAM is not responsible for the safety and security of speakers' computers.

A data (LCD) projector and screen will be provided in all technical session meeting rooms. The data projectors support both VGA and HDMI connections. Presenters requiring an alternate connection must provide their own adaptor.

## Internet Access

Attendees booked within the SIAM room block will receive complimentary wireless internet access in their guest rooms of the hotel. All conference attendees will have complimentary wireless Internet access in the meeting space of the hotel.

SIAM will also provide a limited number of email stations.

## Registration Fee Includes

- Admission to all technical sessions
- Business Meeting (*open to SIAG/MPE members*)
- Coffee breaks daily
- Room set-ups and audio/visual equipment
- Poster Sessions
- Welcome Reception

## Job Postings

Please check with the SIAM registration desk regarding the availability of job postings or visit <https://jobs.siam.org/>.

## Poster Participant Information

The poster sessions will take place during both coffee breaks on Thursday, September 13. The morning coffee break is scheduled from 9:30 AM – 10:00 AM; the afternoon break is scheduled for 3:30 PM – 4:00 PM. Poster presenters must set-up their poster material on the 4' x 8' poster boards in the Overture and Balcony areas on the 3rd Floor after 7:00 PM on Wednesday, September 12. All materials must be posted by 9:30 AM on Thursday, September 13, the official start time of the sessions. **Posters must be removed by Friday, September 14 at 10:00 AM.**

## SIAM Books and Journals

Display copies of books and complimentary copies of journals are available on site. SIAM books are available at a discounted price during

the conference. The books booth will be staffed from 9:00 AM through 5:00 PM on Thursday and Friday. If a SIAM books representative is temporarily away from the booth, completed order forms and payment (credit cards are preferred) may be taken to the SIAM registration desk. The books table will close at 5:00 PM on Friday.

## Table Top Displays

SIAM  
Springer

## Name Badges

A space for emergency contact information is provided on the back of your name badge. Help us help you in the event of an emergency!

## Comments?

Comments about SIAM meetings are encouraged! Please send to: Cynthia Phillips, SIAM Vice President for Programs ([vpp@siam.org](mailto:vpp@siam.org)).

## Get-togethers

Wednesday, September 12  
Welcome Reception  
6:00 PM – 8:00 PM

*Restaurant or Pool Deck (weather permitting)*



Thursday, September 13  
Poster Sessions  
9:30 AM – 10:00 AM and  
3:30 PM – 4:00 PM

*Overture and Balcony - 3rd Floor*



Saturday, September 15  
Business Meeting (*open to SIAG/MPE members*)

8:00 AM – 8:30 AM  
Symphony Ballroom - 3rd Floor  
*Refreshments will be served.*



## Statement on Inclusiveness

As a professional society, SIAM is committed to providing an inclusive climate that encourages the open expression and exchange of ideas, that is free from all forms of discrimination,

harassment, and retaliation, and that is welcoming and comfortable to all members and to those who participate in its activities. In pursuit of that commitment, SIAM is dedicated to the philosophy of equality of opportunity and treatment for all participants regardless of gender, gender identity or expression, sexual orientation, race, color, national or ethnic origin, religion or religious belief, age, marital status, disabilities, veteran status, field of expertise, or any other reason not related to scientific merit. This philosophy extends from SIAM conferences, to its publications, and to its governing structures and bodies. We expect all members of SIAM and participants in SIAM activities to work towards this commitment.

## Please Note

SIAM is not responsible for the safety and security of attendees' computers. Do not leave your laptop computers unattended. Please remember to turn off your cell phones, pagers, etc. during sessions.

## Recording of Presentations

Audio and video recording of presentations at SIAM meetings is prohibited without the written permission of the presenter and SIAM.

## Social Media

SIAM is promoting the use of social media, such as Facebook and Twitter, in order to enhance scientific discussion at its meetings and enable attendees to connect with each other prior to, during and after conferences. If you are tweeting about a conference, please use the designated hashtag to enable other attendees to keep up with the Twitter conversation and to allow better archiving of our conference discussions. The hashtag for this meeting is #MPE18. SIAM's Twitter handle is @TheSIAMNews.

## Changes to the Printed Program

The printed program was current at the time of printing, however, please review the online program schedule ([http://meetings.siam.org/program.cfm?CONF\\_CODE=pe18](http://meetings.siam.org/program.cfm?CONF_CODE=pe18)) or use the mobile app for up-to-date information.

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You can also visit [www.tripbuildermedia.com/apps/siamevents](http://www.tripbuildermedia.com/apps/siamevents)

## Minitutorials

*Minitutorials will take place in Symphony Ballroom - 3rd Floor.*

### Thursday, September 13

10:00 AM - 12:30 PM

MT1 Providing Interdisciplinary Undergraduate Experiences on  
Earth-based Applications

**Organizers:**

Kathleen Kavanagh, *Clarkson University, USA*

Joseph Skufca, *Clarkson University, USA*

### Thursday, September 13

1:30 PM - 3:30 PM

MT2 Solving Environmental Uncertainty Quantification Problems with  
the MIT Uncertainty Quantification Library

**Organizer:**

Matthew Parno, *US Army Corps of Engineers, USA*

## Invited Plenary Speakers

*Invited Plenary Presentations will take place in Symphony Ballroom - 3rd Floor.*

### Thursday, September 13

**8:45 AM - 9:30 AM**

**IP1** Where Water Meets Land: The Mathematics of the Coastal Ocean

**Clint Dawson**, *University of Texas at Austin, USA*

### Friday, September 14

**8:45 AM - 9:30 AM**

**IP2** Optimal Control Techniques Applied to Management of Natural Resource Models

**Suzanne M. Lenhart**, *University of Tennessee, Knoxville, USA and National Institute for Mathematical and Biological Synthesis, USA*

**4:00 PM - 4:45 PM**

**IP3** Insights from Studying the Interface Between Sentience and Sociability in Animal Movement Patterns

**Bertrand Lemasson**, *US Army Corps of Engineers, USA*

### Saturday, September 15

**8:45 AM - 9:30 AM**

**IP4** How Energy Optimization is Responding to the Challenge of Decarbonizing Our Economies

**Claudia Sagastizabal**, *UNICAMP, Brazil*



# **SIAM Activity Group on Mathematics of Planet Earth (SIAG/MPE)**

**[HTTPS://WWW.SIAM.ORG/MEMBERSHIP/ACTIVITY-GROUPS/DETAIL/MATHEMATICS-OF-PLANET-EARTH](https://www.siam.org/membership/activity-groups/detail/mathematics-of-planet-earth)**

The purpose of the SIAM Activity Group on Mathematics of Planet Earth is to provide a forum for mathematicians and computational scientists to study Planet Earth, its life-supporting capacity, and the impact of human activities.

## **ACTIVITIES INCLUDE:**

- Special sessions at SIAM Annual Meetings
- Biennial conference

## **BENEFITS OF SIAG/MPE MEMBERSHIP:**

- Listing in the SIAG's online-only membership directory
- Additional \$15 discount on registration for the SIAM Conference on Mathematics of Planet Earth (excludes student)
- Electronic communications about recent developments in your specialty
- Eligibility for candidacy for SIAG/MPE office
- Participation in the selection of SIAG/MPE officers

## **ELIGIBILITY:**

- Be a current SIAM member

## **COST:**

- \$15 per year
- Student members can join two activity groups for free!

## **2017-18 SIAG/MPE OFFICERS:**

- Chair: Hans Engler, Georgetown University
- Vice-chair: Kathleen Kavanagh, Clarkson University
- Secretary: Eleanor Jenkins, Clemson University
- Program Director: Pedro Gajardo, Universidad Tecnica Federico Santa Maria

## **TO JOIN:**

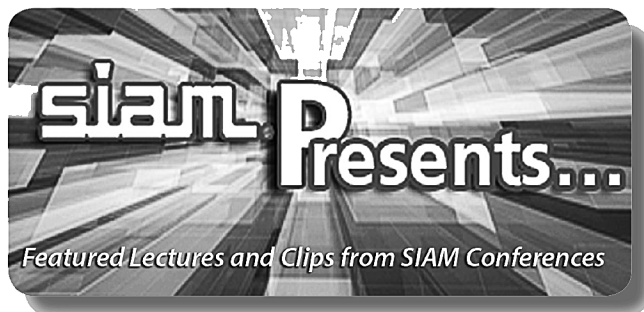
**SIAG/MPE:** [my.siam.org/forms/join\\_siag.htm](https://my.siam.org/forms/join_siag.htm)

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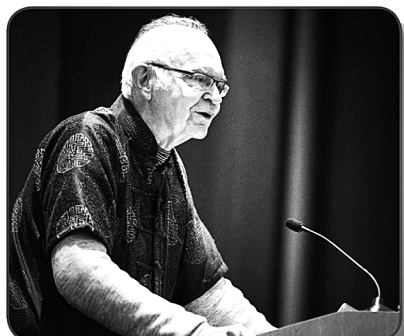


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- algebraic geometry
- atmospheric and oceanographic science
- computational science
- data mining
- geophysical science
- optimization
- uncertainty quantification and more...

The collection, *Featured Lectures from our Archives*, includes audio and slides from more than 30 conferences since 2008, including talks by invited and prize speakers, select minisymposia, and minitutorials. Presentations from SIAM meetings are being added throughout the year.



In addition you can view short video clips of speaker interviews from sessions at Annual Meetings starting in 2010.

Plans for adding more content are on the horizon. Keep an eye out!

The audio, slide, and video presentations are part of SIAM's outreach activities to increase the public's awareness of mathematics and computational science in the real world, and to bring attention to exciting and valuable work being done in the field. Funding from SIAM, the National Science Foundation, and the Department of Energy was used to partially support this project.



New presentations are posted every few months as the program expands with sessions from additional SIAM meetings. Users can search for presentations by category, speaker name, and/or key words.

[www.siam.org/meetings/presents.php](http://www.siam.org/meetings/presents.php)



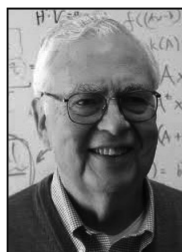
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# Gene Golub g2s3 2019 SIAM Summer School

**June 17-28, 2019  
Aussois, France**

## HIGH PERFORMANCE DATA ANALYTICS



The tenth Gene Golub SIAM Summer School will take place in France, at the Paul Langevin conference center in Aussois, in the French Alps.

The focus of the school will be on large-scale data analytics, which lies at the intersections of data analytics algorithms and high performance computing. Students will be introduced to problems in data analytics arising from both the machine learning and the scientific computing communities. The school will include perspectives from industry, such as Amazon, Google, and IBM, as well as from academic instructors.

Students will be exposed to “end-to-end” multidisciplinary topics, which span several traditionally disparate areas. The series of lectures will develop background on methods and algorithms for data analytics, approximation algorithms to deal with large volumes of data, languages and tools for implementing those algorithms on large scale computers, and data-driven applications from scientific computing and machine learning.

The summer school is being organized by Laura Grigori (Inria and Sorbonne University), Matthew Knepley (University at Buffalo) Olaf Schenk (Università della Svizzera Italiana), and Rich Vuduc (Georgia Institute of Technology).

The intended audience is intermediate graduate students (students with a Master’s degree, 2nd-3rd year Ph.D. students without an MS, or equivalent). Applicants selected to participate pay no registration fee. Funding for local accommodations and meal expenses will be available for all participants.

### Application deadline: February 1, 2019

As information becomes available on how to apply, it will be posted at:

**<http://www.siam.org/students/g2s3/>**



*Sponsored by SIAM through an endowment from the estate of Gene Golub.*

*For more information about prior summer schools and Professor Gene Golub go to*

**<http://www.siam.org/students/g2s3/>**

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## Program Schedule



**SEPTEMBER 13–15, 2018**

**DoubleTree by Hilton Hotel  
Philadelphia Center City  
Philadelphia, Pennsylvania, USA**

## Wednesday, September 12

### Registration

5:30 PM-8:00 PM

Room: Aria B - 3rd Floor

### Welcome Reception

6:00 PM-8:00 PM

Room: Restaurant or Pool Deck  
(weather permitting)



## Thursday, September 13

### Registration

7:45 AM-4:30 PM

Room: Aria B - 3rd Floor

### Opening Remarks

8:30 AM-8:45 AM

Room: Symphony Ballroom - 3rd Floor

Thursday, September 13

## IP1

### Where Water Meets Land: The Mathematics of the Coastal Ocean

8:45 AM-9:30 AM

Room: Symphony Ballroom - 3rd Floor

Chair: Darryl D. Holm, Imperial College  
London, United Kingdom and Los Alamos  
National Laboratory, USA

Coastal regions around the world are home to millions of people. These regions are economic engines and hold delicate ecosystems. However, as we have seen in the past decade or so, they are under threat from a variety of factors, including a combination of hazardous events, climate change, and over-development. In this talk, we will focus on problems related to water at the coast: the interaction of the ocean with land, the impacts of tropical storms and hurricanes, and our attempts at protecting coastal populations while facing the realities of an uncertain future. We will describe mathematical challenges and model and data driven studies to better understand these challenges.

Clint Dawson

University of Texas at Austin, USA

Thursday, September 13

## PP1

**Coffee Break and Poster Session \*\*Posters will be on display during both Thursday coffee breaks\*\***

9:30 AM-10:00 AM

*Room: Overture and Balcony - 3rd Floor*

**Detecting Spatiotemporal Critical Transitions, "Information-Theoretic Catastrophe Alarm"**

*Abd Almomani, Clarkson University, USA*

**A Generalized Stefan Problem Exhibiting Two Moving Boundaries with Application to the Evolution of Fluvial Deltas under Sea-Level Change**

*William M. Anderson and Jorge Lorenzo-Trueba, Montclair State University, USA; Vaughan Voller, University of Minnesota, USA*

**Krylov Subspace Spectral Methods for Navier-Stokes**

*Brianna D. Bingham and James V. Lambers, University of Southern Mississippi, USA*

**Data-Driven Modeling of Phytoplankton Blooms in the Ocean**

*Seth Cowall, Pamela Cook, and Matthew Oliver, University of Delaware, USA*

**Epidemic Spread on Networks Emphasizing Household Size**

*Bree Cummins and Will Dumm, Montana State University, USA*

**Effects of Brine Inclusions and Crystallographic Anisotropy on the Rheological Response of Sea Ice**

*Shuvrangs Das and Pedro Ponte Castañeda, University of Pennsylvania, USA*

**Assessing the Health of Tampa Bay Through a Time Series Analysis of the Cpue**

*Leslie Jones and Bridgette Froeschke, University of Tampa, USA*

**Modelling the Enzootic Cycle of the Black-Legged Tick and *Borrelia burgdorferi***

*Nick Painter, Clarkson University, USA*

**On the Interactions Between Topography, Land-Sea Contrast and Diurnal Cycle During the Passage of An Mjo Event in the Maritime Continent**

*Pallav Ray and Haochen Tan, Florida Institute of Technology, USA; Brad Barrett, United States Naval Academy, USA*

**Vector-Valued Spectral Analysis of Indo-Pacific Ocean Variability**

*Joanna Slawinska, University of Wisconsin, Milwaukee, USA; Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, USA*

**An Iterative Coupling Scheme in Modeling Rate and State Dynamic Ruptures in the Self-Gravitational Prestressed Earth**

*Ruichao Ye and Maarten de Hoop, Rice University, USA; Kundan Kumar, University of Bergen, Norway; Michel Campillo, Universite Joseph Fourier, France*

**A Dynamical Systems Approach to the Pleistocene Climate**

*Hans Engler and Hans G. Kaper, Georgetown University, USA; Tasso J. Kaper, Boston University, USA; Theodore Vo, Florida State University, USA*

Thursday, September 13

## MT1

**Providing Interdisciplinary Undergraduate Experiences on Earth-based Applications**

10:00 AM-12:00 PM

*Room: Symphony Ballroom - 3rd Floor*

*Chair: Kathleen Kavanagh, Clarkson University, USA*

*Chair: Joseph Skufca, Clarkson University, USA*

Engaging undergraduate students in applications of the Mathematics of Planet Earth (MPE) and providing them with research and learning experiences can have countless beneficial outcomes. However, challenges for both the faculty and students naturally arise due to the interdisciplinary nature of the underlying problems. Tackling such problems on a variety of different levels involves modeling, scientific computing, a wide range of mathematical skills, and a willingness to dive into (possibly) unfamiliar disciplines. In this session, Earth-based student-driven projects are presented that have been implemented in the classroom or as extended research projects to demonstrate the various content levels that can be included. These examples span large-scale first year Calculus courses to capstone research projects. Topics include analysis of electrical use in green houses, sustainable farming practices, modeling invasive species, melting sea ice, lyme disease, leaf respiration, solar energy systems, and many more. Challenges, success, and failures are shared to outline some pointers for best practices, getting started, and making the most out of these experiences for everyone involved. The session will conclude with time for a round-table type discussion about developing, implementing, and assessing these types of activities.

*Speakers:*

*Kathleen Kavanagh, Clarkson University, USA*

*Joseph Skufca, Clarkson University, USA*

*continued in next column*

Thursday, September 13

## MS1

### **Sustainable Management of Renewable Resources, Ecosystems, and Biodiversity - Part I of II**

10:00 AM-12:00 PM

*Room: Aria A - 3rd Floor*

#### **For Part 2 see MS5**

Operationalizing sustainability is a major challenge in terms of objectives, quantitative methods and criteria in particular for the management of renewable resources and biodiversity. Is it a matter of equilibrium, of optimal control or viability? This minisymposium aims at presenting and discussing the merits of different mathematical and modeling approaches relating to the sustainable management of renewable resources, ecosystems and biodiversity with a particular interest in applications to fisheries, farming or forest land-uses or water resources.

Organizer: Luc Doyen

*University of Bordeaux, France*

Organizer: Pedro Gajardo

*Universidad Técnica Federico Santa María, Chile*

#### **10:00-10:25 Set of Sustainable Thresholds: An Approach to Operationalize Sustainability Definitions**

*Pedro Gajardo, Universidad Técnica Federico Santa María, Chile*

#### **10:30-10:55 Viability with Multiple Budget Constraints: Theory and Numerical Applications**

*Anna Desilles, ENSTA ParisTech, France*

#### **11:00-11:25 Optimal Harvesting Strategies for Timber and Non-Timber Forest Products in Tropical Systems**

*Orou G. Gaoue, University of Tennessee, USA*

#### **11:30-11:55 Socio-Ecological Model for Sustainable Development Based on SEIC and Complex Networks**

*Rafael R. Rentería-Ramos, University of Pereira, Colombia; Gerard Olivar Tost, Universidad Nacional de Colombia, Colombia; J. David Tàbara, University Autònoma de Barcelona, Spain*

Thursday, September 13

## MS2

### **Challenges in Environmental Remote Sensing - Part I of II**

10:00 AM-12:00 PM

*Room: Concerto A - 3rd Floor*

#### **For Part 2 see MS6**

To address the open mathematical and statistical challenges posed in the study of the Earth system, the Statistical and Applied Mathematical Sciences Institute (SAMSI, [www.samsi.info](http://www.samsi.info)) has organized a 2017-2018 Program on Mathematical and Statistical Methods for Climate and the Earth System. Amongst the many working groups formed by the program, the Remote Sensing working group's goal is to explore new problems in the analysis of large remote sensing data sets, and to develop appropriate quantitative theory, methods, and algorithms for solving these problems. In this session, updates will be provided on progress of research for a number of important topics as they relate to remote sensing retrievals including: spatial statistics, optimization methods, emulators, and the theory of data systems. In addition, specific quantitative applications of remote sensing data for monitoring and analytical purposes will be presented.

Organizer: Jessica Matthews

*Cooperative Institute of Climate and Satellites, USA*

#### **10:00-10:25 Theory, Methods, and Algorithms in Remote Sensing Science**

*Amy Braverman, California Institute of Technology, USA*

#### **10:30-10:55 A Notional Framework for a Theory of Data Analysis Systems**

*Maggie Johnson, North Carolina State University, USA; Amy Braverman, California Institute of Technology, USA; Brian Reich, North Carolina State University, USA; Snigdhasu Chatterjee, University of Minnesota, USA; Zhengyuan Zhu, Iowa State University, USA; Bruno Sanso and Isabelle Grenier, University of California, Santa Cruz, USA; James Rosenberger, Pennsylvania State University, USA; Alexandra Burden, University of Wollongong, Australia*

#### **11:00-11:25 Statistical Approaches for Un-Mixing Problem and Application to Satellite Remote Sensing Data**

*Zhengyuan Zhu and Colin Lewis-Beck, Iowa State University, USA; Jonathan Hobbs, Jet Propulsion Laboratory, California Institute of Technology; Anirban Mondal, Case Western Reserve University, USA; Joon Jin Song, Baylor University, USA; Jenny Brynjarsdottir, Case Western Reserve University, USA; Maggie Johnson, North Carolina State University, USA; Xinyue Chang, Iowa State University, USA*

#### **11:30-11:55 Optimization Methods in Remote Sensing**

*Jessica Matthews, Cooperative Institute of Climate and Satellites, USA*

*continued in next column*



Thursday, September 13

## MS3

### Statistics of Extreme Weather and Climate Events

10:00 AM-12:00 PM

Room: Concerto B - 3rd Floor

Extreme value theory is a well-established branch of statistics that has been greatly extended in recent years, especially in the field of spatial statistics and the class of stochastic processes known as max-stable processes. New applications of this theory are being developed all the time, but especially with reference to weather and climate extremes. This session will feature new developments in both theory and applications. Richard Smith will review models for precipitation extremes motivated by Hurricane Harvey, with particular reference to the increasing probabilities of such events due to climate change. Whitney Huang will present a complementary viewpoint on such problems by presenting new methods for storm surge assessment with applications to coastal hazard assessment. Bo Li will present new methods for large spatial extremes using the fused lasso method and the bootstrap. Finally, Ben Shaby will present stochastic models for extreme events in space that are flexible enough to transition across different classes of extremal dependence, and permit inference through likelihood functions that can be computed for large datasets, by representing stochastic dependence relationships conditionally to induce desirable tail dependence properties and to allow efficient inference through Markov chain Monte Carlo. The whole session will illustrate the interplay between theory and applications that is characteristic of modern environmental statistics.

Organizer: Richard L. Smith  
University of North Carolina, Chapel Hill,  
USA

### 10:00-10:25 Influence of Climate Change on Extreme Weather Events

Richard L. Smith, University of North Carolina, Chapel Hill, USA

### 10:30-10:55 Estimating Extreme Storm Surge Levels: A Statistical Perspective

Whitney Huang, Statistical and Applied Mathematical Sciences Institute, USA;  
Richard L. Smith and Brian Blanton, University of North Carolina, Chapel Hill, USA; Rick Luetlich, University of North Carolina, Moorehead City, USA; Taylor Asher, University of North Carolina, USA

### 11:00-11:25 Return Level Estimation for Large Spatial Extremes

Bo Li, University of Illinois, USA

### 11:30-11:55 Max-Infinitely Divisible Models for Spatial Extremes Using Random Effects

Benjamin Shaby, Pennsylvania State University, USA; Raphael Huser, KAUST Supercomputing Laboratory, Saudi Arabia; Gregory Bopp, Pennsylvania State University, USA

Thursday, September 13

## MS4

### Numerical Methods for Weather, Oceans and Climate - Part I of II

10:00 AM-12:00 PM

Room: Rhapsody - 4th Floor

#### For Part 2 see MS13

This minisymposium will cover current research topics in numerical methods for oceans weather and climate. Specific focus areas are: \* Finite difference, finite element and finite volume methods for atmosphere and ocean dynamical cores \* Unstructured and adaptive numerics for simulations bridging physical scales \* Conservation properties of numerical schemes \* Coupling dynamical and physical processes in numerical simulations

Organizer: Colin J. Cotter  
Imperial College London, United Kingdom

Organizer: Mark A. Taylor  
Sandia National Laboratories, USA

### 10:00-10:25 Climate Modeling with the Spectral-Element Method

Peter H. Lauritzen, National Center for Atmospheric Research, USA

### 10:30-10:55 Moving Meshes for Atmospheric Modelling over Orography

Hiroe Yamazaki and Hilary Weller, University of Reading, United Kingdom

### 11:00-11:25 Multidimensional Tracer Transport in Atmospheric Models

James Kent, University of South Wales, United Kingdom

### 11:30-11:55 Breaking the Boundary Between "Dynamics" and "Physics" in the Gray-Zone

Shian-Jiann Lin, National Oceanic and Atmospheric Administration, USA

*continued in next column*

Thursday, September 13

**CP1****Computational Methods for MPE Applications**

10:00 AM-12:00 PM

*Room: Minuet - 4th Floor**Chair: Haley Dozier, University of Southern Mississippi, USA***10:00-10:15 Shadowing for Data Assimilation with Imperfect Models***Bart M. de Leeuw and Svetlana Dubinkina, Centrum voor Wiskunde en Informatica (CWI), Netherlands***10:20-10:35 Krylov Subspace Spectral Methods with Coarse Grid Residual Correction for Time Dependent Partial Differential Equations***Haley Dozier and James V. Lambers, University of Southern Mississippi, USA***10:40-10:55 Iterative Multi-Level Spectral Deferred Correction Scheme for the Shallow-Water Equations on the Rotating Sphere***Francois Hamon, Lawrence Berkeley National Laboratory, USA; Martin Schreiber, University of Exeter, United Kingdom; Michael Minion, Lawrence Berkeley National Laboratory, USA***11:00-11:15 Simulation of Earthquakes with Self-Gravitation and Rotation Based on Discontinuous Galerkin Method***Ruichao Ye and Maarten de Hoop, Rice University, USA; Rob van der Hilst, Massachusetts Institute of Technology, USA***11:20-11:35 Dynamics of Orbits Near Multiple Lunisolar Secular Resonances***Jessica Pillow and Aaron Rosengren, University of Arizona, USA***11:40-11:55 Massively Parallel Computation of Earth's Normal Modes***Jia Shi, Rice University, USA; Ruipeng Li, Lawrence Livermore National Laboratory, USA; Yuanzhe Xi and Yousef Saad, University of Minnesota, USA; Maarten de Hoop, Rice University, USA***Lunch Break**

12:00 PM-1:30 PM

*Attendees on their own*

Thursday, September 13

**MT2****Solving Environmental Uncertainty Quantification Problems with the MIT Uncertainty Quantification Library**

1:30 PM-3:30 PM

*Room: Symphony Ballroom - 3rd Floor**Chair: Matthew Parno, US Army Corps of Engineers, USA*

Mathematical and numerical models are critical tools in the study of planet earth. However, even the most complicated models are approximations of reality and care must be taken when making real decisions based on model analysis. Formal uncertainty quantification (UQ) can help better inform decisions by statistically capturing the impact of model, parameter, and numerical uncertainties. This minitutorial will start with an overview of the broader UQ landscape before delving into a simple case study based on the heat equation. Various aspects of forward and inverse UQ will be discussed, with a focus on sampling methods like Monte Carlo, Markov chain Monte Carlo, and multi-fidelity Monte Carlo. Live demonstrations will be provided with the MIT Uncertainty Quantification library and code will be provided for attendees to follow along in real time.

*Speaker:**Matthew Parno, US Army Corps of Engineers, USA*

Thursday, September 13

**MS5****Sustainable Management of Renewable Resources, Ecosystems, and Biodiversity - Part II of II**

1:30 PM-3:00 PM

*Room: Aria A - 3rd Floor***For Part I see MS1**

Operationalizing sustainability is a major challenge in terms of objectives, quantitative methods and criteria in particular for the management of renewable resources and biodiversity. Is it a matter of equilibrium, of optimal control or viability? This minisymposium aims at presenting and discussing the merits of different mathematical and modeling approaches relating to the sustainable management of renewable resources, ecosystems and biodiversity with a particular interest in applications to fisheries, farming or forest land-uses or water resources.

**Organizer: Luc Doyen***University of Bordeaux, France***Organizer: Pedro Gajardo***Universidad Técnica Federico Santa María, Chile***1:30-1:55 The Tragedy of Open Ecosystems***Luc Doyen, University of Bordeaux, France***2:00-2:25 A Fishery Model for Harvesting of the Black Sea Anchovy on the South Coast of the Black Sea***Mahir Demir, University of Tennessee, USA***2:30-2:55 Bioremediation of Water Resources: An Optimal Control Approach***Hector Ramirez, Universidad de Chile, Chile*

Thursday, September 13

## MS6

### Challenges in Environmental Remote Sensing - Part II of II

1:30 PM-3:30 PM

Room: Concerto A - 3rd Floor

#### For Part 1 see MS2

To address the open mathematical and statistical challenges posed in the study of the Earth system, the Statistical and Applied Mathematical Sciences Institute (SAMSI, [www.samsi.info](http://www.samsi.info)) has organized a 2017-2018 Program on Mathematical and Statistical Methods for Climate and the Earth System. Amongst the many working groups formed by the program, the Remote Sensing working group's goal is to explore new problems in the analysis of large remote sensing data sets, and to develop appropriate quantitative theory, methods, and algorithms for solving these problems. In this session, updates will be provided on progress of research for a number of important topics as they relate to remote sensing retrievals including: spatial statistics, optimization methods, emulators, and the theory of data systems. In addition, specific quantitative applications of remote sensing data for monitoring and analytical purposes will be presented.

Organizer: Jessica Matthews  
*Cooperative Institute of Climate and Satellites, USA*

#### 1:30-1:55 Statistical Emulation with Dimension Reduction for Complex Physical Forward Models

*Emily L. Kang, University of Cincinnati, USA*

#### 2:00-2:25 Simultaneous Retrieval of Spatial Fields of Atmospheric Carbon Dioxide from High-Resolution Satellite Data

*Jonathan Hobbs, Jet Propulsion Laboratory, California Institute of Technology; Matthias Katzfuss, Texas A&M University, USA; Veronica Berrocal, University of Michigan, USA; Jenny Brynjarsdottir and Anirban Mondal, Case Western Reserve University, USA*

#### 2:30-2:55 Frameworks for Improving Monitoring Snow from Space

*Laurie Huning and Amir AghaKouchak, University of California, Irvine, USA*

#### 3:00-3:25 On Critical Phenomena Detection by Remote Sensing of the Marine Antarctic Ice Sheet

*Erik Bollt, Clarkson University, USA*

Thursday, September 13

## MS7

### STEM Education for the Future of the Planet Earth - Part I of II

1:30 PM-3:30 PM

Room: Concerto B - 3rd Floor

#### For Part 2 see MS12

This minisymposium focuses on integration of science, technology, engineering, and mathematics (STEM) with planet earth as communication systems. Curriculum and current practices of college-level STEM education will be introduced for a better understanding of student success over the progression of introductory mathematics courses. Despite the challenges that lie ahead in saving our planet, there has been a growing movement among STEM educators to change the way that STEM is taught. We aim to share practices and ideas of a high-quality sustainable STEM education in our community.

Organizer: Guangming Yao  
*Clarkson University, USA*

#### 1:30-1:55 Findings from a National Study of Calculus Programs

*Chris Rasmussen, San Diego State University, USA*

#### 2:00-2:25 Math to Save the World

*Ben Galluzzo, Clarkson University, USA*

#### 2:30-2:55 Using the MAA Instructional Practice Guide- Thoughts on Learner-centered Instruction

*Karen Keene, North Carolina State University, USA*

#### 3:00-3:25 The Hudson River Estuarium: Complex Systems Education For All

*Peter R. Turner, Clarkson University, USA*

*continued in next column*

Thursday, September 13

**MS8****Advances and Applications of Time-integration in Earth System Modeling - Part I of II**

1:30 PM-3:30 PM

*Room: Rhapsody - 4th Floor***For Part 2 see MS18**

Earth system models seek to realistically account for all global-scale interactions on Planet Earth, including those of oceans, land, atmosphere, and cryosphere. These models typically exhibit complex dynamics that arise from the underlying heavily-coupled, multiple-scale system. In addition to the theoretical interest in these dynamics, robust computational analyses and methods are needed to produce accurate and stable solutions. The push for exascale computing is allowing for greater spatial grid resolution than was available in recent years. The time integration techniques in existing codes are no longer able to efficiently solve models on these highly-refined grids. Thus, this minisymposium focuses on the challenges, advances, and applications in numerical methods for time-integration in earth system models.

Organizer: Christopher J. Vogl

*Lawrence Livermore National Laboratory, USA*

Organizer: Andrew J. Steyer

*Sandia National Laboratories, USA***1:30-1:55 Implicit-Explicit Time-Integration in the E3SM-Homme Nonhydrostatic Atmosphere Model**

*Andrew J. Steyer, Oksana Guba, and Mark A. Taylor, Sandia National Laboratories, USA*

**2:00-2:25 Efforts to Enhance Performance in the Energy Exascale Earth System Model Dynamical Core Using Implicit Algorithms on Hybrid Architectures**

*Katherine J. Evans, Oak Ridge National Laboratory, USA*

**2:30-2:55 Exponential Integrators for the Shallow Water Equations on the Sphere**

*Vu Thai Luan, Southern Methodist University, USA; Janusz Pudykiewicz, Environment Canada, USA; Daniel R. Reynolds, Southern Methodist University, USA*

**3:00-3:25 Investigating Additive Runge-Kutta Integrators for Atmospheric Dynamics Using Sundials**

*Christopher J. Vogl and David J. Gardner, Lawrence Livermore National Laboratory, USA; Daniel R. Reynolds, Southern Methodist University, USA; Paul Ullrich, University of California, Davis, USA; Carol S. Woodward, Lawrence Livermore National Laboratory, USA; Andrew J. Steyer, Sandia National Laboratories, USA*

Thursday, September 13

**CP2****Physical Systems**

1:30 PM-3:10 PM

*Room: Minuet - 4th Floor*

*Chair: Mikael Kuusela, Carnegie Mellon University, USA*

**1:30-1:45 The Contribution and Influence of Coherent Mesoscale Eddies Off the North-West African Upwelling on the Open Ocean**

*Anass El Aouni, Khalid Daoudi, and Hussein Yahia, Inria Bordeaux Sud-Ouest, France; Khalid Minaoui, Mohammed V University, Morocco*

**1:50-2:05 Locally Stationary Spatio-Temporal Interpolation of Argo Profiling Float Data**

*Mikael Kuusela, Carnegie Mellon University, USA; Michael Stein, University of Chicago, USA*

**2:10-2:25 Extraction and Classification of Convectively Coupled Equatorial Waves Through Eigendecomposition of Koopman Operators**

*Joanna Slawinska, University of Wisconsin, Milwaukee, USA; Dimitrios Giannakis, Courant Institute of Mathematical Sciences, New York University, USA*

**2:30-2:45 Quantifying Historical Indonesian Seismicity Via Bayesian Statistical Inversion**

*Jared P. Whitehead, Brigham Young University, USA*

**2:50-3:05 Fast and Slow Resonant Triads in the Two Layer Rotating Shallow Water Equations**

*Alex Owen, Roger Grimshaw, and Beth Wingate, University of Exeter, United Kingdom*

**Coffee Break and Poster Session \*\*Posters will be on display during both Thursday coffee breaks\*\***

3:30 PM-4:00 PM

*Room: Overture and Balcony - 3rd Floor**continued in next column*



Thursday, September 13

## MS9

### Linking Scales in Earth's Sea Ice System - Part I of III

4:00 PM-6:00 PM

Room: Symphony Ballroom - 3rd Floor

#### For Part 2 see MS14

Realistic mathematical models of Earth's climate system are essential to making projections about what we may experience as climate changes. Sea ice forms the thin boundary layer coupling the polar oceans and atmosphere, and has seen rather dramatic changes over the past two or three decades. An important feature of sea ice is that it displays rich structure and behavior on scales ranging over ten orders of magnitude: length scales from microns to hundreds of kilometers, and time scales from milliseconds to decades. The minisymposium will focus on linkage of scales - relating behavior and structure on small scales to effective or homogenized behavior on larger scales, and estimating parameters controlling small scale processes from large scale observations.

Organizer: Noa Kraitzman

University of Utah, USA

Organizer: Elena Cherkaev

University of Utah, USA

Organizer: Kenneth M. Golden

University of Utah, USA

#### 4:00-4:25 Linking Scales in Earth's Sea Ice System

Kenneth M. Golden, Elena Cherkaev, Noa Kraitzman, N. Benjamin Murphy, and Court Strong, University of Utah, USA; Christian Sampson, University of North Carolina at Chapel Hill, USA; Ivan Sudakov, The University of Dayton, USA; Yiping Ma, Northumbria University, United Kingdom; Kyle R. Steffen, Rebecca Hardenbrook, and Huy Dinh, University of Utah, USA

*continued in next column*

#### 4:30-4:55 Modeling and Analysis of Fluid Flow in Sea Ice: How Does Biology Affect the Physics?

Kyle R. Steffen, Yekaterina Epshteyn, Jingyi Zhu, and Megan J. Bowler, University of Utah, USA; Jody W. Deming, University of Washington, USA; Kenneth M. Golden, University of Utah, USA

#### 5:00-5:25 Frazil-ice Dynamics: From Millimetre-sized Crystals to Geophysical Flows Along the Base of Floating Ice Shelves

David W. Rees Jones and Andrew Wells, University of Oxford, United Kingdom

#### 5:30-5:55 Simple Rules Govern The Patterns of Arctic Sea Ice Melt Ponds

Predrag Popovic, University of Chicago, USA; BB Cael, Massachusetts Institute of Technology, USA; Mary Silber and Dorian S. Abbot, University of Chicago, USA

Thursday, September 13

## MS10

### Bayesian Data Assimilation

4:00 PM-6:00 PM

Room: Aria A - 3rd Floor

Geophysical flows in atmosphere and ocean have high impact on economic and environmental outcomes, therefore it is essential to make their fair predictions. The goal of data assimilation is to combine available observations and model dynamics in order to make those predictions. Bayesian data assimilation methods such as Monte Carlo methods are very attractive for this purpose, as they do not make any assumptions about probability density functions. However, for a long time they were considered unpractical for geophysical applications as they demand a computationally unaffordable number of samples. Ensemble Kalman Filters, on the other hand, do not require many ensemble members but have an assumption of Gaussian probability density functions. The minisymposium highlights recent developments that allow Bayesian data assimilation methods to be applicable to nonlinear high-dimensional dynamical systems.

Organizer: Svetlana Dubinkina

Centrum voor Wiskunde en Informatica (CWI), Netherlands

#### 4:00-4:25 Particle Filtering for Inverse Problems

Svetlana Dubinkina, Centrum voor Wiskunde en Informatica (CWI), Netherlands

*continued on next page*



**4:30-4:55 State Estimation for a High-Dimensional Nonlinear System by Particle-Based Filtering Methods**

*Sangil Kim and Il-Hyo Jung, Pusan National University, South Korea*

**5:00-5:25 What the Collapse of the Ensemble Kalman Filter Tells Us About Particle Filters**

*Matthias Morzfeld, University of Arizona, USA; Chris Snyder, National Center for Atmospheric Research, USA; Daniel Hodyss, Naval Research Laboratory, USA*

**5:30-5:55 Importance Sampling: Intrinsic Dimension and Computational Cost**

*Daniel Sanz-Alonso, Brown University, USA*

Thursday, September 13

## MS11

### Geomathematical Inverse Problems - Part I of II

4:00 PM-6:00 PM

*Room: Concerto A - 3rd Floor*

**For Part 2 see MS16**

The minisymposium focuses on inverse problems related to the planet Earth, from both mathematical and applied points of view. Various kinds of mathematical inverse problems arise when one tries to see below the surface, whether deeply or shallowly, using surface measurements. Inverse problems for wave equations, ambient noise correlations, inverse spectral problems, imaging with optimal transport, inverse problems for Maxwell's equations, X-ray tomography problems and inverse problems for distance functions will be considered. The minisymposium establishes relationships between seismic imaging, geophysical measurements and inverse problems. The uniqueness, stability and reconstruction results are addressed alike. Speakers include both mathematicians and geophysicists.

Organizer: Teemu Saksala  
*Rice University, USA*

Organizer: Maarten de Hoop  
*Rice University, USA*

**4:00-4:25 Seeing Inside the Earth with Distance Functions**

*Teemu Saksala, Rice University, USA*

**4:30-4:55 The Geodesic X-Ray Transform on Noncompact Riemannian Manifolds**

*Jere Lehtonen, University of Jyväskylä, Finland*

**5:00-5:25 Microlocal Analysis of the Attenuated Ray Transform in 2 and 3 Dimensions**

*Sean Holman, University of Manchester, United Kingdom*

**5:30-5:55 Nonparaxial Near-Nondiffracting Accelerating Optical Beams**

*Ting Zhou, Northeastern University, USA; Ru-Yu Lai, University of Minnesota, USA*

Thursday, September 13

## MS12

### STEM Education for the Future of the Planet Earth - Part II of II

4:00 PM-6:00 PM

*Room: Concerto B - 3rd Floor*

**For Part 1 see MS7**

This minisymposium focuses on integration of science, technology, engineering, and mathematics (STEM) with planet earth as communication systems. Curriculum and current practices of college-level STEM education will be introduced for a better understanding of student success over the progression of introductory mathematics courses. Despite the challenges that lie ahead in saving our planet, there has been a growing movement among STEM educators to change the way that STEM is taught. We aim to share practices and ideas of a high-quality sustainable STEM education in our community.

Organizer: Guangming Yao  
*Clarkson University, USA*

**4:00-4:25 Co-Ordinated Math and Physics Assessment for Student Success (COMPASS)**

*Guangming Yao and Michael Ramsdell, Clarkson University, USA*

**4:30-4:55 Infusing Data into Stem Education**

*Anna Bargagliotti, Loyola Marymount University, USA*

**5:00-5:25 MPE Projects in the First Year Calculus Sequence**

*Joseph Skufca, Clarkson University, USA*

**5:30-5:55 Designing MPE Modeling Questions**

*Bliss Karen, North Carolina State University, USA*

Thursday, September 13

## MS13

### Numerical Methods for Weather, Oceans and Climate - Part II of II

4:00 PM-6:00 PM

Room: Rhapsody - 4th Floor

#### For Part 1 see MS4

This minisymposium will cover current research topics in numerical methods for oceans weather and climate.

Specific focus areas are: \* Finite difference, finite element and finite volume methods for atmosphere and ocean dynamical cores \* Unstructured and adaptive numerics for simulations bridging physical scales \* Conservation properties of numerical schemes \* Coupling dynamical and physical processes in numerical simulations

Organizer: Colin J. Cotter

Imperial College London, United Kingdom

Organizer: Mark A. Taylor

Sandia National Laboratories, USA

#### 4:00-4:25 Performance of the E3SM Spectral Element Atmosphere Dynamical Core

Mark A. Taylor, Sandia National Laboratories, USA; Luca Bertagna, Florida State University, USA; Michael Deakin, Monash University, Australia; Oksana Guba, Dan Sunderland, Andrew Bradley, Irina K. Tezaur, and Andrew Salinger, Sandia National Laboratories, USA

#### 4:30-4:55 Quasi-Hamiltonian Numerical Models of Geophysical Fluid Dynamics

Christopher Eldred, AIRSEA, INRIA/Laboratoire Jean Kuntzmann, France; Thomas Dubos, Ecole Polytechnique, France; Francois Gay-Balmaz, Ecole Normale Supérieure de Lyon, France

#### 5:00-5:25 Conservative Multi-Moment Characteristic Galerkin Transport on the Sphere

Peter A. Bosler, Andrew Bradley, and Mark A. Taylor, Sandia National Laboratories, USA

#### 5:30-5:55 An Adaptive Mesh Refinement (AMR) Framework for 2D Shallow Water and 3D Nonhydrostatic Dynamical Cores

Christiane Jablonowski and Jared Ferguson, University of Michigan, USA; Hans Johansen and Phillip Colella, Lawrence Berkeley National Laboratory, USA

Thursday, September 13

## CP3

### Sustainability

4:00 PM-6:00 PM

Room: Minuet - 4th Floor

Chair: Rachel Ulrich, Montana State University, USA

#### 4:00-4:15 Modeling Ice of the Mixed-Phase Clouds

Jaakko Ahola, University of Turku, Finland; Tomi Raatikainen, Juha Tonttila, Sami Romakkaniemi, Harri Kokkola, and Hannele Korhonen, Finnish Meteorological Institute, Helsinki, Finland

#### 4:20-4:35 Modelling Hydrological Processes As Nature Itself Does

Jan M. Baetens, Ghent University, Belgium

#### 4:40-4:55 Mathematical Modeling, Analysis and Data Validation of Wind Turbines System

Sameh Eisa, University of California, Irvine, USA

#### 5:00-5:15 Dynamical Modeling of Social and Eco-Epidemiological Factors for Public Health

Cesar P. Montalvo, Arizona State University, USA

#### 5:20-5:35 Traffic Flow Control Via Autonomous Vehicles and Its Environmental Impact

Benjamin Seibold, Temple University, USA

#### 5:40-5:55 Development of An Intensification Index for Land Use/Land Use Change in the Northwestern U.S., 1990-2010

Rachel Ulrich, Scott Powell, and Andrew Hansen, Montana State University, USA; Dave Theobald, Conservation Science Partners, Inc., USA; Katrina Mullan and Dawson Reising, University of Montana, USA

## Friday, September 14

### Registration

8:15 AM-4:30 PM

Room: Aria B - 3rd Floor

### Remarks

8:40 AM-8:45 AM

Room: Symphony Ballroom - 3rd Floor

Friday, September 14

## IP2

### Optimal Control Techniques Applied to Management of Natural Resource Models

8:45 AM-9:30 AM

Room: Symphony Ballroom - 3rd Floor

Chair: Luc Doyen, University of Bordeaux,  
France

Optimal control techniques have been used to investigate management strategies in a variety of models for natural resources. Two applications involving FISH and FIRE will be discussed, incorporating the economic impacts. Harvesting of fishery stock has led to habitat damage. We present a model with spatiotemporal dynamics of a fish stock and its habitat. Techniques of optimal control of PDEs are used to investigate the harvest rates that maximize the discounted value while minimizing the negative effects on the habitat. The number of large-scale, high-severity forest fires occurring is increasing, as is the cost to suppress these fires. We incorporate the stochasticity of the time of a forest fire into our model and explore the trade-offs between prevention management spending and suppression spending.

Suzanne M. Lenhart

University of Tennessee, Knoxville, USA  
and National Institute for Mathematical and  
Biological Synthesis, USA

### Coffee Break

9:30 AM-10:00 AM



Room: Overture and Balcony - 3rd Floor

Friday, September 14

## MS14

### Linking Scales in Earth's Sea Ice System - Part II of III

10:00 AM-12:00 PM

Room: Symphony Ballroom - 3rd Floor

For Part 1 see MS9

For Part 3 see MS19

Realistic mathematical models of Earth's climate system are essential to making projections about what we may experience as climate changes. Sea ice forms the thin boundary layer coupling the polar oceans and atmosphere, and has seen rather dramatic changes over the past two or three decades. An important feature of sea ice is that it displays rich structure and behavior on scales ranging over ten orders of magnitude: length scales from microns to hundreds of kilometers, and time scales from milliseconds to decades. The minisymposium will focus on linkage of scales - relating behavior and structure on small scales to effective or homogenized behavior on larger scales, and estimating parameters controlling small scale processes from large scale observations.

Organizer: Noa Kraitzman

University of Utah, USA

Organizer: Elena Cherkaev

University of Utah, USA

Organizer: Kenneth M. Golden

University of Utah, USA

**10:00-10:25 Forward and Inverse  
Homogenization: Relating Properties  
and Structure of Heterogeneous Sea  
Ice**

Elena Cherkaev, University of Utah, USA

**10:30-10:55 Advection Enhanced  
Diffusion Processes**

Noa Kraitzman, University of Utah, USA

continued on next page

Friday, September 14

## MS14

### Linking Scales in Earth's Sea Ice System - Part II of III

10:00 AM-12:00 PM

Room: Symphony Ballroom - 3rd Floor

continued

#### 11:00-11:25 Effective Rheology and Wave Attenuation in the Marginal Ice Zone

*Christian Sampson*, University of North Carolina at Chapel Hill, USA; *N. Benjamin Murphy*, *Elena Cherkaev*, and *Kenneth M. Golden*, University of Utah, USA

#### 11:30-11:55 Homogenization Estimates for the Rheological Properties of Sea Ice

*Shuvrangu Das* and *Pedro Ponte Castañeda*, University of Pennsylvania, USA

Friday, September 14

## MS15

### Seasonal Forecasting of Hydrological Anomalies and Their Impact on Society

10:00 AM-12:00 PM

Room: Aria A - 3rd Floor

Hydrological anomalies in the form of droughts and floods are among the most costly climate related hazards. In this session, we present the results of recent work to forecast the occurrence of extreme surface water anomalies and their impact on society. The Water Security Indicator Model provides global monitoring and forecasts of extreme surface water anomalies with lead times of 1-9 months. The Stream Flow Prediction tool provides more detailed seasonal forecasts of extreme stream flow anomalies on a regional basis. We also present work on applying these forecasts to assess likely impact on society.

Organizer: *Thomas M. Parris*  
*ISciences, LLC, USA*

Organizer: *Matthew Farthing*  
*U.S. Army Engineer Research and Development Center, USA*

#### 10:00-10:25 Global Monitoring and Seasonal Forecasts of Extreme Surface Water Anomalies: The Water Security Indicator Model (WSIM)

*Daniel Baston*, ISciences, LLC, USA

#### 10:30-10:55 Forecasting Extreme Hydrologic Events: The Stream Flow Prediction Tool (SPT)

*Mark D. Wahl*, *Matthew Farthing*, *Joseph Gutenson*, and *Scott Christensen*, U.S. Army Engineer Research and Development Center, USA

#### 11:00-11:25 Comparing the Accuracy of Global Spatial Population Surfaces

*Marc Levy*, Columbia University, USA; *Deborah Balk*, Baruch College, CUNY, USA; *Susana B. Adamo*, Columbia University, USA

#### 11:30-11:55 Applying Bayesian Hierarchical Modeling to Understand the Relationships Between Climate, Security, and Migration

*Joshua S. Brinks*, ISciences, LLC, USA

Friday, September 14

## MS16

### Geomathematical Inverse Problems - Part II of II

10:00 AM-12:00 PM

Room: Concerto A - 3rd Floor

For Part 1 see MS11

The minisymposium focuses on inverse problems related to the planet Earth, from both mathematical and applied points of view. Various kinds of mathematical inverse problems arise when one tries to see below the surface, whether deeply or shallowly, using surface measurements. Inverse problems for wave equations, ambient noise correlations, inverse spectral problems, imaging with optimal transport, inverse problems for Maxwell's equations, X-ray tomography problems and inverse problems for distance functions will be considered. The minisymposium establishes relationships between seismic imaging, geophysical measurements and inverse problems. The uniqueness, stability and reconstruction results are addressed alike. Speakers include both mathematicians and geophysicists.

Organizer: *Teemu Saksala*  
*Rice University, USA*

Organizer: *Maarten de Hoop*  
*Rice University, USA*

#### 10:00-10:25 Spectral Geometry for the Earth

*Joonas Ilmavirta*, University of Jyväskylä, Finland

#### 10:30-10:55 Imaging the Earth Via Inverse Problems: Stability and Reconstruction

*Romina Gaburro*, University of Limerick, Ireland

#### 11:00-11:25 Body Waves Reconstruction from Correlation of Ambient Seismic Noise and Coda: A New Window into Deep Earth and Challenges

*Piero Poli*, Massachusetts Institute of Technology, USA

#### 11:30-11:55 Imaging with Optimal Transport

*Peter A. Caday*, Rice University, USA

Friday, September 14

**MS17****Efforts Toward Evaluation and Reproducibility for Science of Planet Earth - Part I of II**

10:00 AM-12:00 PM

*Room: Concerto B - 3rd Floor***For Part 2 see MS22**

As Earth system models and data collection campaigns continuously grow larger and more complex, the need for robust evaluation and reproducibility becomes increasingly important for credible projections of the Earth system. Models and data infrastructure need robust and scalable software tools to handle petabytes of data and computational needs for full system verification, validation, and uncertainty quantification. Similarly, these tools need to be usable, portable to different architectures, and flexible and extensible to new scientific developments. These are most useful when deployed within robust workflows. Related to these efforts, advanced metrics and visualization provide model/data insight, and in turn, credible and reproducible Earth system science. Novel ideas for collecting and assessing simulation and observational data that addresses the issues of diversity and scale are being developed across the earth sciences, for example in atmospheric data collection, cryosphere modeling, seismology, cloud physics testing, and watershed modeling. This minisymposium will provide a forum for those interested and working in the area of reproducibility and credibility across areas of the planet Earth to share their capabilities and knowledge, and discuss gaps and next steps to advance the field.

Organizer: Katherine J. Evans  
Oak Ridge National Laboratory, USA

Organizer: Joseph H. Kennedy  
Oak Ridge National Laboratory, USA

**10:00-10:25 Efforts Toward Evaluation and Reproducibility for Ice Sheet Modeling**

Joseph H. Kennedy and Katherine J. Evans,  
Oak Ridge National Laboratory, USA

**10:30-10:55 Fingerprinting Hydrologic Models by Identifying Coupling Structures**

Andrew Bennett and Bart Nijssen, University  
of Washington, USA; Martyn Clark,  
University of Colorado Boulder, USA

**11:00-11:25 Statistical Consistency Testing for the Community Earth System Model**

Allison H. Baker and Dorit Hammerling,  
National Center for Atmospheric Research,  
USA; Daniel Milroy, University of  
Colorado, USA; Haiying Xu, National  
Center for Atmospheric Research, USA

**11:30-11:55 Development of An Open-Source, Community Hydrology Model: Discussion of Best Software Practices**

Reed M. Maxwell, Colorado School of  
Mines, USA; Stefan J. Kollet, Agrosphere  
Institute, Germany; Steven Smith,  
Lawrence Livermore National Laboratory,  
USA; Laura Condon, University of  
Arizona, USA; Klaus Goergen, Jülich  
Supercomputing Centre, Germany; Carol  
S. Woodward and Daniel Osei-Kuffuor,  
Lawrence Livermore National Laboratory,  
USA

Friday, September 14

**MS18****Advances and Applications of Time-integration in Earth System Modeling - Part II of II**

10:00 AM-12:00 PM

*Room: Rhapsody - 4th Floor***For Part 1 see MS8**

Earth system models seek to realistically account for all global-scale interactions on Planet Earth, including those of oceans, land, atmosphere, and cryosphere. These models typically exhibit complex dynamics that arise from the underlying heavily-coupled, multiple-scale system. In addition to the theoretical interest in these dynamics, robust computational analyses and methods are needed to produce accurate and stable solutions. The push for exascale computing is allowing for greater spatial grid resolution than was available in recent years. The time integration techniques in existing codes are no longer able to efficiently solve models on these highly-refined grids. Thus, this minisymposium focuses on the challenges, advances, and applications in numerical methods for time-integration in earth system models.

Organizer: Christopher J. Vogl  
Lawrence Livermore National Laboratory,  
USA

Organizer: Andrew J. Steyer  
Sandia National Laboratories, USA

**10:00-10:25 On the Way to the Limit: Time Parallelism with Oscillatory Time-Scale Separation**

Beth Wingate, University of Exeter, United  
Kingdom

*continued in next column**continued on next page*



Friday, September 14

## MS18

### Advances and Applications of Time-integration in Earth System Modeling - Part II of II

10:00 AM-12:00 PM

Room: Rhapsody - 4th Floor

continued

#### 10:30-10:55 Towards Parallel-in-Time Methods for Numerical Weather Prediction

Jemma Shipton, Imperial College, United Kingdom; Colin J. Cotter, Imperial College London, United Kingdom; Beth Wingate and Martin Schreiber, University of Exeter, United Kingdom

#### 11:00-11:25 Assessing and Improving the Numerical Solution of Atmospheric Physics in E3sm

David J. Gardner and Carol S. Woodward, Lawrence Livermore National Laboratory, USA; Hui Wan, Pacific Northwest National Laboratory, USA; Christopher J. Vogl, Lawrence Livermore National Laboratory, USA; Philip Rasch, Pacific Northwest National Laboratory, USA

#### 11:30-11:55 Measuring Numerically Relevant Timescales in Parameterizations of Cloud Microphysics

Sean Santos, University of Washington, USA; Peter Caldwell, Lawrence Livermore National Laboratory, USA; Chris Bretherton, University of Washington, USA

Friday, September 14

## CP4

### Modelling for Systems Supporting Life

10:00 AM-12:00 PM

Room: Minuet - 4th Floor

Chair: Nicholas J. Russell, University of Delaware, USA

#### 10:00-10:15 On One Biological Model in Mathematical Point of View

Zurab Kiguradze, Missouri University of Science and Technology, USA; Temur Jangveladze, Georgian Technical University, Georgia; Aleksandre Kratsashvili, Ilia State University, Georgia; David Jangveladze, Georgian Technical University, Georgia

#### 10:20-10:35 The Effect of Invasive Epibionts on Crab Mussel Communities

Rana Parshad and Jingjing Lyu, Clarkson University, USA; Linda Auker, Saint Lawrence University, USA

#### 10:40-10:55 Species Extinctions in a Population Model with Different Kinds of Environmental Forcing

Ivan Sudakov, The University of Dayton, USA

#### 11:00-11:15 How to Understand Terminal Dynamics of Stochastic Dynamic Programming Models in Ecology

Jody R. Reimer, Mark Lewis, and Andrew Derocher, University of Alberta, Canada

#### 11:20-11:35 Small Organisms Causing Big Problems: Modeling Heterosigma Akashiwo

Nicholas J. Russell, University of Delaware, USA

#### 11:40-11:55 A Structural Perspective on Ecological Connectivity in Western Himalayas

Shashankaditya Upadhyay, Shiv Nadar University, India; Arijit Roy and M Ramprakash, Indian Institute of Remote Sensing, India; Jobin Idiculla, Central University of Tamil Nadu, India; A Kumar, Indian Institute of Remote Sensing, India; Sudepto Bhattacharya, Shiv Nadar University, India

### Lunch Break

12:00 PM-1:30 PM

Attendees on their own

Friday, September 14

## MS19

### Linking Scales in Earth's Sea Ice System - Part III of III

1:30 PM-3:30 PM

Room: Symphony Ballroom - 3rd Floor

#### For Part 2 see MS14

Realistic mathematical models of Earth's climate system are essential to making projections about what we may experience as climate changes. Sea ice forms the thin boundary layer coupling the polar oceans and atmosphere, and has seen rather dramatic changes over the past two or three decades. An important feature of sea ice is that it displays rich structure and behavior on scales ranging over ten orders of magnitude: length scales from microns to hundreds of kilometers, and time scales from milliseconds to decades. The minisymposium will focus on linkage of scales - relating behavior and structure on small scales to effective or homogenized behavior on larger scales, and estimating parameters controlling small scale processes from large scale observations.

Organizer: Noa Kraitzman  
University of Utah, USA

Organizer: Elena Cherkaev  
University of Utah, USA

Organizer: Kenneth M. Golden  
University of Utah, USA

#### 1:30-1:55 The Quantum and Statistical Mechanics of Arctic Sea Ice

John S. Wettlaufer, Yale University, USA

#### 2:00-2:25 Regional Arctic Sea Ice Predictability: Mechanisms, Prediction Skill, and Future Outlook

Mitch Bushuk, New York University, USA

#### 2:30-2:55 Kernel Analog Methods for Sea Ice Prediction

Romeo Alexander, Courant Institute of Mathematical Sciences, New York University, USA

#### 3:00-3:25 Arctic Sea Ice Retreat in Global Climate Models: The Influence of Volcanoes and Global Warming Biases

Ian Eisenman, Scripps Institution of Oceanography, USA

Friday, September 14

## MS20

### Recent Advances in Computational Methods for Data Assimilation - Part I of II

1:30 PM-3:30 PM

Room: Aria A - 3rd Floor

#### For Part 2 see MS26

Data assimilation is the process by which observational data is fused with computational models to estimate the trajectory or state of dynamical systems. This method has been extensively used in meteorology, hydrology, oceanography among other applications, to make accurate predictions about the state of these systems. Two approaches to data assimilation have gained widespread popularity: ensemble-based estimation and variational methods. The ensemble-based methods are rooted in statistical theory, whereas the variational approach is derived from optimal control theory. The focus of this minisymposium is on recent advances in computational algorithms for both strategies. Specific topics include (but not limited to) 1) efficient computational infrastructure for data assimilation, 2) robust data assimilation techniques, 3) non-Gaussian data assimilation, 4) model errors in data assimilation, 5) hybrid data assimilation.

Organizer: Vishwas Hebbur  
Venkata Subba Rao

Argonne National Laboratory, USA

Organizer: Ahmed Attia  
Argonne National Laboratory, USA

Organizer: Emil M. Constantinescu  
Argonne National Laboratory, USA

Organizer: Mihai Anitescu  
Argonne National Laboratory, USA

#### 1:30-1:55 Forecast Sensitivity on Observation in Global Data Assimilation System

Kayo Ide, University of Maryland, College Park, USA

#### 2:00-2:25 On Proposal, Mapping, and Localisation Methods for Particle Filtering in High-Dimensional Geophysical Applications

Peter Jan van Leeuwen, University of Reading, United Kingdom and Colorado State University, USA

#### 2:30-2:55 A Framework for Adaptive Inflation and Covariance Localization for Ensemble Filters

Ahmed Attia and Emil M. Constantinescu, Argonne National Laboratory, USA

#### 3:00-3:25 Why and How Feature-based Data Assimilation Can Be Useful

Spencer C. Lunderman, University of Arizona, USA

Friday, September 14

## MS21

### Mathematical Methods for Conceptual Climate Modeling: From Deterministic to Stochastic

1:30 PM-3:30 PM

Room: Concerto A - 3rd Floor

Conceptual models of climate can provide qualitative insight into the complexities of climate change. In this minisymposium, we survey a sampling of current methods and techniques that are being used to study climate change from a conceptual viewpoint, including both deterministic and stochastic approaches. Methods include the least action method, to investigate noise-induced tipping events between metastable states that occur in climate systems; finite time Lyapunov exponents and Steklov averages, to investigate rate-induced tipping in nonautonomous systems; delay differential equations for models of El Niño; and to apply rate-induced tipping to study hurricanes formulation.

Organizer: Yuxin Chen  
Northwestern University, USA

Organizer: Kaitlin Hill  
University of Minnesota, USA

#### 1:30-1:55 Bifurcations and Multi-Frequency Tipping in a Delay Differential Equation Model for El Niño

Andrew Keane and Bernd Krauskopf, University of Auckland, New Zealand

#### 2:00-2:25 Hurricanes and Rate-Induced Tipping

Claire Kiers, University of North Carolina, Chapel Hill, USA

*continued in next column*

*continued on next page*

Friday, September 14

## MS21

### Mathematical Methods for Conceptual Climate Modeling: From Deterministic to Stochastic

1:30 PM-3:30 PM

Room: Concerto A - 3rd Floor

continued

#### 2:30-2:55 Detecting Rate-Induced Tipping in An Ecological Resource-Consumer Model

Alanna Hoyer-Leitzel, Mount Holyoke College, USA; Alice Nadeau, University of Minnesota, USA; Andrew Roberts, Cerner Corporation, USA; Andrew J. Steyer, Sandia National Laboratories, USA

#### 3:00-3:25 Noise-induced Tipping in a Periodically Forced System: The Noise-drift Balanced Regime

John Gemmer, Wake Forest University, USA; Yuxin Chen, Northwestern University, USA; Alexandria Volkening, Ohio State University, USA; Mary Silber, University of Chicago, USA

Friday, September 14

## MS22

### Efforts Toward Evaluation and Reproducibility for Science of Planet Earth - Part II of II

1:30 PM-3:00 PM

Room: Concerto B - 3rd Floor

For Part 1 see MS17

As Earth system models and data collection campaigns continuously grow larger and more complex, the need for robust evaluation and reproducibility becomes increasingly important for credible projections of the Earth system. Models and data infrastructure need robust and scalable software tools to handle petabytes of data and computational needs for full system verification, validation, and uncertainty quantification. Similarly, these tools need to be usable, portable to different architectures, and flexible and extensible to new scientific developments.

These are most useful when deployed within robust workflows. Related to these efforts, advanced metrics and visualization provide model/data insight, and in turn, credible and reproducible Earth system science. Novel ideas for collecting and assessing simulation and observational data that addresses the issues of diversity and scale are being developed across the earth sciences, for example in atmospheric data collection, cryosphere modeling, seismology, cloud physics testing, and watershed modeling. This minisymposium will provide a forum for those interested and working in the area of reproducibility and credibility across areas of the planet Earth to share their capabilities and knowledge, and discuss gaps and next steps to advance the field.

Organizer: Katherine J. Evans  
Oak Ridge National Laboratory, USA

Organizer: Joseph H. Kennedy  
Oak Ridge National Laboratory, USA

#### 1:30-1:55 Towards a Representation of Physical Understanding with Mathematical Rigor – Assessing Solution Accuracy for Atmospheric Physics in Weather and Climate Models

Hui Wan, Pacific Northwest National Laboratory, USA

#### 2:00-2:25 Mathematical Aspects of the Terrestrial Carbon Dynamics

Ying Wang, University of Oklahoma, USA

#### 2:30-2:55 A Multivariate Approach Using Short Simulation Ensembles to Evaluate Reproducibility of Climate Model Simulations on Hybrid Architectures

Salil Mahajan, Katherine J. Evans, and Joseph H. Kennedy, Oak Ridge National Laboratory, USA

continued in next column

Friday, September 14

**MS23****Doctoral Training Showcase  
in Mathematics of Planet  
Earth (MPE CDT) - Part I of II**

1:30 PM-3:30 PM

*Room: Minuet - 4th Floor***For Part 2 see MS25**

This minisymposium highlights some of the research activities in the EPSRC Centre for Doctoral Training in Mathematics of Planet Earth (MPE CDT), which is run jointly at Imperial College London and the University of Reading. The MPE CDT is training about seventy new PhDs in Mathematics of Planet Earth in the period. More information about MPE CDT is available at <http://mpecdt.org/>.

Organizer: Colin J. Cotter

*Imperial College London, United Kingdom*

Organizer: Darryl D. Holm

*Imperial College London, United Kingdom  
and Los Alamos National Laboratory, USA***1:30-1:55 Potential Vorticity  
Redistribution by Localised Transient  
Forcing in the Shallow-Water Model***Michael Haigh, Imperial College London,  
United Kingdom***2:00-2:25 Parameterising Eddy-  
Induced Lagrangian Transport in An  
Idealised Oceanic Jet***Josephine Park, Imperial College London,  
United Kingdom***2:30-2:55 Quantifying the Skill in  
Probabilistic Forecast for the Sea  
Breeze Deriving from Large-Scale  
Variables***Carlo Cafaro, University of Reading, United  
Kingdom***3:00-3:25 Rate-Induced Tipping in  
Nonautonomous Dynamical Systems  
with Bounded Noise***Giulia Carigi and Jochen Broecker, University  
of Reading, United Kingdom; Martin  
Rasmussen, Imperial College London,  
United Kingdom*

Friday, September 14

**MS24****One Health: Connecting  
Humans, Animals and the  
Environment - Part I of II**

1:30 PM-3:30 PM

*Room: Rhapsody - 4th Floor***For Part 2 see MS28**

'One Health' is the multidisciplinary approach to improving the health of people, animals and the environment. Environmental, wildlife, domestic animal, and human health fall under the One Health concept. Models of Infectious diseases and other health issues involving plants, animals, environmental features and humans will be presented. The importance of connection with data will be illustrated in some talks.

Organizer: Suzanne M. Lenhart

*University of Tennessee, Knoxville, USA  
and National Institute for Mathematical and  
Biological Synthesis, USA***1:30-1:55 Application and Modeling of  
a Tick-killing Robot to Protect Humans  
and Livestock***Alexis White and Holly Gaff, Old Dominion  
University, USA***2:00-2:25 Modeling the Opioid  
Epidemic***Nicholas Battista, College of New Jersey,  
USA; Leigh Percy, University of North  
Carolina at Chapel Hill, USA; Christopher  
Strickland, University of Tennessee,  
Knoxville, USA***2:30-2:55 Outbreak Size and  
Intervention on Discrete Spatial  
Networks***Michael Kelly, Transylvania University, USA;  
Joseph Tien and Karly Jacobsen, The Ohio  
State University, USA***3:00-3:25 Risk Structured Model of  
Cholera Infections In Cameroon***Fnu Eric Ngang Che, Howard University,  
USA***Coffee Break**

3:30 PM-4:00 PM

*Room: Overture and Balcony - 3rd Floor*

Friday, September 14

**IP3****Insights from Studying the  
Interface Between Sentience  
and Sociability in Animal  
Movement Patterns**

4:00 PM-4:45 PM

*Room: Symphony Ballroom - 3rd Floor**Chair: Lea Jenkins, Clemson University, USA*

An animal's sensory capabilities and its sociability have important fitness consequences. Creatures large and small rely on their senses to navigate their way through this world and social interactions can play a significant role in defining how they interact with their environment and the decisions they make. While individual capabilities and population densities are common predictive metrics, the interplay between individual sensory processing and sociability is rarely considered when managing or mitigating for anthropogenic impacts on individuals, communities, and populations. In this presentation I will demonstrate why individual interactions are relevant and review how we may integrate them into our efforts to better manage our ecological footprint. I will show how basic sensory features can shape social feedbacks, how interactions influence individual capabilities like stamina and memory, and how even ephemeral social ties can generate movements that deviate drastically from our expectations. Lastly, I'll discuss how studying cognition's role in animal collectives is providing novel insights into some of nature's most captivating examples of complex adaptive systems.

Bertrand Lemasson

*US Army Corps of Engineers, USA***Intermission**

4:45 PM-5:00 PM



Friday, September 14

## PD1

### Forward Looking Panel on Emerging Topics

5:00 PM-6:00 PM

Room: Symphony Ballroom - 3rd Floor

Chair: Emil Constantinescu, Argonne National Laboratory, USA

The SIAM Activity Group on Mathematics of Planet Earth (SIAG/MPE) focuses on mathematical and computational issues related to planet Earth, with particular emphasis on the effects of human activities on Earth's physical environment and its life-supporting capabilities. This forward-looking panel will discuss strategies for establishing and coordinating interdisciplinary research teams with the right domain experts for solving the complex problems associated with MPE applications, the scientific challenges needing resolution over the next 10 years, and better ways to establish communication channels between academic and industrial research partners. The panel includes researchers from academia and industry who will give their perspectives on these and other related issues. Anyone interested in the state of our planet and the future of MPE is invited to join and participate in the discussion. We want the panel to consider at least the following questions: 1 - What are your success stories in getting interdisciplinary work accomplished? How to you accumulate the correct domain experts to resolve a complex problem? 2 - What are the biggest scientific challenges needing resolution over the next 10 years? 3 - What are ways to establish better communication channels between academia and industry?

#### Panelists:

Jessica Matthews, North Carolina State University, USA

Mihai Anitescu, Argonne National Laboratory, USA

Hans Kaper, Argonne National Laboratory and Georgetown University, USA

Christiane Rousseau, Université de Montreal, Canada

## Saturday, September 15

### SIAG/MPE Business Meeting (open to SIAG/MPE members)

8:00 AM-8:30 AM

Room: Symphony Ballroom - 3rd Floor

Refreshments will be served.



### Registration

8:00 AM-10:30 AM

Room: Aria B - 3rd Floor

### Intermission

8:30 AM-8:40 AM

### Closing Remarks

8:40 AM-8:45 AM

Room: Symphony Ballroom - 3rd Floor

Saturday, September 15

## IP4

### How Energy Optimization is Responding to the Challenge of Decarbonizing Our Economies

8:45 AM-9:30 AM

Room: Symphony Ballroom - 3rd Floor

Chair: Hans G. Kaper, Georgetown University, USA

The future of energy production lies at the heart of worldwide efforts to reach the transition to sustainable energy systems. Success in this respect depends on shifting from fossil-based electricity generation to renewables. Intermittent renewable sources and their storage need more distributed generation, new flexibility markets, and the facilitation of the roles of "prosumers" and aggregators in the energy value chain. Together with the massive electrification of transport, these issues make the demand of electricity less predictable, but potentially more versatile. The new situation brings fundamental interdisciplinary challenges and presents a unique opportunity for researchers working on the Mathematics of Planet Earth. We shall discuss how to model the new paradigms for operating and pricing energy systems and describe some new problems of control and optimization that arise in this setting.

Claudia Sagastizabal

UNICAMP, Brazil

### Coffee Break

9:30 AM-10:00 AM



Room: Overture and Balcony - 3rd Floor



Saturday, September 15

## MS25

### Doctoral Training Showcase in Mathematics of Planet Earth (MPE CDT) - Part II of II

10:00 AM-12:00 PM

*Room: Symphony Ballroom - 3rd Floor*

#### For Part 1 see MS23

This minisymposium highlights some of the research activities in the EPSRC Centre for Doctoral Training in Mathematics of Planet Earth (MPE CDT), which is run jointly at Imperial College London and the University of Reading. The MPE CDT is training about seventy new PhDs in Mathematics of Planet Earth in the period. More information about MPE CDT is available at <http://mpecdt.org/>.

Organizer: Colin J. Cotter

*Imperial College London, United Kingdom*

Organizer: Darryl D. Holm

*Imperial College London, United Kingdom and  
Los Alamos National Laboratory, USA*

#### 10:00-10:25 A New Discretisation for the Stochastic Quasi-Geostrophic Equations

*Thomas Bendall and Colin J. Cotter, Imperial  
College London, United Kingdom*

#### 10:30-10:55 A Novel Scaling Indicator of Early Warning Signals Helps Anticipate Tropical Cyclones

*Joshua Prettyman, National Physical  
Laboratory, United Kingdom*

#### 11:00-11:25 Optimisation of Tidal Turbine Arrays in the Alderney Race

*Zoe Goss, Matthew Piggott, and Stephan  
Kramer, Imperial College of London, United  
Kingdom*

#### 11:30-11:55 Reflection of Rossby Waves in the Stratosphere: The Role of Critical Layer Nonlinearity

*Imogen Dell, Imperial College London, United  
Kingdom*

Saturday, September 15

## MS26

### Recent Advances in Computational Methods for Data Assimilation - Part II of II

10:00 AM-12:00 PM

*Room: Aria A - 3rd Floor*

#### For Part 1 see MS20

Data assimilation is the process by which observational data is fused with computational models to estimate the trajectory or state of dynamical systems. This method has been extensively used in meteorology, hydrology, oceanography among other applications, to make accurate predictions about the state of these systems. Two approaches to data assimilation have gained widespread popularity: ensemble-based estimation and variational methods. The ensemble-based methods are rooted in statistical theory, whereas the variational approach is derived from optimal control theory. The focus of this minisymposium is on recent advances in computational algorithms for both strategies. Specific topics include (but not limited to) 1) efficient computational infrastructure for data assimilation, 2) robust data assimilation techniques, 3) non-Gaussian data assimilation, 4) model errors in data assimilation, 5) hybrid data assimilation.

Organizer: Vishwas Hebbur  
Venkata Subba Rao

*Argonne National Laboratory, USA*

Organizer: Ahmed Attia

*Argonne National Laboratory, USA*

Organizer: Emil M.  
Constantinescu

*Argonne National Laboratory, USA*

Organizer: Mihai Anitescu

*Argonne National Laboratory, USA*

#### 10:00-10:25 Scalable in Time Algorithms for Large Scale Predictive Science

*Luisa D'Amore, University of Naples and  
CNR, Italy*

#### 10:30-10:55 4dvar with Model Errors

*Vishwas Hebbur Venkata Subba Rao, Emil  
M. Constantinescu, and Julie Bessac,  
Argonne National Laboratory, USA*

#### 11:00-11:25 A Line Search Method For Non-Linear Data Assimilation Via Random Descent Directions

*Elias D. Nino-Ruiz, Universidad del Norte,  
BAQ 080001, Colombia; Adrian Sandu,  
Virginia Polytechnic Institute & State  
University, USA*

#### 11:30-11:55 Title Not Available At Time Of Publication

*Georg Stadler, Courant Institute of  
Mathematical Sciences, New York  
University, USA*

*continued in next column*

Saturday, September 15

## MS27

### Decision Tools for Water Resources

10:00 AM-12:00 PM

Room: Concerto A - 3rd Floor

Optimization algorithms can be a powerful tool for providing practitioners with strategies for managing resources. In this session, approaches to groundwater and surface water management using a range of derivative-free optimization frameworks is presented including mixed integer formulations and hybridized methods. Applications include bioremediation, hydraulic capture of a contaminant plume, agricultural planting portfolios, and infiltration basins.

Organizer: Kathleen Kavanagh

Clarkson University, USA

Organizer: Eleanor Jenkins

Clemson University, USA

#### 10:00-10:25 Simulation-Based Optimization and Agricultural Water Management

Eleanor Jenkins, Clemson University, USA;

Kathleen Kavanagh, Clarkson University, USA

#### 10:30-10:55 Simulation Based Optimization Using the Implicit Filtering Genetic Algorithm for Optimal Placement of Slow Release Oxidant Cylinders in Groundwater Remediation

Jesse Clark-Stone, Kathleen Kavanagh, Guangming Yao, Michelle Crimi, and Wen Li, Clarkson University, USA

#### 11:00-11:25 Optimization of a Retention Basin Using a Hybridized Pso-Aco Method for Mixed-Integer Problems

Joshua Beauregard, Clarkson University, USA

#### 11:30-11:55 Optimal Groundwater Remediation with PSO and the Filter Method

Ahmad Almomani, State University of New York, Geneseo, USA

Saturday, September 15

## MS28

### One Health: Connecting Humans, Animals and the Environment - Part II of II

10:00 AM-12:00 PM

Room: Rhapsody - 4th Floor

#### For Part 1 see MS24

'One Health' is the multidisciplinary approach to improving the health of people, animals and the environment. Environmental, wildlife, domestic animal, and human health fall under the One Health concept. Models of Infectious diseases and other health issues involving plants, animals, environmental features and humans will be presented. The importance of connection with data will be illustrated in some talks.

Organizer: Suzanne M. Lenhart

University of Tennessee, Knoxville, USA and National Institute for Mathematical and Biological Synthesis, USA

#### 10:00-10:25 A Discrete Data-Driven Pseudorabies Model for Feral Hogs in Great Smoky Mountains National Park

Benjamin Levy, Fitchburg State University, USA; Suzanne M. Lenhart, University of Tennessee, Knoxville, USA and National Institute for Mathematical and Biological Synthesis, USA; Charles Collins, University of Tennessee, USA; Bill Stiver, Great Smoky Mountains National Park, USA

#### 10:30-10:55 Modeling and Control of Enzootic West Nile Virus Transmission

Suzanne Robertson, Virginia Commonwealth University, USA

#### 11:00-11:25 Managing the Commons Against Infectious Diseases

Timothy C. Reluga, Pennsylvania State University, USA

#### 11:30-11:55 Modeling Differential Transmission Mechanisms in Vector-Borne Viral Cassava Diseases in Africa

Ariel Cintron-Arias, East Tennessee State University, USA

Saturday, September 15

## CP5

### Climate Modelling

10:00 AM-11:40 AM

Room: Minuet - 4th Floor

Chair: Jorge Lorenzo Trueba, Montclair State University, USA

#### 10:00-10:15 Mathematical Analysis of the Effect of Some Climatic Factors, and Altitude on the Plant-Herbivore Interactions

Manalebish D. Asfaw, Addis Ababa University, Ethiopia; Semu Mitiku Kassa and Edward Lungu, Botswana International University of Science and Technology, Botswana; Weldeamlak Bewket, Addis Ababa University, Ethiopia

#### 10:20-10:35 Winter Wheat Yield in a Changing Climate

Bree Cummins, Montana State University, USA

#### 10:40-10:55 A Geometric Model for the Dynamics a Barrier-Marsh-Lagoon System under Sea-Level Rise Including Blue Carbon Storage

Jorge Lorenzo-Trueba, Montclair State University, USA

#### 11:00-11:15 The Mid-Pleistocene Transition Explored Through a Bistable Delay Model

Courtney Quinn and Jan Sieber, University of Exeter, United Kingdom; Anna von der Heydt, Utrecht University, The Netherlands; Timothy Lenton, University of Exeter, United Kingdom

#### 11:20-11:35 Tipping Events in Stochastically Perturbed Linear Filippov Systems

Jessica Zanetell and John Gemmer, Wake Forest University, USA

## Organizer and Speaker Index



**SEPTEMBER 13–15, 2018**

DoubleTree by Hilton Hotel  
Philadelphia Center City  
Philadelphia, Pennsylvania, USA

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*Attia, Ahmed, MS26, 10:00 Sat*

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 Cherkaev, Elena, MS14, 10:00 Fri  
*Cherkaev, Elena, MS19, 1:30 Fri*  
 Cintron-Arias, Ariel, MS28, 11:30 Sat  
 Clark-Stone, Jesse, MS27, 10:30 Sat

*Constantinescu, Emil M., MS20, 1:30 Fri*

*Constantinescu, Emil, PD1, 5:00 Fri*

*Constantinescu, Emil M., MS26, 10:00 Sat*

*Cotter, Colin J., MS4, 10:00 Thu*

*Cotter, Colin J., MS13, 4:00 Thu*

*Cotter, Colin J., MS23, 1:30 Fri*

*Cotter, Colin J., MS25, 10:00 Sat*

Cowall, Seth, PP1, 9:30 Thu

Cummins, Bree, PP1, 9:30 Thu

Cummins, Bree, CP5, 10:20 Sat

**D**

D'Amore, Luisa, MS26, 10:00 Sat

Das, Shuvrangs, PP1, 9:30 Thu

Dawson, Clint, IP1, 8:45 Thu

*de Hoop, Maarten, MS11, 4:00 Thu*

*de Hoop, Maarten, MS16, 10:00 Fri*

de Leeuw, Bart M., CP1, 10:00 Thu

Dell, Imogen, MS25, 11:30 Sat

Demir, Mahir, MS5, 2:00 Thu

Desilles, Anna, MS1, 10:30 Thu

*Doyen, Luc, MS1, 10:00 Thu*

*Doyen, Luc, MS5, 1:30 Thu*

Doyen, Luc, MS5, 1:30 Thu

Dozier, Haley, CP1, 10:20 Thu

*Dubinkina, Svetlana, MS10, 4:00 Thu*

Dubinkina, Svetlana, MS10, 4:00 Thu

**E**

Eisa, Sameh, CP3, 4:40 Thu

Eisenman, Ian, MS19, 3:00 Fri

El Aouni, Anass, CP2, 1:30 Thu

Eldred, Christopher, MS13, 4:30 Thu

Eric Ngang Che, Fnu, MS24, 3:00 Fri

Evans, Katherine J., MS8, 2:00 Thu

*Evans, Katherine J., MS17, 10:00 Fri*

*Evans, Katherine J., MS22, 1:30 Fri*

**F**

*Farthing, Matthew, MS15, 10:00 Fri*

**G**

Gaburro, Romina, MS16, 10:30 Fri

*Gajardo, Pedro, MS1, 10:00 Thu*

Gajardo, Pedro, MS1, 10:00 Thu

*Gajardo, Pedro, MS5, 1:30 Thu*

Galluzzo, Ben, MS7, 2:00 Thu

Gaoue, Orou G., MS1, 11:00 Thu

Gardner, David J., MS18, 11:00 Fri

Gemmer, John, MS21, 3:00 Fri

*Golden, Kenneth M., MS9, 4:00 Thu*

Golden, Kenneth M., MS9, 4:00 Thu

*Golden, Kenneth M., MS14, 10:00 Fri*

*Golden, Kenneth M., MS19, 1:30 Fri*

Goss, Zoe, MS25, 11:00 Sat

**H**

Haigh, Michael, MS23, 1:30 Fri

Hamon, Francois, CP1, 10:40 Thu

*Hebbur Venkata Subba Rao, Vishwas, MS20, 1:30 Fri*

*Hebbur Venkata Subba Rao, Vishwas, MS26, 10:00 Sat*

Hebbur Venkata Subba Rao, Vishwas, MS26, 10:30 Sat

*Hill, Kaitlin, MS21, 1:30 Fri*

Hobbs, Jonathan, MS6, 2:00 Thu

*Holm, Darryl D., MS23, 1:30 Fri*

*Holm, Darryl D., MS25, 10:00 Sat*

Holman, Sean, MS11, 5:00 Thu

Huang, Whitney, MS3, 10:30 Thu

**I**

Ide, Kayo, MS20, 1:30 Fri

Ilmavirta, Joonas, MS16, 10:00 Fri

**J**

Jablonowski, Christiane, MS13, 5:30 Thu

*Jenkins, Eleanor, MS27, 10:00 Sat*

Jenkins, Eleanor, MS27, 10:00 Sat

Johnson, Maggie, MS2, 10:30 Thu

Jones, Leslie, PP1, 9:30 Thu

**K**

Kang, Emily L., MS6, 1:30 Thu  
 Kaper, Hans G., PP1, 9:30 Thu  
 Kaper, Hans G., PD1, 5:00 Fri  
 Karen, Bliss, MS12, 5:30 Thu  
 Kavanagh, Kathleen, MT1, 10:00 Thu  
*Kavanagh, Kathleen, MT1, 10:00 Thu*  
*Kavanagh, Kathleen, MS27, 10:00 Sat*  
 Keane, Andrew, MS21, 1:30 Fri  
 Keene, Karen, MS7, 2:30 Thu  
 Kelly, Michael, MS24, 2:30 Fri  
*Kennedy, Joseph H., MS17, 10:00 Fri*  
 Kennedy, Joseph H., MS17, 10:00 Fri  
*Kennedy, Joseph H., MS22, 1:30 Fri*  
 Kent, James, MS4, 11:00 Thu  
 Kiers, Claire, MS21, 2:00 Fri  
 Kim, Sangil, MS10, 4:30 Thu  
*Kraitzman, Noa, MS9, 4:00 Thu*  
*Kraitzman, Noa, MS14, 10:00 Fri*  
 Kraitzman, Noa, MS14, 10:30 Fri  
*Kraitzman, Noa, MS19, 1:30 Fri*  
 Kratsashvili, Aleksandre, CP4, 10:00 Fri  
 Kuusela, Mikael, CP2, 1:50 Thu

**L**

Lauritzen, Peter H., MS4, 10:00 Thu  
 Lehtonen, Jere, MS11, 4:30 Thu  
 Lemasson, Bertrand, IP3, 4:00 Fri  
 Lenhart, Suzanne M., IP2, 8:45 Fri  
*Lenhart, Suzanne M., MS24, 1:30 Fri*  
*Lenhart, Suzanne M., MS28, 10:00 Sat*  
 Levy, Benjamin, MS28, 10:00 Sat  
 Levy, Marc, MS15, 11:00 Fri  
 Li, Bo, MS3, 11:00 Thu

Lin, Shian-Jiann, MS4, 11:30 Thu  
 Lorenzo-Trueba, Jorge, CP5, 10:40 Sat  
 Luan, Vu Thai, MS8, 2:30 Thu  
 Lunderman, Spencer C., MS20, 3:00 Fri

**M**

Mahajan, Salil, MS22, 2:30 Fri  
*Matthews, Jessica, MS2, 10:00 Thu*  
 Matthews, Jessica, MS2, 11:30 Thu  
*Matthews, Jessica, MS6, 1:30 Thu*  
 Matthews, Jessica, PD1, 5:00 Fri  
 Maxwell, Reed M., MS17, 11:30 Fri  
 Montalvo, Cesar P., CP3, 5:00 Thu  
 Morzfeld, Matthias, MS10, 5:00 Thu

**N**

Nadeau, Alice, MS21, 2:30 Fri  
 Nino-Ruiz, Elias D., MS26, 11:00 Sat

**O**

Olivar Tost, Gerard, MS1, 11:30 Thu  
 Owen, Alex, CP2, 2:50 Thu

**P**

Painter, Nick, PP1, 9:30 Thu  
 Park, Josephine, MS23, 2:00 Fri  
 Parno, Matthew, MT2, 1:30 Thu  
*Parno, Matthew, MT2, 1:30 Thu*  
*Parris, Thomas M., MS15, 10:00 Fri*  
 Parshad, Rana, CP4, 10:20 Fri  
 Pillow, Jessica, CP1, 11:20 Thu  
 Poli, Piero, MS16, 11:00 Fri  
 Ponte Castañeda, Pedro, MS14, 11:30 Fri  
 Popovic, Predrag, MS9, 5:30 Thu  
 Prettyman, Joshua, MS25, 10:30 Sat

**Q**

Quinn, Courtney, CP5, 11:00 Sat

**R**

Ramirez, Hector, MS5, 2:30 Thu  
 Rasmussen, Chris, MS7, 1:30 Thu  
 Ray, Pallav, PP1, 9:30 Thu

Rees Jones, David W., MS9, 5:00 Thu  
 Reimer, Jody R., CP4, 11:00 Fri  
 Reluga, Timothy C., MS28, 11:00 Sat  
 Robertson, Suzanne, MS28, 10:30 Sat  
 Rousseau, Christiane, PD1, 5:00 Fri  
 Russell, Nicholas J., CP4, 11:20 Fri

**S**

Sagastizabal, Claudia, IP4, 8:45 Sat  
*Saksala, Teemu, MS11, 4:00 Thu*  
 Saksala, Teemu, MS11, 4:00 Thu  
*Saksala, Teemu, MS16, 10:00 Fri*  
 Sampson, Christian, MS14, 11:00 Fri  
 Santos, Sean, MS18, 11:30 Fri  
 Sanz-Alonso, Daniel, MS10, 5:30 Thu  
 Seibold, Benjamin, CP3, 5:20 Thu  
 Shaby, Benjamin, MS3, 11:30 Thu  
 Shi, Jia, CP1, 11:40 Thu  
 Shipton, Jemma, MS18, 10:30 Fri  
 Skufca, Joseph, MT1, 10:00 Thu  
*Skufca, Joseph, MT1, 10:00 Thu*  
 Skufca, Joseph, MS12, 5:00 Thu  
 Slawinska, Joanna, PP1, 9:30 Thu  
 Slawinska, Joanna, CP2, 2:10 Thu  
*Smith, Richard L., MS3, 10:00 Thu*  
 Smith, Richard L., MS3, 10:00 Thu  
 Stadler, Georg, MS26, 11:30 Sat  
 Steffen, Kyle R., MS9, 4:30 Thu  
*Steyer, Andrew J., MS8, 1:30 Thu*  
 Steyer, Andrew J., MS8, 1:30 Thu  
*Steyer, Andrew J., MS18, 10:00 Fri*  
 Strickland, Christopher, MS24, 2:00 Fri  
 Sudakov, Ivan, CP4, 10:40 Fri

**T**

*Taylor, Mark A., MS4, 10:00 Thu*  
*Taylor, Mark A., MS13, 4:00 Thu*  
 Taylor, Mark A., MS13, 4:00 Thu  
 Turner, Peter R., MS7, 3:00 Thu



**U**

Ulrich, Rachel, CP3, 5:40 Thu

Upadhyay, Shashankaditya, CP4, 11:40  
Fri

**V**

van Leeuwen, Peter Jan, MS20, 2:00 Fri

*Vogl, Christopher J., MS8, 1:30 Thu*

Vogl, Christopher J., MS8, 3:00 Thu

*Vogl, Christopher J., MS18, 10:00 Fri*

**W**

Wahl, Mark D., MS15, 10:30 Fri

Wan, Hui, MS22, 1:30 Fri

Wang, Ying, MS22, 2:00 Fri

Wettlaufer, John S., MS19, 1:30 Fri

White, Alexis, MS24, 1:30 Fri

Whitehead, Jared P., CP2, 2:30 Thu

Wingate, Beth, MS18, 10:00 Fri

**Y**

Yamazaki, Hiroe, MS4, 10:30 Thu

Yao, Guagming, MS12, 4:00 Thu

*Yao, Guangming, MS7, 1:30 Thu*

*Yao, Guangming, MS12, 4:00 Thu*

Ye, Ruichao, PP1, 9:30 Thu

Ye, Ruichao, CP1, 11:00 Thu

**Z**

Zanetell, Jessica, CP5, 11:20 Sat

Zhou, Ting, MS11, 5:30 Thu

Zhu, Zhengyuan, MS2, 11:00 Thu

## MPE18 Budget

**Conference Budget**  
**SIAM Conference on Mathematics of Planet Earth**  
**September 13-15, 2018**  
**Philadelphia, PA**

**Expected Paid Attendance** 200

**Revenue**

Registration Income	\$73,810
Total	\$73,810

**Expenses**

Printing	\$965
Organizing Committee	\$1,800
Invited Speakers	\$6,600
Food and Beverage	\$11,000
AV Equipment and Telecommunication	\$15,505
Advertising	\$3,650
Proceedings	\$0
Conference Labor (including benefits)	\$36,228
Other (supplies, staff travel, freight, misc.)	\$6,108
Administrative	\$7,713
Accounting/Distribution & Shipping	\$5,045
Information Systems	\$8,534
Customer Service	\$3,291
Marketing	\$5,386
Office Space (Building)	\$3,499
Other SIAM Services	\$4,306
Total	\$119,630

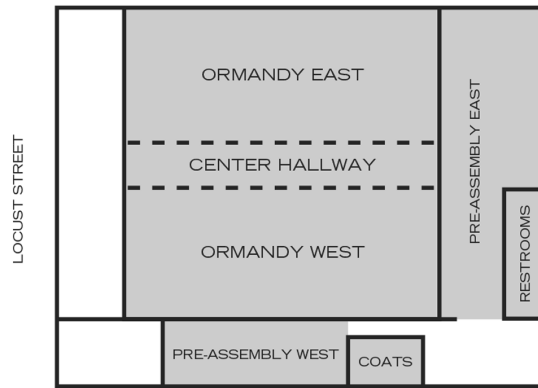
Net Conference Expense -\$45,820

Support Provided by SIAM	\$45,820
	\$0

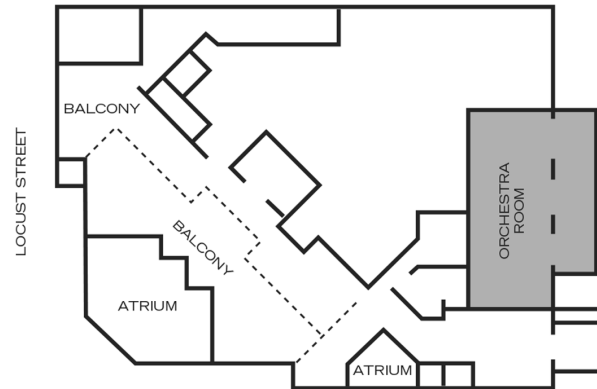
**Estimated Support for Travel Awards not included above:**

Early Career and Students	12	\$9,175
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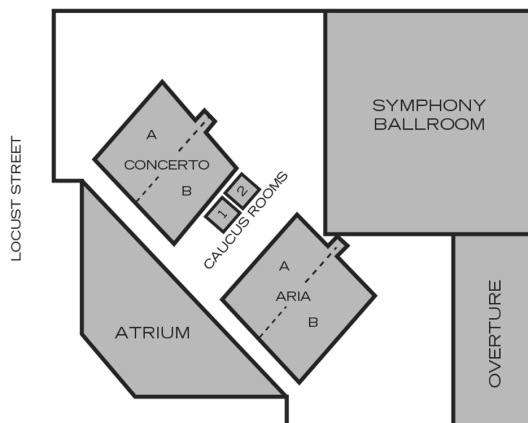
# DoubleTree by Hilton Hotel Philadelphia



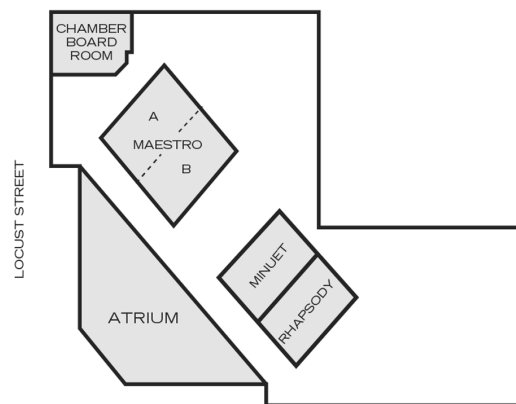
BROAD STREET  
LOBBY LEVEL



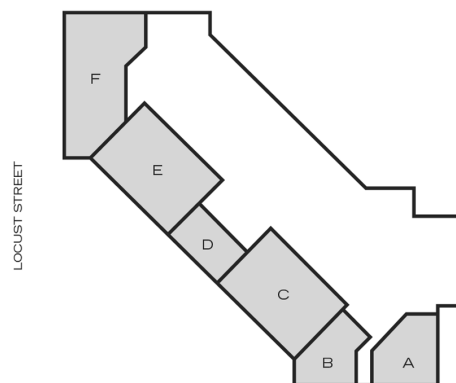
BROAD STREET  
MEZZANINE LEVEL



BROAD STREET  
THIRD FLOOR



BROAD STREET  
FOURTH FLOOR



BROAD STREET  
FIFTH FLOOR  
ASSEMBLY ON FIVE

**IP1****Where Water Meets Land: The Mathematics of the Coastal Ocean**

Coastal regions around the world are home to millions of people. These regions are economic engines and hold delicate ecosystems. However, as we have seen in the past decade or so, they are under threat from a variety of factors, including a combination of hazardous events, climate change, and over-development. In this talk, we will focus on problems related to water at the coast: the interaction of the ocean with land, the impacts of tropical storms and hurricanes, and our attempts at protecting coastal populations while facing the realities of an uncertain future. We will describe mathematical challenges and model and data driven studies to better understand these challenges.

Clint Dawson

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**IP2****Optimal Control Techniques Applied to Management of Natural Resource Models**

Optimal control techniques have been used to investigate management strategies in a variety of models for natural resources. Two applications involving FISH and FIRE will be discussed, incorporating the economic impacts. Harvesting of fishery stock has led to habitat damage. We present a model with spatiotemporal dynamics of a fish stock and its habitat. Techniques of optimal control of PDEs are used to investigate the harvest rates that maximize the discounted value while minimizing the negative effects on the habitat. The number of large-scale, high-severity forest fires occurring is increasing, as is the cost to suppress these fires. We incorporate the stochasticity of the time of a forest fire into our model and explore the trade-offs between prevention management spending and suppression spending.

Suzanne M. Lenhart

University of Tennessee and  
National Institute for Mathematical and Biological  
Synthesis  
slenhart@utk.edu

**IP3****Insights from Studying the Interface Between Sentience and Sociability in Animal Movement Patterns**

An animal's sensory capabilities and its sociability have important fitness consequences. Creatures large and small rely on their senses to navigate their way through this world and social interactions can play a significant role in defining how they interact with their environment and the decisions they make. While individual capabilities and population densities are common predictive metrics, the interplay between individual sensory processing and sociability is rarely considered when managing or mitigating for anthropogenic impacts on individuals, communities, and populations. In this presentation I will demonstrate why individual interactions are relevant and review how we may integrate them into our efforts to better manage our ecological footprint. I will show how basic sensory features can shape social feedbacks, how interactions influence individual capabilities like stamina and memory, and how even ephemeral

social ties can generate movements that deviate drastically from our expectations. Lastly, I'll discuss how studying cognition's role in animal collectives is providing novel insights into some of nature's most captivating examples of complex adaptive systems.

Bertrand Lemasson

U.S. Army Corps of Engineers  
brilraven@gmail.com

**IP4****How Energy Optimization is Responding to the Challenge of Decarbonizing Our Economies**

The future of energy production lies at the heart of worldwide efforts to reach the transition to sustainable energy systems. Success in this respect depends on shifting from fossil-based electricity generation to renewables. Intermittent renewable sources and their storage need more distributed generation, new flexibility markets, and the facilitation of the roles of prosumers and aggregators in the energy value chain. Together with the massive electrification of transport, these issues make the demand of electricity less predictable, but potentially more versatile. The new situation brings fundamental interdisciplinary challenges and presents a unique opportunity for researchers working on the Mathematics for Planet Earth. We shall discuss how to model the new paradigms for operating and pricing energy systems and describe some new problems of control and optimization that arise in this setting.

Claudia Sagastizabal

IMPA  
sagastiz.bup@gmail.com

**CP1****Krylov Subspace Spectral Methods with Coarse Grid Residual Correction for Time Dependent Partial Differential Equations**

Depending on the type of equation, finding the solution of a time-dependent partial differential equation can be quite challenging. Although modern time-stepping methods for solving these equations have become more accurate for a small number of grid points, in a lot of cases the scalability of those methods leaves much to be desired. That is, unless the time-step is chosen to be sufficiently small, the computed solutions might exhibit unreasonable behavior with large input sizes. Therefore, to improve accuracy as the number of grid points increase, the time-steps must be chosen to be even smaller to reach a reasonable solution. Krylov subspace spectral (KSS) methods are component-wise, scalable, methods used to solve time-dependent, variable coefficient partial differential equations. The main idea behind KSS methods are to use an interpolating polynomial with frequency dependent interpolation points to approximate a solution operator for each Fourier coefficient. This talk will discuss the effectiveness of using a multigrid inspired technique (coarse grid residual correction) with KSS methods to eliminate error in the low frequency components of the computed solution.

Haley Dozier

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James V. Lambers

University of Southern Mississippi  
Department of Mathematics

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## CP1

### Iterative Multi-Level Spectral Deferred Correction Scheme for the Shallow-Water Equations on the Rotating Sphere

Efficient high-order time integration schemes are necessary to capture the complex processes involved in atmospheric flows over long periods of time. In this work, we propose a high-order implicit-explicit numerical scheme that combines Multi-Level Spectral Deferred Corrections (MLSDC) and the Spherical Harmonics (SH) transform to solve the shallow-water equations on the rotating sphere. The iterative temporal integration is based on a sequence of corrections distributed on coupled space-time levels to perform a large fraction of the calculations on a coarse representation of the problem, and therefore, reduce the time-to-solution. In our scheme, referred to as MLSDC-SH, the spatial discretization plays a key role in the efficiency of MLSDC, since the SH transform allows for accurate transfer functions between space-time levels that preserve important physical properties of the solution. The SH transform also leads to an optimized local solver for the implicit linear systems. Using test cases commonly used in numerical atmospheric modeling, we demonstrate the excellent stability properties of MLSDC-SH. We show that our implicit-explicit MLSDC-SH achieves up to fifth-order accuracy in time and that it reduces the computational cost compared to single-level integration schemes. These results are a first step towards a successful parallel-in-time integration of the full atmospheric dynamics using the Parallel Full Approximation Scheme in Space and Time (PFASST).

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Martin Schreiber

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College of Engineering, Mathematics and Physical Sciences  
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Michael Minion

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Stanford University  
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## CP1

### Massively Parallel Computation of Earth's Normal Modes

We developed and exploited a highly parallel algorithm to compute the Earth's normal modes of the elastogravitational system, which is discretized via the mixed finite element method on unstructured tetrahedral meshes. The eigenmodes of the resulting generalized eigenvalue problem were extracted with a Lanczos approach combined with polynomial filtering. In contrast with the standard shift-and-invert and the full-mode coupling algorithms, the polynomial filtering technique is ideally suited for solving large-scale three-dimensional interior eigenvalue problems since it remarkably enhances the memory and computational efficiency without loss of accuracy. The high efficiency and scalability of this approach are demonstrated on Stampede2 at the Texas Advanced Computing Center. The direct calculation of the normal modes of a three-dimensional heterogeneous Earth is made feasible via a

combination of multiple matrix-free methods, which allow us to deal with fluid separation and self-gravitation efficiently.

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Ruipeng Li

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Lawrence Livermore National Laboratory  
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Yuanzhe Xi, Yousef Saad

University of Minnesota  
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Maarten de Hoop

Rice University  
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## CP1

### Simulation of Earthquakes with Self-Gravitation and Rotation Based on Discontinuous Galerkin Method

We present the methodology for modeling seismic wave propagation in the discretized 3-D Earth model with the full complexity containing general heterogeneity, self-gravitation, rotation, and fluid-solid interfaces. We take specific consideration for the effects of self-gravitation beyond Cowling approximation by solving Poisson-Laplace equation for the potential perturbation of non-spherical Earth, using domain decomposition with interconnection by Robin boundary conditions, which permits the weak formulation to reside in finite domain. We employ the IPDG for the solution of gravitational potential, and the DG method with modified penalty flux for the equation of motion, which is based on the sesquilinear form with proofs of well-posedness.

Ruichao Ye, Maarten de Hoop

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Rob van der Hilst

Massachusetts Institute of Technology  
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## CP1

### Shadowing for Data Assimilation with Imperfect Models

Data assimilation is used for state and parameter estimation of physical systems such as weather. We study the smoothing data assimilation problem for long trajectories of chaotic systems. Chaotic systems exhibit sensitive dependence on initial conditions, which make state and parameter estimation non-trivial and, if one intends to do forecasting, also crucially important. Shadowing methods for data assimilation are well-suited to take into account large amounts of data spread over long time intervals simultaneously. The focus on finding model trajectories helps in preserving non-linear properties of the model, such as for example attractors. The strength of shadowing methods lies in their ability to find long model trajectories that stay as close as possible to observations. However, if there



are (structural) imperfections in the model, even the best model trajectory may become incompatible with those observations. We shall discuss how shadowing algorithms may be adapted to deal with this. The resulting shadowing algorithms are related to weak constraint 4DVar methods and we shall discuss some similarities and differences.

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Svetlana Dubinkina  
CWI, Amsterdam  
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## CP2

### The Contribution and Influence of Coherent Mesoscale Eddies Off the North-West African Upwelling on the Open Ocean

Eastern Boundary Upwelling zones include some of the most productive ecosystems in the world, particularly the North-West (NW) African upwelling which presents one of the world's major upwelling regions. This latter is forced by the equator-ward trade winds which are known to exhibit mesoscale instabilities; thus, in addition to upwelled cold and nutrient-rich deep waters, significant energy is transferred into mesoscale fronts and eddies in the upper ocean. Oceanic structures of type eddies are well known to stir and mix surrounding water masses. However, they can also carry and transport organic matter and marine in a coherent manner. Here, we are interested in those that remain coherent. The Aim of this work, is to understand the impact of mesoscale eddies off the NW African margin on the open ocean. Our approach to analyze such coherent eddies is based upon the use of our recently developed technique from nonlinear dynamics theory, which is capable of identifying coherent vortices and their centers in an automatic manner. The role of these mesoscale eddies is investigated based on a statistical study of eddies properties off NW African margin (cyclone/anticyclone, their lifetimes, traveled distance, transnational speeds, quantity of water masses transported to the open ocean). This statistical study is carried out over a set of 24 years (from 1993 to 2016) of sea surface velocity field derived from satellite surface altimetry under the geostrophic approximation.

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Khalid Daoudi  
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Hussein Yahia  
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hussein.yahia@inria.fr

Khalid Minaoui  
LRIT, MOHAMMED V UNIVERSITY IN RABAT,  
MOROCCO  
khalid.minaoui@fsr.ac.ma

## CP2

### Locally Stationary Spatio-Temporal Interpolation

### of Argo Profiling Float Data

Argo floats measure sea water temperature and salinity in the upper 2,000 m of the global ocean. Statistical analysis of the resulting spatio-temporal data set is challenging due to its nonstationary structure and large size. We propose mapping these data using locally stationary Gaussian process regression where covariance parameter estimation and spatio-temporal prediction are carried out in a moving-window fashion. This yields computationally tractable nonstationary anomaly fields without the need to explicitly model the nonstationary covariance structure. We also investigate Student- $t$  distributed microscale variation as a means to account for non-Gaussian heavy tails in Argo data. Cross-validation studies comparing the proposed approach with the existing state-of-the-art demonstrate clear improvements in point predictions and show that accounting for the nonstationarity and non-Gaussianity is crucial for obtaining well-calibrated uncertainties. This approach also provides data-driven local estimates of the spatial and temporal dependence scales for the global ocean which are of scientific interest in their own right.

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SAMSU and University of North Carolina at Chapel Hill  
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Michael Stein  
University of Chicago  
stein@galton.uchicago.edu

## CP2

### Fast and Slow Resonant Triads in the Two Layer Rotating Shallow Water Equations

The one-layer rotating shallow-water equations are a commonly used model reduction of the stratified rotating flows. Here we extend this to a two-layer fluid system where both interfaces are free. We take the commonly used quasi-geostrophic limit, while maintaining the non-geostrophic inertia-gravity wave modes, to investigate the full set of wave interactions in the system. Past analysis of the wave interactions in this system has fixed the top layer using a rigid lid assumption. Allowing the second layer to have a completely free interface we analyse the triad resonances found amongst the gravity wave interactions, finding that new resonances are permitted. Consideration of these resonances shows some interesting features that depend on the Burger number of the system. These resonances include interactions between large and small wave numbers, with implications in geophysical fluid dynamics.

Alex Owen, Roger Grimshaw, Beth Wingate  
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B.Wingate@exeter.ac.uk

## CP2

### Extraction and Classification of Convectively Coupled Equatorial Waves Through Eigendecomposition of Koopman Operators

We study convective organization in the Earth's tropics. For that, we apply a recently developed technique for feature extraction and mode decomposition of high-dimensional data generated by ergodic dynamical systems. The method relies on constructing low-dimensional representation of spatiotemporal signals using eigenfunctions of the Koopman operator. Koopman operators are a class

of operators in dynamical systems theory that govern the temporal evolution of observables. They have the remarkable property of being linear even if the underlying dynamics is nonlinear, and provide, through their spectral decomposition, natural ways of extracting intrinsic coherent patterns and performing statistical predictions. Here, data-driven approximation of Koopman operator is obtained from time-ordered unprocessed data through a Galerkin scheme applied to basis functions computed via the diffusion maps algorithm. We apply this technique to brightness temperature data from the CLAUS archive and extract a multiscale hierarchy of spatiotemporal patterns spanning many timescales. Notably, we detect for the first time, without prefiltering the input data, modes of variability acting on timescales of days (convectively coupled equatorial waves) to decades (ocean circulation). Furthermore, we discuss the dynamical nature of coherent structures corresponding to atmospheric waves, in particular their propagation characteristics and interaction with other scales.

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University of Wisconsin-Milwaukee  
slawinsk@uwm.edu

Dimitrios Giannakis  
Courant Institute of Mathematical Sciences  
New York University  
dimitris@cims.nyu.edu

## CP2

### Quantifying Historical Indonesian Seismicity Via Bayesian Statistical Inversion

Recently published translations of Dutch colonial records from the 17th, 18th, and 19th centuries (the so-called ‘Wichmann catalog’) suggest that large Indonesian tsunamis may have occurred with more intensity, higher frequency, and in more locations than was previously understood. In a Bayesian setting, these anecdotal observations form the basis for an inverse problem wherein the input parameters of the forward model describe the earthquake type and location. With the careful construction of a universal prior on certain geometric parameters, Markov Chain Monte Carlo methods are employed to compute a posterior distribution that describes the location, strength, and geometric constraints of these historical earthquakes. As seismic events are repetitive on geologic time-scales, this posterior distribution describes the potential for a recurring mega-thrust earthquake and tsunami that would devastate one of the most densely populated coastal regions in the world.

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Brigham Young University  
whitehead@mathematics.byu.edu

## CP3

### Modeling Ice of the Mixed-Phase Clouds

The Arctic mixed-phase clouds have a significant role for the Arctic climate due to their ability to absorb and reflect radiation. Since the climate change is amplified in polar areas, it is vital to apprehend the mixed-phase cloud processes. From a mathematical modeling point of view, combining turbulence, clouds, aerosols, rain and ice is a computationally demanding task. To explore the role of ice particles in these clouds in necessary detail, we have implemented ice microphysics to a large-eddy simulation cloud

model UCLALES-SALSA (Tonttila et al., *Geosci. Mod. Dev.*, 10:169-188, 2017). The model includes aerosol-cloud interactions represented with discretised size bins in the SALSA module (Kokkola et al., *Atmos. Chem. Phys.*, 8, 2469-2483, 2008). The dynamical part of the model is based on the UCLA-LES model (Stevens et al., *J. Atmos. Sci.*, 56, 3963-3984, 1999). The main idea behind LES is to cut down the computational cost by ignoring the smallest length scales by low-pass filtering the Navier-Stokes equations. We tested the implementation of ice microphysics by initializing cloud simulations as described by Ovchinnikov et al. (*J. Adv. Model. Earth Syst.*, 6, 223-248, 2014). The initial state is based on observations from the Indirect and Semi-Direct Aerosol Campaign (ISDAC). We compared our results with other model results and they match well. Overall, the updated UCLALES-SALSA model represents a good compromise between accuracy and computational expense.

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## CP3

### Modelling Hydrological Processes As Nature Itself Does

Although partial differential equations (PDEs) are well-established and widely adopted to describe hydrological processes such as subsurface flow and surface flow, their use in practice typically requires (advanced) numerical methods, unavoidably giving rise to approximation and truncation errors. Moreover, for increasingly more hydrological processes it has been pointed out – and in some cases even proofed – that PDEs fail at describing well-known phenomena, such as finger-like infiltration fronts that occurs when water infiltrates a dry soil. Here, we present an alternative modelling paradigm based on continuous cellular automata that describe the governing physical processes at micro level by resorting at that level to a rigorous formulation of conservation laws. More precisely, in the case of water flow, we explicitly account for the movement of water between neighboring microscopically small volumes. In this way, there is no more need to move up to the continuum limit where one finds a PDE, which then, however, has to be discretized again. With the computing resources that are nowadays available, this allows to simulate natural processes in a more direct way. We illustrate this approach for surface flow in a 25km watershed in Belgium, and compare our results with those obtained by means of a probability

distributed rainfall-runoff model and field observations.

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### CP3

#### Mathematical Modeling, Analysis and Data Validation of Wind Turbines System

We present results for modeling, analysis and data validation for the wind turbines system. The system proposed in transfer functions by industry is taken and transferred into a dynamical time domain-based nonlinear system. We perform a complete mathematical analysis and computation for the system, including stability, sensitivity and simulation of extreme scenarios. The results show a lot of new insight that can help industry improving the current wind turbines system, as there are some inherent problems found in the system. The model major output (the generated electric power) is validated versus real measured data, which support the seriousness of the claims made in our study.

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### CP3

#### Dynamical Modeling of Social and Epidemiological Factors for Public Health

Modeling Social and Epidemiological Factors that affect Public Health attracts increasing attention from scholars and authorities to understand their dynamical behavior. Dynamic modeling of health-related problems includes multiple socio-ecological approaches that incorporate health risk behaviors, demographical and environmental factors, socio-economic status, use of resources and control programs. Leading work in this field discusses dynamical modeling for infectious diseases like Visceral Leishmaniasis, Ebola, MERS, socio-behavioral contagions like high school dropouts, substance abuse, non-adherence to treatment, and increasing water-stress problems that link water-borne diseases with increasing socio-economic disparity issues. Education, health and preventive systems require a deep exploration of the connections between social underlying processes to explain and help correcting disparities and failures of diagnosis. The lecture will foster the work in direction of developing data-driven models that capture these dynamics of behavioral and social determinants of contagion spread in order to create an adequate set of policies with sound scientific support.

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### CP3

#### Traffic Flow Control Via Autonomous Vehicles and Its Environmental Impact

In a near future, a few connected and automated vehicles (CAVs) will be on our roadways. We demonstrate, via analysis, simulations, and experiments, that even a small percentage of CAVs, properly controlled, can be used to prevent stop-and-go traffic waves, and steer the heterogeneous system of human-CAV traffic into a smooth flow

regime. These findings motivate a paradigm shift in traffic flow control, from Eulerian (variable speed limits, ramp metering) to Lagrangian actuators. Moreover, we quantify the overall reduction in fuel consumption and emissions that traffic can experience due to these new means of control.

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### CP3

#### Development of An Intensification Index for Land Use/Land Use Change in the Northwestern U.S., 1990-2010

Land use and land cover maps for the northwestern U.S. have typically failed to accurately depict low density ex-urban development. As one of the fastest-growing types of land cover and land use change (LCLUC) in this region, inaccuracies have limited efforts to assess vulnerability of wildland ecosystems. Under NASA's LCLUC program, this study uses fine-scale aerial imagery to quantify exurban development in an effort to better understand context-dependent drivers. A stratified sampling technique was developed using geospatial data layers to define strata, and yielding a total of 96 strata. We interpreted land use indicators in 3,090 plots at scales of three and sixteen hectares, and in 618 plots at a scale of 96 hectares, at 1990, 2000, and 2010 time intervals. Due to the resolution of ancillary data sets, analyses were conducted at the 96-hectare scale. Aggregating data to this scale can be problematic, as both fine-scale and rural development are masked by the presence of more intense land use. Particularly, change in secondary and tertiary land use indicators are lost. We hypothesize that these indicators are useful predictors of low-density development. By leveraging data to develop a continuous variable describing land use intensification, we hope to identify finer-scale development. These results will improve future analyses of hypothesized drivers of low-density development, prediction modeling, and inform greater wildland ecosystems vulnerability assessments.

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#### CP4

##### On One Biological Model in Mathematical Point of View

Applied mathematics plays key role in environmental and natural sciences. The system of two-dimensional nonlinear partial differential equations describing the process of vein formation in higher plants as well as its generalization is considered. Economical finite-difference scheme is constructed and absolute stability and convergence of that scheme are proven. Rate of convergence is given too. Generalization of the proposed model to the multi-dimensional case is considered too. The modern computer opportunities give the possibility for the direct numerical solution of the multi-dimensional problem, but the corresponding algorithms are non-economical and difficult for realization. Therefore, naturally arises the question of constructing the economical algorithms for solution of multi-dimensional problems. Approach proposed in our note can be applied for multi-dimensional cases as well to get numerical solution by economical algorithms. Using modern computer software the various numerical experiments are carried out for different dimensionality. The comparison analysis of the obtained results to other methods as well as to the theoretical findings are given. Conducted analysis justify the efficiency of the constructed schemes.

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#### CP4

##### The Effect of Invasive Epibionts on Crab Mussel Communities

Blue mussels (*Mytilus edulis*) are an important keystone species that are severely declining in areas such as the Gulf of Maine. The exact reasons for this decline are unknown, but could be attributed to a variety of complex factors. One particular factor, invasion of crab-mussel communities by epibionts has remained unexplored mathematically. Based on classical optimal foraging theory and anti-fouling defense mechanisms of mussels, we derive an ODE model for crab-mussel interactions in the presence of an invasive epibiont, such as the colonial ascidian *Didemnum vexillum*. The dynamical analysis leads to results on stability, global boundedness and bifurcations of the model. Next, via optimal control methods we predict various outcomes, from the viewpoints of the different species involved. Our results have key implications for preserving mussel populations in the advent of invasion by non-native epibionts. In particular they help us understand the changing dynamics

of local predator-prey communities, due to *indirect* effects that such epibionts confer.

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#### CP4

##### Insights into Stochastic Dynamic Programming from Ergodic Theory

Organisms across taxa must continuously make decisions in the face of uncertainty. This includes both conscious decisions (e.g., an animals choice of foraging habitat) and decisions made on a physiological level (e.g., whether a plant should allocate energy to reproduction or growth). Many questions in the biological sciences can thus be framed as optimal control problems. One method commonly used to determine an individuals optimal decision is stochastic dynamic programming. This method determines the optimal decision for an individual in each possible state at any given time using the numerical method of backwards induction. In many cases, the optimal decisions are stationary for all time steps sufficiently far away from the end of the time horizon. While these stationary decisions are often determined numerically, we draw on analytic results from the ergodic theory of nonnegative matrices to explore both the stationary decisions and the nature of convergence. This allows us to explain some non-intuitive results occurring in biologically realistic applications.

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#### CP4

##### Small Organisms Causing Big Problems: Modeling Heterosigma Akashiwo

A specific species of phytoplankton, *Heterosigma Akashiwo*, has been the cause of harmful algal blooms (HABs) in waterways around the world causing millions of dollars in damage to farmed animals and destroying ecosystems. Developing a fundamental understanding of their movements and interactions through phototaxis and chemotaxis is vital to comprehending why these HABs start to form and how they can be prevented. In this talk, we attempt to create a complex and biologically accurate mathematical and computational model reflecting the movement of an ecology of plankton, incorporating phototaxis, chemotaxis, and the fluid dynamics that may be affecting the flow. We present and analyze a succession of models together with a sequence of laboratory and computational experiments that inform the mathematical ideas underlying the model. Lastly, we discuss further experiments and research necessary for our continued insight into problems that we are encountering, such as planktons formation of aggregations, the gaps in-between those aggregations, and the difficulty of expanding our models to higher dimensions biologically, mathematically, and computationally.

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#### CP4

##### Species Extinctions in a Population Model with Different Kinds of Environmental Forcing

The extinction of species is a core process that affects the diversity of life on Earth. One way of investigating the causes and consequences of extinctions is to build conceptual ecological models, and to use the dynamical outcomes of such models to provide quantitative formalization of changes to Earth's biosphere. In this paper we propose and study a conceptual resource model that describes a simple and easily understandable mechanism for resource competition, generalizes the well-known Huisman and Weissing model (1999), and takes into account species self-regulation, extinctions, and time dependence of resources. We use analytical investigations and numerical simulations to study the dynamics of our model under chaotic and periodic environmental forcing oscillations, and show that the stochastic dynamics of our model exhibit strong dependence on initial parameters. We also demonstrate that extinctions in our model are inevitable if an ecosystem has the maximal possible biodiversity and uses the maximal amount of resources. Our conceptual modeling provides theoretical support for suggestions that nonlinear processes were important during major extinction events in Earth history.

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#### CP4

##### A Structural Perspective on Ecological Connectivity in Western Himalayas

Ecological connectivity on landscape level of anemochory (wind dispersal) of some Himalayan moist temperate forest species in the Western Himalaya region is studied using a network-theoretic modeling approach. A network is derived for seed dispersion model of target floral species where habitat patches (vertices) are adjacent if the distance between them is less than a pre-justified threshold. The study aims to understand the impact of the organization of the ecological network on the process of flow of ecological information at the local as well as global scale. Gharwal region and eastern Himachal Pradesh of Indian Himalaya are established as the critically important geographical areas for passage of ecological information (seeds) across the network by using centrality indices. We find that the network of forest patches in Western Himalaya region showcase both a scale-free as well as a small-world network topology. Thus ecological information propagates rapidly and evenly on a local scale. Hubs in the network are identified as important centers for dissemination of seeds and need to be conserved against a potential attack by malicious agents and climate change. The network showcase a well-formed community structure. In aggregate, the results of this structural study indicates that the focal collection of anemochory floral species studied in this work are likely to thrive across the ecological network of forest patches in the Western Himalaya region over time.

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#### CP5

##### Mathematical Analysis of the Effect of Some Climatic Factors and Altitude on the Plant-Herbivore Interactions

In ecology, plant-herbivore relationships are the crucial link generating animal biomass from mere sunlight through photosynthesis. These interactions are basic in understanding the ecology and evolution of virtually any ecosystem. The relationship depends also on the environmental factors like rainfall, temperature and altitude. Understanding the trend analysis of these environment-dependent interactions will help to make better predictions and to suggestion any possible conservation mechanisms. Many of existing mathematical models for plant-herbivore interactions and their analysis do not include these environmental factors. In this study, a mathematical model that incorporates variations of some of the parameter values due to changes in temperature and rainfall is formulated, and the model is used to determine necessary threshold values for co-existence. To validate the results of the mathematical model, real data from the Genale-Dawa river basin in the south eastern part of Ethiopia, is collected and used. The river basin represents the three major climatic zones of the country, the cool zone, temperate zone and hot lowlands. Hence, this data is used also to compare the trend values obtained for the three different climatic zones and it is applied to check the effect of altitude on the entire dynamics.

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#### CP5

##### A Geometric Model for the Dynamics a Barrier-Marsh-Lagoon System under Sea-Level Rise In-



## cluding Blue Carbon Storage

Barrier islands and their associated backbarrier environments (e.g., marsh, lagoons) support diverse ecologic communities, provide a wide range of ecosystem services, and serve as long-term carbon storage reservoirs. Despite their economic and ecological importance, however, there exists a critical gap in understanding how barriers will respond to sea level rise over the coming century and whether barrier-backbarrier systems will store or release carbon as they migrate landward. To address this knowledge gap, I have extended a recently developed morphodynamic model for barrier-backbarrier evolution to account for marsh restoration activities and carbon storage dynamics. The model assumes an idealized cross-section that includes a barrier island, a backbarrier marsh, a lagoon, and an inland marsh. Overwash, the key process that connects the barrier shoreface with the marsh-lagoon ecosystem, is a function of barrier geometry, and accounts for the role of the backbarrier marsh. The problem reduces, in its most general form, to solving a coupled system of ten non-linear ODEs. This solution can be achieved by using a simple explicit Euler based time stepping algorithm. The simplicity of the model allows exploration across a wide range of parameter values. Overall, model results highlight the importance of considering barriers and their associated backbarriers as part of an integrated system in which sediment is exchanged.

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## CP5

### The Mid-Pleistocene Transition Explored Through a Bistable Delay Model

We present a study of a delay differential equation (DDE) model for the Mid-Pleistocene Transition (having occurred between 1200 and 800 kyr BP). The model has a bistable region consisting of a stable equilibrium along with a large amplitude stable periodic orbit. We analyse the behaviour of the model within this region when subjected to periodic and quasiperiodic (astronomical) forcing, and how the forcing amplitude affects the response. In the periodically forced case, there is a sharp transition in responses when increasing the parameter for forcing strength. We show that the forcing amplitude at which we observe this transition is far away from any bifurcations. The only alternative mechanism is that the initial condition of our simulation moves from the basin of attraction of the small-amplitude response to the basin of the large-amplitude response. In the quasiperiodically forced case two transitions are seen, one in time and one in forcing strength, however the mechanism is different. We show through finite-time Lyapunov exponents that there is an attracting response prior to any transition. This makes the transition independent of initial history. We also explore the sensitivity of the phase of oscillation to noise, and introduce the idea of noise-induced desynchronisation.

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## CP5

### Tipping Events in Stochastically Perturbed Linear Filippov Systems

This project explores a system of stochastic differential equations with piecewise smooth linear drift, piecewise additive white noise, and external periodic forcing. The goal of this study is to determine the probability of a tipping event between two metastable states, such as limit cycles or fixed points. Methods involve Monte Carlo simulations, calculations of exit time from basins of attraction, numerical simulations of Fokker-Planck equations, and statistical measurements such as expected value and variance. The bifurcation points of the system are analyzed in connection with noise to find the most probable location in the phase for a tipping event and the most probable transition path. This system is then used as a proxy for the model of thermodynamics in Arctic sea ice described by I. Eisenman and J.S. Wettlaufer.

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## MS1

### Viability with Multiple Budget Constraints: Theory and Numerical Applications

In this talk we consider a class of viability problems for a controlled dynamical system

$$x'(t) = f(x(t), u(t)), \quad t \geq 0, \quad u(t) \in U, \quad x(t) \in K$$

under path-dependent constraints of integral type :

$$\int_0^t \ell_i(x(s), u(s)) ds \leq b_i, \quad i = 1, \dots, p.$$

It is shown that the viability of such a system can be characterized from the viability kernel of an auxiliary dynamical system with augmented state vector. It is also shown that the boundary of this augmented viability kernel allows to define the set of Pareto optimal budget vectors  $b = (b_1, \dots, b_p)$  for each initial condition  $x_0$ . These results are illustrated with some numerical applications in the domain of sustainable management of natural resources.

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## MS1

### Set of Sustainable Thresholds: An Approach to Operationalize Sustainability Definitions

What is the ability of a natural resource to satisfy some constraints (objectives), usually in conflict, from now over time? (e.g., to sustain a minimal level of biomass and to get a minimum profit due to harvesting). What is the minimal percentage of infected people that a city can sustain as upper bound for a given healthcare budget? The viability theory has addressed this type of problems for more than

30 years. In general, given a controlled dynamical system under state and control constraints, the idea is to find the initial conditions (e.g., current state of a natural resource or current percentage of infected people), for which it can be assured there exists a future viable trajectory, that is, a way to manage the associated dynamical system over time in order to satisfy the desired constraints. The set of these (initial) states is called the viability kernel, a key concept in the mentioned theory. During last years we have analyzed a different problem but strongly related: given an initial condition, what are the constraints (parametrized by thresholds) that can be satisfied from now on? We call the set of these constraints the *set of sustainable thresholds*, which actually is the inverse mapping of the viability kernel. In this talk I will present some interpretations of the set of sustainable thresholds, advantages with respect to the viability kernel, methods for computing this set, and applications related to fishery management and epidemiology.

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## MS1

### Optimal Harvesting Strategies for Timber and Non-Timber Forest Products in Tropical Systems

Harvesting wild plants for non-timber forest products (NTFPs) can be ecologically sustainable without long-term consequences to the dynamics of targeted and associated species but it may not be economically satisfying because it fails to provide enough revenues for local people over time. Three decades of studies on the sustainability of NTFP harvest for local peoples livelihood have failed to successfully integrate these socio-economic and ecological factors. We develop and analyse a simple model that incorporates non-lethal harvest implicitly through the population growth rate of plants and lethal harvest explicitly through permanent removal of whole plants, with additional synergistic effects on population growth rate. We apply optimal control theory to investigate optimal strategies for the combinations of non-lethal (e.g., NTFP) and lethal (e.g., timber) harvest that minimize the cost of harvesting while maximizing the benefits (revenue) that accrue to harvesters and the conservation value of harvested ecosystems. Optimal harvesting strategies include starting with non-lethal NTFP harvest and postponing lethal timber harvesting to begin after a few years. We clearly demonstrate that slow growth species have lower optimal harvesting rates than fast growth species. However, contrary to expectation, the effect of species lifespan on optimal harvesting rates was weak suggesting that life history is a better indicator of species resilience to harvest than lifespan.

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## MS1

### Socio-Ecological Model for Sustainable Development Based on SEIC and Complex Networks

Practical cases of sustainability have benefited from mathematical models since some ideas that are sometimes counterintuitive, can be foreseen. Lately, hybridization techniques have been proposed to improve modeling. Mixing models are considered taking advantage of complex net-

works, non-linear dynamics, and stochasticity. Control and optimization issues can be included in the model that sometimes results in piecewise-smooth dynamic systems. In this work, we consider a development model through multiplex complex networks. Each layer takes into account the trade and exploitation of different resources in the territory and different social characteristics. Modeling is performed numerically through systems of non-linear differential equations, which include stochastic perturbations. SEIC model is considered primarily for the dimensions in each node. The general model presented finally applies to a real case in the Choc region (Colombia). Forests, land, fisheries, and mining are the primary natural resources available. Also, intrinsic cultural traditions are taken into account. Then we perform numerical simulations, considering the estimated parameters from the available data. Conclusions are finally derived from the simulations, and several policies are proposed with regards to different scenarios related to climate and economic investments in the regions. These new policies consider the path from conventional adaptation-mitigation to transformation.

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## MS2

### Theory, Methods, and Algorithms in Remote Sensing Science

Massive remote sensing data sets are now collected routinely by NASA, NOAA, and other space agencies. These data promise to provide new insights into Earth's systems and their interactions with humans if these data can be distilled to provide useful information. However, the sizes of these data sets, and their placement in distributed archives around the world, impede efficient use of many modern statistical and mathematical methods that could potentially increase their value for science and decision support activities. In this talk, I will give an overview of some important aspects of remote sensing data, the analysis questions posed by them, and motivations for the work undertaken by the SAMSI Working Group on Remote Sensing.

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## MS2

### A Notional Framework for a Theory of Data Analysis Systems

Modern, large scale data analysis typically involves the use of massive data stored on different computers that do not share the same file system. Computing complex statistical quantities, such as those that characterize spatial or temporal statistical dependence, requires information that crosses the boundaries imposed by this partitioning of the data. To leverage the information in these distributed data

sets, analysts are faced with a trade-off between various costs (e.g., computational, transmission, and even the cost of building an appropriate data system infrastructure) and inferential uncertainties (bias, variance, etc.) in the estimates produced by the analysis. In this talk we introduce a framework for quantifying this trade-off by optimizing over both statistical and data system design aspects of the problem. We illustrate with a simple spatial analysis example, and discuss how it may be extended to more complex settings.

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## MS2

### Optimization Methods in Remote Sensing

Statistical estimation and inference for large data sets require computationally efficient optimization methods. Remote sensing retrievals are, in fact, estimates of the underlying true state, and their optimization routines must necessarily make compromises in order to keep up with large data volumes. A sub-group of the Remote Sensing Working Group of the SAMSI Program on Mathematical and Statistical Methods for Climate and the Earth System is investigating how optimization in Bayesian-inspired retrievals and off-line statistical methods could be made more computationally efficient. In particular we will focus on a case study of intersatellite calibration for the High Resolution Infrared Radiometer Sensor (HIRS) onboard the NOAA Polar Operational Environmental Satellite (POES) series, and how that impacts the subsequent retrieval of atmospheric temperature and humidity profile observations

from 1980-present.

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## MS2

### Statistical Approaches for Un-Mixing Problem and Application to Satellite Remote Sensing Data

Remote sensing data from satellite with high temporal resolution typically have lower spatial resolution, with one pixel often spanning over a square kilometer. The signal recorded by such satellite at a pixel is typically a mixture of reflectance from different types of land covers within the pixel, resulting in a mixed pixel. In this talk we introduce a couple of parametric and non-parametric statistical approaches to deal with the un-mixing problem which integrate information from multiple sources. The methodology is applied to data from the SMOS (Soil Moisture and Ocean Salinity) mission and the OCO-2 (Orbiting Carbon Observatory 2) mission, which motivated this research.

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## MS3

### Estimating Extreme Storm Surge Levels: A Statistical Perspective

Storm surge is an abnormal rise of water, largely induced by the strong winds of a hurricane, that could cause tremendous damage in coastal areas. Therefore, it is critically important to estimate the surge levels especially those extreme ones. However, the estimation of surge levels poses an unique statistical challenge due to the rareness of hurricanes in space and time. To overcome this difficulty, the joint probability modeling of hurricane characteristics combined with hydrodynamic simulations is currently the

recommended method by the Federal Emergency Management Agency (FEMA) for calculating the extreme surges in terms of 10-, 50-, 100-, and 500-year return levels. In this talk, I will present the FEMA's approach from a statistical perspective starting from the estimation of the distributions of hurricane characteristics to the design and analysis of the hydrodynamic simulations. I will highlight the challenges and how we might improve the current practice in terms of estimation and uncertainty qualification.

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### MS3

#### Return Level Estimation for Large Spatial Extremes

Abstract Not Available At Time Of Publication.

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### MS3

#### Max-Infinitely Divisible Models for Spatial Extremes Using Random Effects

Distinguishing between the subtly different dependence characteristics implied by current families of stochastic process models for spatial extremes is difficult or impossible based on exploratory analysis of data that is by definition scarce. Furthermore, different choices of extremal dependence classes have large consequences in the analysis they produce. I will present stochastic models for extreme events in space that are 1) flexible enough to transition across different classes of extremal dependence, and 2) permit inference through likelihood functions that can be computed for large datasets. These modeling goals will be accomplished by representing stochastic dependence relationships conditionally, which will induce desirable tail dependence properties and allow efficient inference through Markov chain Monte Carlo. I will present models for spatial extremes in the class of max-infinitely divisible processes, a generalization of the limiting max-stable class of processes which has received a great deal of attention. This work extends an old family of max-stable models based on a conditional hierarchical representation to the more flexible max-id class, thus accommodating a wider variety of extremal dependence characteristics while retaining the

structure that makes it computationally attractive.

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### MS3

#### Influence of Climate Change on Extreme Weather Events

Abstract Not Available At Time Of Publication.

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### MS4

#### Multidimensional Tracer Transport in Atmospheric Models

Tracer transport is an essential component of an atmospheric model. For any tracer transport algorithm there is a trade off between accuracy and efficiency. This talk will investigate novel numerical methods that allow high-order accuracy without a significant increase in computational cost. The focus will be on multidimensional flow and how these numerical methods capture the associated cross-terms. Other desirable properties, such as monotonicity and the use of long time steps, will also be discussed. A set of newly developed idealised test cases will be used to show the performance of these tracer transport schemes within the framework of an atmospheric model.

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### MS4

#### Climate Modeling with the Spectral-Element Method

For a while NCAR has been using a spectral-element dynamical core in CAM (Community Atmosphere Model). The deliberations from developing a dynamical core in an idealized framework to realistic coupled climate modeling are many. I will be talking about the further developments of the original version of spectral-elements (referred to as CAM-HOMME; High-Order Modeling Methods Environment) in CAM. This includes moving to a dry-mass vertical coordinate, changing the details of hyperviscosity, introducing thermodynamically active condensates, replacing spectral-element advection with a finite-volume scheme, and running physics on a quasi-uniform grid rather than a non-uniform quadrature grid.

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#### MS4

##### **Breaking the Boundary Between "Dynamics" and "Physics" in the Gray-Zone**

The Gray Zone describes a regime of numerical simulation of the atmosphere where convection processes are "permitted" but not resolved. It is becoming topical since super-computer capability is now bringing this zone within reach. This is challenging for climate simulation since these processes are critical to obtain a realistic climate; if they are not resolved then they can be replaced by subgridscale parameterisations. This talk will address recent research at NOAA-GFDL addressing the problem of how to couple parameterised physics and resolved dynamics in this regime.

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#### MS4

##### **Moving Meshes for Atmospheric Modelling over Orography**

This talk is about the application of an r-adaptive moving mesh method to atmospheric simulations over orography. R-adaptivity means mesh redistribution where the local resolution varies without changing the connectivity of the mesh. We use an optimal transport technique to generate a mesh which is not tangled and equidistributed with respect to a monitor function. A problem when introducing orography on a horizontally moving mesh is that the shape of orography could change every time step. Therefore the volume of the domain is changeable as the mesh moves, which leads to unphysical compression or expansion of the model fluid. To solve this problem, we introduce a parameter which tracks the change in cell volumes caused by the change in the shape of orography. We will describe the implementation of the parameter and demonstrate, through a numerical experiment using the 3D advection equation, that this new parameter avoids unphysical compression or expansion of the fluid while conserving mass. We will explain some of our recent work on extending this approach to different sets of equations.

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#### MS5

##### **A Fishery Model for Harvesting of the Black Sea Anchovy on the South Coast of the Black Sea**

Abstract Fishery management is an increasingly useful tool in the commercial fishing industry to conserve and manage natural renewable food resources. One method for sustainable fishery stocks and maintaining our renewable food resources is optimal control theory to investigate harvesting strategies for maximizing the discounted net value of a fish population. Since fish do not exist in a habitat by themselves, the presence of predators and/or competing species is an important feature in harvest and conservation in a

food web. We present a spatial food chain model for harvesting of Black Sea Anchovy on the South Coast of the Black Sea. The Anchovy stock coupled with a prey species and a predator species is modeled using nonlinear partial differential equations with logistic growth, movement by diffusion and advection, and with Neumann boundary conditions. Necessary conditions for the optimal harvesting control are established. The objective for the problem is to find the optimal harvesting strategy that maximizes the discounted net value of the Anchovy population with seasonal harvesting. Numerical simulations will also be presented. Key Words: Partial differential equations, optimal control theory, fisheries, harvesting, Black sea anchovy.

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#### MS5

##### **The Tragedy of Open Ecosystems**

This paper investigates the role played by cooperation for the sustainable harvesting of an ecosystem. To achieve this, a bio-economic model based on a multi-species dynamics with interspecific relationships and multi-agent catches is considered. A comparison between the non-cooperative and cooperative optimal strategies is carried out. Revisiting the Tragedy of Open Access and over-exploitation issues, it is first proved analytically how harvesting pressure is larger in the non-cooperative case for every species. Then it is examined to what extent gains from cooperation can also be derived for the state of the ecosystem. It turns out that cooperation clearly promotes the conservation of every species when the number of agents is high. When the number of agents remains limited, results are more complicated, especially if a species-by-species viewpoint is adopted. However, we identify two metrics involving the state of every species and accounting for their ecological interactions which exhibit gains from cooperation at the ecosystem scale in the general case. Numerical examples illustrate the mathematical findings.

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#### MS5

##### **Bioremediation of Water Resources: An Optimal Control Approach**

This talk deals with the bioremediation, in minimal time, of a water resource (such as lakes, reservoirs, etc.) using a single continuous bioreactor. The bioreactor is connected to the reservoir through several pumps. Typically, one pump extracts polluted water and other on injects back sufficiently clean water with the same flow rate. However, we also analyse more complex pumps configurations. So, we state minimal-time optimal control problems where the control variables are related to the inflow rates of the pumps. For those problems, we analyse the existence of their solutions as well as their optimal synthesis (via Pontryaguins principle). We also obtain, for some pumps configurations, explicit expressions of their value functions via Hamilton-Jacobi-Bellman techniques.

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## MS6

### On Critical Phenomena Detection by Remote Sensing of the Marine Antarctic Ice Sheet

Earth sciences as inferred from remote sensing involves Hyperspectral imagery as amazingly sharp and detailed information concerning the time evolving systems they view, including ocean, atmosphere and solid structures such as ice, amongst others and we will develop new methods to analyze these systems. In the scenario of critical transitions, it becomes very important to develop methods to infer early warnings. We are especially interested here to observe spatiotemporal dynamics, notably in marine ice settings. We describe an image processing perspective inference of coherent sets from a fluidic system directly from image data, without attempting to first model underlying flow fields, related to a concept in image processing called motion tracking. We develop an anisotropic, directed diffusion operator corresponding to flow on a directed graph, from a directed affinity matrix developed with coherence in mind, and corresponding spectral graph theory. As our pilot study of these methods we will present here successfully (post)prediction of the cracks and eventual breakup of a huge ice structure, the Larcen C shelf of marine ice in Antarctica. The early success of our approach, even in its early and primitive form promises suitability for marine ice, and other settings where changing stress and strain of large structures gives rise to critical failures.

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## MS6

### Simultaneous Retrieval of Spatial Fields of Atmospheric Carbon Dioxide from High-Resolution Satellite Data

A new generation of Earth-orbiting satellites is providing high-resolution estimates of atmospheric greenhouse gas concentrations. These estimates result from processing observed satellite radiance spectra through complex retrieval algorithms. Most greenhouse gas retrievals incorporate a Bayesian framework that combines prior information about the atmospheric state with a physical model relating radiances to atmospheric conditions. For satellites with high spatial and temporal resolution, such as NASA's Orbiting Carbon Observatory-2 (OCO-2), retrieval error properties can be improved through a multi-pixel retrieval strategy that includes knowledge of spatio-temporal correlation of the atmospheric conditions corresponding to a collection of nearby pixels. We compare the performance of this retrieval strategy to an operational one-at-a-time approach under a range of conditions for the OCO-2 retrieval of column-averaged carbon dioxide.

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## MS6

### Frameworks for Improving Monitoring Snow from Space

The western United States relies on snowmelt-derived runoff for a significant fraction of its water resources, especially during seasons of low precipitation. Warming temperatures and other hydrometeorological variability impact the distribution and amount of snow water equivalent (SWE) stored across mountain ranges and more broadly, the terrestrial water storage. To characterize the montane snowpack response to different levels of warming ranging from 1.0 to 2.0C, we combine remote sensing-derived SWE information with a multivariate conditional framework across Sierra Nevada, USA. We show the extent to which hydrometeorological variability impacts the SWE volume and the location of its center of mass across multiple scales.

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## MS6

### Statistical Emulation with Dimension Reduction for Complex Physical Forward Models

The retrieval algorithms in remote sensing generally involve complex physical forward models that are nonlinear and computationally expensive to evaluate. Statistical emulation provides an alternative with cheap computation and can be used to calibrate model parameters and to improve computational efficiency of the retrieval algorithms. We introduce a framework of combining dimension reduction of input and output spaces and Gaussian process emulation technique. The functional principal component analysis (FPCA) is chosen to reduce to the output space of thousands of dimensions by orders of magnitude. In addition, instead of making restrictive assumptions regarding the correlation structure of the high-dimensional input space, we identify and exploit the most important directions of this space and thus construct a Gaussian process emulator with feasible computation. We will present preliminary results obtained from applying our method to OCO-2 data, and discuss how our framework can be generalized in distributed systems. This is joint work with Jon Hobbs (JPL), Alex Konomi (Univ. of Cincinnati), Pulong Ma (Univ. of Cincinnati), and Anirban Mondal (Case Western), and Joon Jin Song (Baylor Univ.).

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## MS7

### Math to Save the World

Many of the decisions we make, as well as many that are made for us, are based on mathematical models. This talk highlights the work from an NSF funded research initiative to develop and test the effectiveness of learning tools that integrate computational thinking, curricular mathematical content and mathematical modeling. A semester-long curriculum of an environmental sustainability themed general education course will be introduced. Data-driven projects with undergraduates in ecology, manufacturing efficiency and sports analytics will also be discussed, as well as extensions for future research.

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## MS7

### Using the MAA Instructional Practice Guide- Thoughts on Learner-centered Instruction

What can we do to make a difference for Planet Earth? One way might be to engage students more actively in their own learning in early mathematics courses using evidence-based instructional practices. Using strategies that will bring students together to discuss mathematical problems of interest to students both at a personal area and larger STEM focused problems in the environment may go a long way to encouraging new students, particularly those from underrepresented populations to want to study mathematics and other STEM disciplines as a major, bring new talent and ability into the STEM world. This presentation offers some instructional strategies from the new Mathematical Association of America's Instructional Practices Guide to help engage students in mathematics learning. It will offer ten Quick Tips that can be introduced into both small size and large size classrooms that might make a big difference for student motivation and engagement in the long run. These tips are about designing instruction, classroom practices, and assessment to help students consider their own learning.

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## MS7

### Findings from a National Study of Calculus Programs

In this talk I present findings from a national study of Calculus programs, which included both a national survey and case studies of institutions identified as having a relatively successful calculus program. Based on survey results I first present characteristics of STEM intending students who begin their post secondary studies with Calculus and either persist or switch out of the calculus sequence, and hence either remain or leave the STEM pipeline. I then present case study findings from five doctoral degree-granting institutions, including technical universities and medium to large public institutions. Understanding the features that characterize exemplary calculus programs at doctoral degree granting institutions is particularly important because

the vast majority of STEM graduates come from such institutions. Analysis of over 95 hours of interviews with faculty, administrators and students reveals seven different programmatic and structural features that are common across the five institutions. A community of practice and a social-academic integrations perspective are used to illuminate why and how these seven features contribute to successful calculus programs and high-quality sustainable STEM education.

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## MS7

### The Hudson River Estuarium: Complex Systems Education For All

Clarkson University's soon-to-be Hudson River Estuarium will provide education at all levels on a highly complex, highly dynamic environmental system. The dynamics are physical, chemical, biological, and cultural, on multiple time and physical scales: historical, annual, seasonal, daily and nonperiodic; microbial to large aquatic, land and bird life; natural salinity and turbidity, microplastics and other chemical and bio-pollutants. Estuaries are a vital cradle of life and home to a high percentage of the country's and world's population. Such complex systems are amenable to a sound mathematical modeling and holistic education. The design for highly interactive dynamic digital exhibits is a challenge for current and future education on a key aspect of Planet Earth in order to build awareness, knowledge at several levels, and a commitment to preservation/conservation.

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## MS8

### Efforts to Enhance Performance in the Energy Exascale Earth System Model Dynamical Core Using Implicit Algorithms on Hybrid Architectures

As computer architectures evolve, algorithms that continue to enable fast and accurate solutions to global atmosphere models are needed. In this vein, Newton-Krylov (NK) time-stepping methods are evaluated for a range of configurations within the spectral-element Community Atmosphere Model (CAM), to measure current and potential future computational performance. These configurations explore the attributes of the method under different but relevant model usage scenarios including varied spectral order within an element, static regional refinement, and scaling to the largest relevant problem sizes. These are analyzed for cases that scale to maximum processor counts or make use of hybrid CPU/GPU nodes within the function evaluation. Given the performance behavior across the configurations analyzed here, the recommendation for future work using the implicit solvers is conditional based on scale separation, the stiffness of the problem, and better use of the GPU through reduced data transfer across the device. We outline a strategy to update the current Fortran interface to make use of its new capabilities. In this scenario, the Fortran code accesses the solver libraries within Trilinos directly through the use of SWIG generated Fortran interface code. With access to Trilinos, access to the data structures defined by the Kokkos environment is

also planned and will remove current performance bottlenecks due to multiple data transfers during the iterative process.

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## MS8

### Exponential Integrators for the Shallow Water Equations on the Sphere

The shallow water equations are commonly used to test and design atmospheric models. Since they involve a wide range of different time scales, a right choice of time integration techniques plays a crucial role for an accurate and efficient simulation. So far, semi-implicit schemes have been widely used as they can take longer time steps compared to classical methods. Recently, it was shown in [Gaudreault and Pudykiewicz, 2016] that a classical third-order exponential multistep scheme (epi3) can beat semi-implicit schemes in terms of accuracy and is comparable to them in terms of efficiency. Thus it offers a good potential for use in meteorological models. In this talk, however, we propose the use of exponential Rosenbrock methods, which are designed for large stiff nonlinear models. They are fully explicit and do not require the solution of linear or nonlinear systems. For the accuracy and efficiency purposes, we identify the three efficient schemes of orders 4 and 5 (exprb42, exprb43, exprb53) based on a suite of four challenging tests problems performed with the shallow water model on a geodesic icosahedral grid. Moreover, we propose an efficient modification of one of state-of-the-art algorithms for the implementation of exponential integrators. Altogether, this allows the proposed schemes enable accurate solutions at much longer time-steps than epi3, proving considerably more efficient as the desired accuracy decreases or as the problem nonlinearity increases.

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## MS8

### Implicit-Explicit Time-Integration in the E3SM-Homme Nonhydrostatic Atmosphere Model

Global models of the Earth's atmosphere have traditionally made use of the hydrostatic approximation to simplify the primitive equations of atmospheric motion. However, nonhydrostatic effects become relevant to resolve when the horizontal grid-scale of a computer model of the atmosphere reaches the 10km threshold. The potential for high-resolution global modeling on an exascale machine and high-resolution regional modeling using variable resolution make the development of efficient nonhydrostatic global atmosphere models critical for future global Earth-system modeling. In this talk we present the nonhydrostatic atmosphere dynamic core, E3SM-HOMME, of the US Department of Energy's E3SM global Earth-system model.

In E3SM-HOMME the maximum stable time-step of purely explicit time-integration methods is restricted by the presence of vertically propagating acoustic waves. The formulation of the primitive equations in E3SM-HOMME results in a natural splitting into stiff terms generating vertical acoustic waves and non-stiff hydrostatic terms and we discuss the efficient implementation of implicit-explicit Runge-Kutta methods for stable and accurate time-integration.

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## MS8

### Investigating Additive Runge-Kutta Integrators for Atmospheric Dynamics Using Sundials

A standard global atmospheric model is comprised of the Euler equations coupled with an equation of state that is a modified ideal gas law. This system of equations includes acoustic waves that must be simulated in a stable manner. Furthermore, this system is solved on computational grids that are typically more refined in the vertical direction. Thus, the discretized system contains stiff elements both from the presence of acoustic waves in the model equations and from the domain discretization. For this discretized system, the class of Implicit-Explicit (IMEX), Additive Runge-Kutta (ARK) methods is investigated. The ability of these methods to accurately simulate atmospheric dynamics at large timesteps is a primary focus. Various approaches to splitting the model equations into stiff components, which are treated implicitly, and non-stiff components, which are treated explicitly, are explored. The Suite of Nonlinear and Differential/Algebraic Equation Solvers (SUNDIALS) package is used to quickly incorporate IMEX, ARK methods into the High-Order Methods Modeling Environment (HOMME) dynamical core within the Energy Exascale Earth System Model (E3SM). Both existing methods, as well as ones that were recently developed for this specific discretized system, are considered. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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## MS9

### Linking Scales in Earth's Sea Ice System

Polar sea ice is a key component of the Earth's climate system. It exhibits complex composite structure ranging from the sub-millimeter scale brine inclusions to kilometer scale melt ponds on top of individual ice floes tens of kilometers across. Theories of composite materials and statistical physics have been used to link behavior over a broad range of scales in the sea ice system. Here we address key questions in sea ice homogenization and the rigorous analysis of effective properties, such as fluid flow through the porous brine microstructure, ocean wave propagation in the marginal ice zone, advection enhanced diffusivity, and melt pond evolution. This work is helping to advance how sea ice is represented in climate models, and to improve projections of climate change and the response of polar ecosystems.

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## MS9

### Simple Rules Govern The Patterns of Arctic Sea Ice Melt Ponds

Climate change, amplified in the far north, has led to rapid sea ice decline in recent years. In the summer, melt ponds form on the surface of Arctic sea ice, significantly lowering the ice reflectivity and thereby accelerating ice melt. Pond geometry controls the details of this crucial feedback. Here we show that a simple model of voids surrounding randomly sized and placed overlapping circles reproduces the essential features of pond patterns. The only two model parameters, characteristic circle radius and coverage fraction, are chosen by comparing, between the model and the aerial photographs of the ponds, two correlation functions which determine the typical pond size and their connectedness. Using these parameters, the void model robustly reproduces the ponds' area-perimeter and area-abundance relationships over more than 6 orders of magnitude. By analyzing the correlation functions of ponds on several dates, we also find that the pond scale and the connectedness are surprisingly constant across different years and ice types. Moreover, we find that ponds resemble percolation clusters near the percolation threshold. These results demonstrate that the geometry and abundance of Arctic melt ponds can be simply described, which can be exploited in future models of Arctic melt ponds that would improve predictions of the response of sea ice to Arctic warming.

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## MS9

### Frazil-ice Dynamics: From Millimetre-sized Crystals to Geophysical Flows Along the Base of Floating Ice Shelves

The growth of frazil ice is an important mode of sea-ice formation. Frazil ice crystals have a scale of millimetres, and yet they can impact processes that happen at a vastly greater scale. We consider continuum models of a population of ice crystals with different sizes to provide insight into the treatment of frazil ice at the large scale. We apply our model to a simple mixed layer (such as at the surface of the ocean, with a depth of say tens of metres) and to a buoyant plume under a floating ice shelf (extending over hundreds of kilometres). We provide numerical calculations and scaling arguments to predict the occurrence of frazil-ice explosions (periods of rapid ice growth). Faster crystal growth rate, higher secondary nucleation and slower gravitational removal make frazil-ice explosions more likely. We identify steady-state crystal size distribu-

tions, which are largely insensitive to crystal growth rate but are affected by the relative importance of secondary nucleation to gravitational removal. Finally, we show that the fate of plumes underneath ice shelves is dramatically affected by frazil-ice dynamics. Differences in the parameterization of crystal growth and nucleation give rise to radically different predictions of basal accretion and plume dynamics; and can even impact whether a plume reaches the end of the ice shelf or intrudes at depth. Rees Jones, D. W. and Wells, A. J. (2018) *The Cryosphere*, 12, 25-38, <https://doi.org/10.5194/tc-12-25-2018>.

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## MS9

### Modeling and Analysis of Fluid Flow in Sea Ice: How Does Biology Affect the Physics?

Sea ice is a multiscale composite material that constrains, and is affected by, a wide variety of biological, chemical, and physical processes. The effective fluid permeability of sea ice, for example, impacts both Arctic melt pond evolution and polar microbial ecology. Among the microorganisms living within the porous brine microstructure of the ice, diatoms (algae) secrete gelatinous exopolymeric substances (EPS), which are thought to protect them from extreme variations in their cold, highly saline habitat. Algae, in turn, affect their environment – algal EPS has been shown to alter the physical properties of young sea ice, including its microgeometry and effective fluid permeability. In this talk, I will discuss recent work in which we propose a mathematical model for EPS-induced changes in the fluid permeability of sea ice, based on a random network of pipes with cross-sectional areas chosen from a bimodal distribution. I will also discuss rigorous upper bounds for sea ice fluid permeability, and future directions. This presentation is based on joint work with Y. Epshteyn, J. Zhu, M. J. Bowler, J. W. Deming, and K. M. Golden.

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## MS10

### Particle Filtering for Inverse Problems

Particle filtering has been considered impractical for high-dimensional problems for a long time. Recent developments have shown, however, that the curse of dimensionality can be avoided. Localized ensemble transform particle filter [Reich, S. and Cotter, C., Probabilistic forecasting and Bayesian data assimilation, Cambridge University Press, 2015] is an example of such a development. The distinguished feature of particle filtering to represent any probability density function is, however, destroyed by localization. In my talk I will introduce an improved ensemble transform particle filter that does not use any localization and show that it provides excellent results in parameter estimation of high-dimensional problems of subsurface reservoir simulations, which are comparable to MCMC but are significantly less computationally demanding.

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## MS10

### State Estimation for a High-Dimensional Nonlinear System by Particle-Based Filtering Methods

The sequential filtering scheme provides a suitable framework for estimating and tracking geophysical states of systems as new data become available online. Mathematical foundations of sequential Bayesian filtering are reviewed with emphasis on practical issues for both particle filters and Kalman-based filters. In this study, we further investigate the study of Kim (2005) such that the sequential Importance resampling method (SIR), Ensemble Kalman Filter (EnKF), and the Maximum Entropy Filter (MEF) are tested in a relatively high dimensional ocean model that conceptually represents the Atlantic thermohaline circulation. The model exhibits large-amplitude transitions between strong (thermo-dominated) and weak (salinity-dominated) circulations that represent climate states between ice-age and normal climate. The performance of the particle-based schemes is compared with the convergent results from SIR based on measurement errors, observation locations, and particle sizes in various sets of twin experiments. The sensitivity analysis shows strength and weakness of each filtering method when applied to multimodal non-linear systems.

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## MS10

### What the Collapse of the Ensemble Kalman Filter Tells Us About Particle Filters

The ensemble Kalman filter (EnKF) is a reliable data assimilation tool for high-dimensional meteorological problems. On the other hand, the EnKF can be interpreted as a particle filter, and particle filters (PF) collapse in high-

dimensional problems. We explain that these seemingly contradictory statements offer insights about how PF function in certain high-dimensional problems, and in particular support recent efforts in meteorology to "localize" particle filters, i.e. to restrict the influence of an observation to its neighborhood.

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## MS10

### Importance Sampling: Intrinsic Dimension and Computational Cost

Importance sampling is a building block of many algorithms in computational statistics, perhaps most notably particle filters. It is the importance sampling step that often limits the accuracy of these algorithms. In this talk I will introduce a new way of understanding importance sampling based on information theory. I will argue that the fundamental problem facing algorithms based on importance sampling can be understood in terms of the distance between certain measures. The results give new understanding on the potential use of importance sampling and particle filters in high (possibly infinite) dimensional spaces.

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## MS11

### Microlocal Analysis of the Attenuated Ray Transform in 2 and 3 Dimensions

In this talk I will discuss stability issues related to the attenuated geodesic X-ray transform where an interplay between the (attenuation type) weight in the transform and the underlying geometry strongly impact whether inversion is stable. In unstable cases I will specifically describe the types of artifacts expected to appear in reconstructions, and also illustrate the theoretical results with numerical examples. Finally, I will discuss the Landweber iteration specifically and analysis of the artifacts that are predicted to appear in reconstructions using this algorithm. This talk is based on joint work with Francois Monard and Plamen Stefanov

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## MS11

### The Geodesic X-Ray Transform on Noncompact Riemannian Manifolds

We present results concerning solenoidal injectivity of the

geodesic X-ray transform acting on functions and tensor fields on Cartan-Hadamard manifolds, i.e. on complete and simply connected Riemannian manifolds with nonpositive sectional curvature. This is joint work with J. Railo and M. Salo.

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## MS11

### Inverse Problems for Maxwell's Equations in a Slab with Partial Boundary Data

We consider two inverse boundary value problems for the time-harmonic Maxwell equations in an infinite slab. Assuming that tangential boundary data for the electric and magnetic fields at a fixed frequency is available either on subsets of one boundary hyperplane, or on subsets of different boundary hyperplanes, we show that the electromagnetic material parameters, the conductivity, electric permittivity, and magnetic permeability, are uniquely determined by these partial measurements.

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## MS11

### Seeing Inside the Earth with Distance Functions

Earthquakes produce seismic waves. They provide a way to obtain information about the deep structures of our planet. The typical measurement is to record the travel time difference of the seismic waves produced by an earthquake. Suppose that at the North pole occurs an earthquake, and it produces a seismic wave that propagates through the Earth. Say that there is a seismometer in London and in Tokyo which record the time of arrival of the seismic wave. Then, we can compute the travel time difference of the seismic wave. If the network of seismometers is dense enough and they measure a large amount of earthquakes, we can hope to recover the wave speed of the seismic wave. In this talk we will consider several inverse problems related to the data described above. We will prove uniqueness result for the Riemannian travel time difference problem and the Finslerian boundary distance problem on smooth compact manifold. We will also establish a connection between the travel time data and a scattering data of interior point source. The talk is based on joint works with: Maarten de Hoop, Joonas Ilmavirta, Matti Lassas and Hanming Zhou

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## MS12

### Infusing Data into Stem Education

While societys demand for people educated in statistics



and data science has grown tremendously over the past decade, at universities, statistics and data education are not well infused throughout the curriculum. Across disciplines, universities typically have several different statistics and data analytics course offerings and often times these courses overlap, however, their prerequisite structures do not allow students to move from a statistics course offered in one department to a more advanced course offered by another department. These structures cripple students in their ability to reach higher levels of understanding with data analysis and statistics. To respond to the increased attention to statistics in society and work force, as well as to contribute to improved career preparation for students, it is imperative that we foster data proficiency in our undergraduate population across all disciplines. In this talk, we will present initial results from the Undergraduate Data Proficiencies (UDaP) NSF-funded project outlining processes universities can take for achieving data proficiency across disciplines focused on the important data science themes of working with real data, communication with data, and using technology with data.

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## MS12

### Designing MPE Modeling Questions

Modeling offers an excellent opportunity for students to both learn about aspects of the environment they didn't know before and to help develop potential solutions for tackling the big problems facing the environment. We will discuss how to develop such questions and how to support students in answering the questions by way of discussing questions that have been used in classes and in SIAM's M3 Challenge.

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## MS12

### MPE Projects in the First Year Calculus Sequence

Our standard calculus sequence for 1st year STEM majors requires students to engage in project based learning using real-world problems. These projects may touch a broad spectrum of applications, but several have been addresses relevant issues related to significant large-scale environmental problems. We discuss implementation of several of these projects as tackled within our core Calc 1 and Calc 2 courses.

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## MS12

### Co-Ordinated Math and Physics Assessment for Student Success (COMPASS)

In this talk we describe a cross-disciplinary effort to help STEM students navigate through their first year. The COMPASS program is designed to achieve improved student performance in early STEM courses and increase retention through a targeted assessment strategy. This approach identifies students needs prior to enrollment using a

conceptual physics survey coupled with a mathematics diagnostic test. Based on the combined results students are assigned one of three risk categories which leads them to different pathways designed to leverage these students relative strengths (in math or physical intuition) to motivated the development of the other. Details of the student experience for each path will be described and we will report on students course performance.

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## MS13

### Conservative Multi-Moment Characteristic Galerkin Transport on the Sphere

A newly developed transport scheme for passive tracer advection on the sphere is presented. The scheme's design prioritizes computational performance and efficiency, particularly with respect to next-generation heterogeneous computing environments, by 1) employing spatially local numerical methods and 2) using large time steps relative to the advective CFL constraint. At each time step, a standard discontinuous Galerkin mesh is transported forward in time along the flow characteristics; a semi-Lagrangian incremental remap procedure updates the solution on the mesh at each time step using a locally constructed overlap mesh and conservative quadrature. Constrained density reconstruction assures shape preservation and tracer consistency. Results from several standard tracer transport test cases are presented. The scheme's performance is compared to the current method employed by the U.S. Dept. of Energy's E3SM atmospheric model, and shown to produce a factor of 2.24 speedup for the model's standard configuration with 40 tracers. The scheme serves as an algorithmic prototype, and we introduce plans for development of the scheme into a full 3D non-hydrostatic dynamical core.

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## MS13

### Quasi-Hamiltonian Numerical Models of Geophysical Fluid Dynamics

The equations of reversible fluid dynamics have a well-known Hamiltonian variational structure, which underlies many of the most basic principles that we know about geophysical fluid flows, such as conservation laws. Quasi-Hamiltonian numerical models can be developed that emulate this structure, by combining a continuous Hamiltonian formulation with a mimetic discretization. Such models preserve many of the important properties of the continuous equations; such as: conservation laws, mimetic relationships and potential vorticity dynamics. This spatial discretization can then be combined with a fully implicit energy-conserving time integrator to yield a fully discrete, energy-conserving model. Extending previous work on the hydrostatic equations, this talk will discuss a concrete realization of this approach: the Mistral atmospheric dynamical core. This is a high order, structure-preserving, nonhydrostatic model built using compatible Galerkin methods,

targeting geophysical fluid dynamics at a range of scale. Mass, entropy and total energy are conserved to machine precision, including time discretization. A range of vertical coordinates (Eulerian, Lagrangian and Mass-Based) are supported. Results will be presented from standard test cases. If time permits, current progress on the extension to irreversible dynamics (such that discrete analogues of 1st and 2nd laws of thermodynamics are satisfied for all time) through a (quasi-)metriplectic formulation will be discussed.

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### MS13

#### An Adaptive Mesh Refinement (AMR) Framework for 2D Shallow Water and 3D Nonhydrostatic Dynamical Cores

In recent years we have developed a high-order, finite-volume, multi-block Adaptive Mesh Refinement (AMR) framework for solving the 2D shallow water equations on the sphere. The framework is built upon the AMR library Chombo which has been designed at the Lawrence Berkeley National Laboratory. Chombo supports the cubed-sphere grid geometry which serves as the base computational grid for atmospheric AMR applications. The paper provides insight into the latest Chombo-AMR model developments. In particular, moisture processes have been added to the 2D shallow water framework which mimics the addition of a simplified physical parameterization package to the atmospheric dynamical core. The moisture interactions provide nonlinear forcing effects which challenge the AMR technique and the scale dependencies in the moist atmospheric model. In addition, the Chombo-AMR framework supports the 3D nonhydrostatic, shallow-atmosphere equation set with 2D (horizontal) mesh adaptations. Idealized dynamical core test cases, like a colliding modons test and selected examples from the Dynamical Core Model Intercomparison Project (DCMIP) test case suite, are used to illustrate the characteristics of the dynamically adaptive atmospheric model. It is suggested that AMR dynamical cores have the potential to serve as the basis for future-generation weather and climate models. They allow the flow-dependent generation of high-resolution domains while limiting the overall computational workload.

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### MS13

#### Performance of the E3SM Spectral Element Atmosphere Dynamical Core

The E3SM atmosphere component model's dynamical core is based on the spectral element method. I'll present performance results from our Fortran and C++/kokkos implementations of this dynamical core on a range of processors (Ivy Bridge, Haswell, KNL, and P100 and V100 GPUs). With a careful implementation, the C++ code is competitive with the Fortran code on all processors and also supports GPUs. With sufficient work per node, the KNL and V100 processors can obtain significant speedups over conventional Xeons. But in the strong scaling limit, we see little or no improvement over the circa-2012 Ivy Bridge processor.

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### MS14

#### Forward and Inverse Homogenization: Relating Properties and Structure of Heterogeneous Sea Ice

Sea ice is a composite material consisting of pure ice and brine pockets connected by brine channels, with the microgeometry dependent on the salinity and temperature. The Stieltjes analytical representation of the homogenized properties of composites is used to relate the effective parameters of ice and its microstructure. The spectral measure in this representation contains information about the microgeometry of the heterogeneous porous medium and can be used to bound the effective properties of ice, as well as to characterize the structural information about the mi-

crogeometry from measured ice transport properties.

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#### MS14

##### Advection Enhanced Diffusion Processes

We investigate thermal conduction in sea ice in the presence of fluid flow, as an important example of an advection diffusion process in the polar marine environment. Using new Stieltjes integral representations for the effective diffusivity in turbulent transport, we present a series of rigorous bounds on the effective diffusivity, obtained using Padé approximates in terms of the Péclet number. We first analyze the effective thermal conductivity of sea ice in the presence of an averaged convective velocity field, neglecting the two phase microstructure of sea ice, and then present a homogenization analysis of the full two component system composed of brine and ice.

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#### MS14

##### Homogenization Estimates for the Rheological Properties of Sea Ice

Sea ice is a multi-phase material, with complex structure at several length scales, and exhibits strongly nonlinear rheology. At the smaller scales, sea ice consists of polycrystalline aggregates of hexagonal ice crystals with embedded inclusions of brine. The grains are columnar in shape, aligned with the vertical direction and display a pronounced S2 texture where the c-symmetry axes of the crystals lie in the horizontal plane, but with random orientations in this plane. Because the HCP ice crystals exhibit highly anisotropic viscoplastic behavior, with ‘easy’ glide on basal planes and ‘hard’ slip on non-basal systems, this strong texture has significant implications for the highly anisotropic macroscopic response. On the other hand, the brine inclusions—which have volume fractions ranging from nearly zero for multi-year ice to 10% for first-year ice and exhibit elongated shapes with the largest dimension in the vertical direction—also have significant implications for the rheological response, especially for loadings with large in-plane hydrostatic components. In this presentation, we make use of the recently developed iterated second-order homogenization method to characterize the effect of brine porosity and associated pore morphology, as well as crystallographic texture, on the instantaneous response of the sea ice. We will also consider the effect texture evolution under finite-strain conditions.

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#### MS14

##### Effective Rheology and Wave Attenuation in the Marginal Ice Zone

Wave-ice interactions in the polar oceans comprise a complex but important set of processes influencing sea ice extent, ice pack albedo, and ice thickness. In both the Arctic and Antarctic, the ice floe size distribution in the Marginal Ice Zone (MIZ) plays a central role in the properties of wave propagation. Ocean waves break up and shape the ice floes which, in turn, attenuate various wave characteristics. Recently, continuum models have been developed which treat the MIZ as a two-component composite of ice and slushy water. The top layer has been taken to be purely elastic, purely viscous or viscoelastic. At the heart of these models are effective parameters, namely, the effective elasticity, viscosity, and complex viscoelasticity. In practice, these effective parameters, which depend on the composite geometry and the physical properties of the constituents, are quite difficult to determine. To help overcome this limitation, we employ the methods of homogenization theory, in a quasistatic, fixed frequency regime, to find a Stieltjes integral representation for the complex viscoelasticity. This integral representation involves the spectral measure of a self adjoint operator and provides what we believe are the first rigorous bounds on the effective viscoelasticity of the sea ice pack. The bounds themselves depend on the moments of the measure which in turn depend on the geometry of the ice floe configurations.

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#### MS15

##### Global Monitoring and Seasonal Forecasts of Extreme Surface Water Anomalies: The Water Security Indicator Model (WSIM)

The Water Security Indicator Model (WSIM) monitors and forecasts global environmental conditions relevant to human security analysis, such as soil moisture, runoff, and evapotranspiration. A statistical analysis of the results using generalized extreme value (GEV) distributions is used to compute composite indices of overall water surplus and deficit, and place those indices in a historical context. Seasonal forecast data such as those produced by the Climate Forecast System (CFS) are used to provide projections of surplus and deficit with lead times up to nine months. The model and associated tools have recently been released as an open-source package that supports multiple use-cases and provides a platform suitable for community experimentation. We present some applications of the model and describe areas for further research and expansion of its capabilities, including assessments of the impact of water stress

on agricultural production and electric power generation.

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## MS15

### **Applying Bayesian Hierarchical Modeling to Understand the Relationships Between Climate, Security, and Migration**

While data on environmental stresses and security outcomes have improved, they are provided by disparate sources, have widely varying formats, and are updated on different schedules. These differences create significant barriers to entry for environment-security researchers and practitioners that impede the advancement of understanding complex environment-security relationships. An open community data-harvesting, integration, exploration, and analysis platform would accelerate the development and deployment of anticipatory models linking environmental stressors with security outcomes. The core of traditional migration research has focused on conflict and political violence as drivers of global migration and forced displacement. However, recent studies have identified the need to also examine IDPs as a function of climate and natural disasters. There has been an increase in literature on the cascading effects of climate change and impacts of natural disasters on migration. For this study we investigated the efficacy of an open source platform to develop Bayesian hierarchical models estimating provincial migration in the Philippines from 1990-2000 as a function of individual and household characteristics in conjunction with spatially explicit indicators of drought and flooding.

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## MS15

### **Forecasting Extreme Hydrologic Events: The Stream Flow Prediction Tool (SPT)**

The U.S. Army Engineer Research and Development Center (ERDC) Streamflow Prediction Tool (SPT) provides timely and actionable hydrologic information in data sparse regions around the globe. It uses a matrix solution of the Muskingum Equation from the Routing Application for Parallel computation of Discharge (RAPID) to compute flows over a distributed network of rivers, streams, and tributaries at the continental scale. An interactive web interface presents an intuitive flood warning scheme that is accessible online and on-demand.

Ensemble forecasts provide flow estimates at virtually any ungauged location. The forecasts are paired with recurrence interval flows calculated from 35 years of reconstructed historical flow to generate flood warnings. High-resolution flood inundation maps can be generated to provide river stage insights.

The SPT is a tool planners and policy makers can employ to quantitatively inform decisions. The tool provides high-level situational awareness to humanitarian assistance and disaster response efforts related to flooding. The same information can enable water managers to make forecast-informed decisions that conserve water during periods of drought without compromising flood protection. Additionally, the SPT allows engineers to more fully consider the implications from climate non-stationarity on the long-

term effectiveness of flood control infrastructure.

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## MS15

### **Comparing the Accuracy of Global Spatial Population Surfaces**

Marc Levy, Deborah Balk and S. Adamo Comparing the Accuracy of Global Spatial Population Surfaces The development of global population surfaces or rasters integrates different types of input data (e.g. censuses, registers, surveys, other ancillary information) using different methods (e.g. downscaling census data dasymmetrically or pyncnophylactically, or estimating estimate population distribution statistically). This contribution explores the challenges involved in estimating and comparing spatial accuracy across global spatial population surfaces.

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## MS16

### **Imaging with Optimal Transport**

Abstract Not Available At Time Of Publication.

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## MS16

### **Imaging the Earth Via Inverse Problems: Stability and Reconstruction**

We discuss the problem of imaging the subsurface of the Earth via the inverse problems known in geophysics as Electrical Resistivity Tomography (ERT) and Full Waveform Inversion (FWI) with partial data. For the ERT problem we model the data in terms of the so-called Neumann-to-Dirichlet (NtoD) map; for the FWI we employ time-harmonic Cauchy data obtained with dual sensors measuring the pressure and the normal velocity and do not suffer from eigenfrequencies unlike the Dirichlet-to-Neumann

map, which, in fact, cannot be observed directly in seismic marine acquisition. The main focus of the two inverse problems considered here is the study of conditional well-posedness and reconstruction. The conditional well-posedness is obtained for a hierarchy of subspaces in which the inverse problem with partial data is Lipschitz stable. Here, these subspaces yield piecewise linear representations of the isotropic resistivity and the wave speed on given domain partitions, respectively. Domain partitions can be adaptively obtained through segmentation of the gradient. For the FWI problem, the domain partitions can be taken as a coarsening of an unstructured tetrahedral mesh associated with a finite element discretization of the Helmholtz equation. We illustrate the effectiveness of the iterative regularization through computational experiments with three-dimensional data. This is joint work with Giovanni Alessandrini, Florian Faucher, Maarten V. de Hoop and Eva Sincich.

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## MS16

### Spectral Geometry for the Earth

The speed of sound is different in different points and directions. These variations can be seen as a non-Euclidean geometry in which elastic waves travel along straight lines (geodesics). In this view the Earth becomes a geometric object, and the problem of finding the interior structure of a planet from the spectrum of free oscillations becomes an inverse problem in spectral geometry. I will discuss the geometric point of view and some recent results.

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## MS16

### Body Waves Reconstruction from Correlation of Ambient Seismic Noise and Coda: A New Window into Deep Earth and Challenges

Abstract Not Available At Time Of Publication.

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## MS17

### Statistical Consistency Testing for the Community Earth System Model

Earth system models tend to be large and complex as well as in a state of near constant development, and, therefore, quality assurance is a critical. In this talk, we overview our multi-year effort to better evaluate the quality and correctness of the widely-used Community Earth System Model (CESM). Our approach depends on an ensemble-based consistency test that was developed as an alternative to requiring bitwise identical output. This objective test provides a statistical measurement of consistency between an accepted ensemble created by small initial temperature perturbations and a test set of CESM simulations. This approach has proved successful in practice in terms of facilitating more in-depth code optimization, porting to new machines, and error detection in the CESM hardware or software stack. Our current efforts focus on developing a

means of easily tracing a consistency test failure to its root cause, and we discuss our efforts toward that goal as well.

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## MS17

### Fingerprinting Hydrologic Models by Identifying Coupling Structures

The hydrologic modeling community has developed a wide range of numerical models which encompass a large span of complexity. This diversity has sparked many debates over the suitability of each modeling approach. These debates often focus on the level of detail of process representations, lack of input and parameter data, and computational limitations. Further debates have centered around whether more complex models actually provide more information than less complex models, or whether the added errors and uncertainty outweigh the increases in fidelity. Recent trends in the hydrology community have worked towards answering these questions by asking how well a particular model uses the information it is given. In this presentation we will build on these ideas by evaluating entire instances of hydrologic models, which include the initial and boundary conditions, parameter values, internal, and output states and fluxes. The goal of evaluating the entire modeling chain in a single analysis is to identify coupling structures which explain the emergent behavior of the model. Ultimately we aim to use this analysis to develop meta-models which can be thought of as a model fingerprint. These model fingerprints can be used for myriad further applications including guiding model development, model inter-comparison, evaluation against observations, and generating lower complexity model surrogates.

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## MS17

### Efforts Toward Evaluation and Reproducibility for Ice Sheet Modeling

Robust real-world projections of ice sheets, and their associated climate impacts, require the use of credible ice sheet models. Verification and Validation (V&V) testing allows users and developers to gain confidence in the underlying mathematics, construction, performance and physics of the



model. When V&V testing is done in a transparent and reproducible way, with contextualized and shareable testing results, it can be used to enhance the credibility of models. Here we will discuss efforts within the Energy Exascale Earth System Model (E3SM) and Community Earth System Model (CESM) communities to develop LIVVkit, a land ice verification and validation toolkit, which analyzes both the ice sheet model component as well couplings between the ice sheet and other components. Furthermore, we will discuss some of the related efforts across Earth system model components and how to tie them all together.

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## MS17

### Development of An Open-Source, Community Hydrology Model: Discussion of Best Software Practices

The integrated hydrology model, ParFlow solves the simplified shallow water equations implicitly coupled to Richards equation using the KINSOL nonlinear solver package from the SUNDIALS library and multigrid preconditioners from the hypre library and is developed by an international community. It is massively parallel and has been ported to a wide range of architectures. The model is coupled to the CLM 4.5 and CoLM land surface models, the COSMO and WRF mesoscale atmospheric systems and the reactive transport code CRUNCH. ParFlowE has been developed for coupled flow and energy transport. ParFlow is available under the GNU LGPL license on Github and has well over 100 active users. The model has been extensively benchmarked, has more than 70 publications, has been applied continental US and European domains and more than a dozen watersheds worldwide. This active community development presents interesting challenges and we have implemented software standards, regression tests (more than 200 serial and parallel benchmark problems) that allow a user to check proper build and help manage development and educational materials and short courses.

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## MS18

### Assessing and Improving the Numerical Solution of Atmospheric Physics in E3sm

The numerical errors arising from parameterized subgrid-scale atmospheric physics have been largely overlooked in Earth system models. As spatial resolution increases, the computational effort expended on atmospheric dynamics will only provide limited gains in overall accuracy due to numerical errors from parameterizations. In this talk, we focus on assessing the time integration and process coupling methods utilized in the Energy Exascale Earth System Model (E3SM) and explore approaches to improve process convergence and accuracy. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-748073

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## MS18

### Measuring Numerically Relevant Timescales in Parameterizations of Cloud Microphysics

Earth system model developers often find evidence that model results are afflicted by a failure to resolve short time scale behavior. Due to the complexity of these models, in some cases it is not clear which physical process is responsible for these short time scales, or whether the issue is actually due to an inadequate coupling frequency between multiple processes in a model. In order to address these issues, it is useful to be able to *experimentally* associate each process in a model with a distribution of time scales that are relevant to that process. We examine several methods of associating a process with relevant time scales. These time scales include the time taken for a process to activate physically relevant limiters, the inverse eigenvalues of the Jacobian of each particular process rate function, and the inverse eigenvalues of the Jacobian of the sum of all process rates. We compare these methods using the Morrison-Gettelman microphysics version 2 (MG2), a component of the Energy Exascale Earth System Model (E3SM), as a test case. We also compare the results across different model conditions, to examine when the time scales can be associated not only with particular processes, but with the operation of those processes in particular regimes.

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## MS18

### Towards Parallel-in-Time Methods for Numerical Weather Prediction

We present recent work on a parareal algorithm for solving the rotating shallow water equations on the sphere. The parareal algorithm has two ingredients: a cheap (coarse) integrator and a more accurate (fine) integrator. The efficiency of the scheme is determined by the rate at which convergence is achieved. It is therefore essential that the coarse integrator is sufficiently accurate to enable convergence, while remaining cheap enough that it is not a bottleneck that slows down the scheme. Our approach follows that of [Haut, T. et al An asymptotic parallel-in-time method for highly oscillatory PDEs, 2014] which showed that averaging the nonlinear terms over fast oscillations includes the effects of near-resonances, essential for accuracy and hence convergence. A key component of this scheme is the computation of an approximation to the exponential of the linear operator corresponding to the fast linear waves in the system. Here we use a rational approximation [Haut, T. et al A high-order scheme for solving wave propagation problems via the direct construction of an approximate time-evolution operator, 2015]. This requires the solution of an elliptic problem for each term. The method is highly parallelisable but it is vital that the solution of each term is efficient. In this talk, we will describe the construction of an efficient coarse integrator for the rotating shallow water equations and present the latest results from various test cases.

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## MS18

### On the Way to the Limit: Time Parallelism with Oscillatory Time-Scale Separation

One of the most well-known breakthroughs in scientific

computing came just after WWII when a group of mathematicians and scientists came together to create the world's first numerical weather prediction on one of the world's first computers - ENIAC. One of the most important lessons learned from that experience was that there is an intimate relationship between the mathematical structure of the governing equations, their numerical approximation, and understanding their dynamics. Building on that history, I will discuss one of the mathematical issues that leads to computational limitations for many different types of physical phenomenon including climate and weather prediction oscillatory stiffness in the PDEs from time-scale separation that leads to low-frequency dynamics. I will discuss some of the first mathematical discoveries from geophysical fluid dynamics about how nonlinear phenomenon gives rise to low-frequency solutions and the relationship to fast singular limits studied in PDEs analysis and numerical analysis. Finally, I will discuss some of the key mathematical ideas behind new time-parallel numerical integrators, where we use frequency-averaging to approximate the low frequency dynamics.

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## MS19

### Kernel Analog Methods for Sea Ice Prediction

Nonlinear Laplacian Spectral Analysis (NLSA) is a data analysis technique for high-dimensional nonlinear data sets that has recently been used to study modes of sea ice variability. One such mode of importance, whose improved understanding is crucial in increasing the forecast skill of operational prediction systems, is sea ice reemergence, which refers to the tendency of melt-season sea ice area anomalies to recur the following growth season, and growth-season anomalies to recur the following melt-season. Applications of NLSA to sea surface temperature (SST) data has extracted signals corresponding to reemergence phenomena in the North Pacific Ocean, and applications of a generalized version of NLSA to SST, sea ice concentration (SIC), and sea level pressure (SLP) data have recovered reemergence patterns in the Arctic sea as well. Recent research focusing on the exploitation of NLSA-derived signals have led to a number of optimally convergent algorithms for time series prediction, referred to as Nonlinear Laplacian Spectral Forecasting (NLSF).

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## MS19

### Regional Arctic Sea Ice Predictability: Mechanisms, Prediction Skill, and Future Outlook

Seasonal predictions of Arctic sea ice on regional spatial scales are a pressing need for a broad group of stakeholders, however, most assessments of predictability and forecast skill to date have focused on pan-Arctic sea-ice extent (SIE). In this work, we present the first direct comparison of perfect model (PM) and operational (OP) seasonal prediction skill for regional Arctic SIE within a common dynamical prediction system. This assessment is based on two complementary suites of seasonal prediction ensemble experiments performed with a global coupled climate model. First, we present a suite of PM predictability experiments with start dates spanning the calendar year, which

are used to quantify the potential regional SIE prediction skill of this system. Second, we assess the system's OP prediction skill for detrended regional SIE using a suite of retrospective initialized seasonal forecasts spanning 1981-2016. We also introduce a set of skill metrics specifically designed to provide an "apples-to-apples" comparison between PM and OP predictions. In nearly all Arctic regions and for all target months, we find a substantial skill gap between PM and OP predictions of regional SIE. The PM experiments reveal that regional winter SIE is potentially predictable at lead times beyond 12 months, substantially longer than the skill of their OP counterparts. The skill gap identified in this work indicates a promising potential for future improvements in regional SIE predictions.

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## MS19

### Arctic Sea Ice Retreat in Global Climate Models: The Influence of Volcanoes and Global Warming Biases

Arctic sea ice has retreated rapidly during recent decades. Global climate models have struggled to reproduce this trend, typically simulating a slower rate of sea ice retreat than has been observed. However, this bias is substantially smaller in the current generation of models (CMIP5) compared with the previous generation (CMIP3), and a subset of the CMIP5 simulations have Arctic sea ice trends comparable with observations. Based on this, a number of recent studies have suggested that current climate models are consistent with the observations up to when simulated internal climate variability is taken into account. This presentation will examine Arctic sea ice retreat in the CMIP3 and CMIP5 simulations of the historical period. Two main results will be discussed. First, our analysis suggests that the model bias reduction in CMIP5 compared with CMIP3 occurred because of the inclusion of volcanic forcing, rather than improved sea ice physics or resolution. Volcanic forcing was included in all of the CMIP5 models but in only about half of the CMIP3 models. Second, we find that the CMIP5 simulations that have Arctic sea ice retreat as fast as observations all have considerably too much global warming during this period. The results are analyzed drawing on previous work that found a close relationship between global-mean temperature and sea ice extent. These findings suggest that current climate models may be getting the right Arctic sea ice trends for the wrong reasons.

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## MS19

### The Quantum and Statistical Mechanics of Arctic Sea Ice

In 1975, Thorndike et al., proposed to treat the combined mechanical and thermodynamic evolution of the ice pack in the form of a probability density function,  $g(h)$ , using a PDE. Whilst the concept has been essential for progress, and has been adopted in a variety of forms, the mechanical term thwarted closure of the theory. We derive a generalized description using concepts from stochastic dynamics and have closed the theory thereby allowing systematic study of the climatology of the ice pack using a sin-

gle equation. Moreover, this problem can be simplified in terms of a Bessel-like process with a negative constant drift, described by a Fokker-Planck equation with a logarithmic potential. The Bessel-like process we consider can be solved by seeking solutions through an expansion into a complete set of eigenfunctions. The associated imaginary-time Schrodinger equation exhibits a mix of discrete and continuous eigenvalue spectra, corresponding to the quantum Coulomb potential describing the bound states of the hydrogen atom. We demonstrate this technique by solving the Brownian motion problem and the Bessel process both with a constant negative drift. The new theory, or appropriate simplifications, is ideal for incorporation into climate models, which do a particularly poor job of treating mechanical processes.

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## MS20

### A Framework for Adaptive Inflation and Covariance Localization for Ensemble Filters

Ensemble Kalman Filter (EnKF) has gained wide popularity as the main ensemble-based data assimilation algorithm. EnKF follows a Monte-Carlo approach to estimate the forecast, and hence the analysis, error covariance matrices using a small-sized ensemble of model forecasts. Using a small number of ensemble members to approximate the covariances is the main cause of sampling errors. Such sampling errors are responsible for producing spurious correlations, and underestimation of the true variances, thus leading to filter divergence. Inflation, and covariance localization are both necessary for almost any EnKF implementation. While fixed, e.g. space-independent, inflation and localization can increase the reliability of the estimated covariance matrices, in many cases it may result in information loss. Tuning the space-time inflation and localization coefficients is a hard problem, and has to be done adaptively and automatically. In this talk, we present a consistent and efficient framework for adaptive inflation and covariance localization in EnKF. We also present computational results using a standard Lorenz-96 experiment.

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## MS20

### Forecast Sensitivity on Observation in Global Data Assimilation System

In data assimilation that attempts to predict nonlinear evolution of the system by combining complex computational model, observations, and uncertainties associated with them, it is useful to be able to quantify the amount of information provided by an observation or by an observing system. Measures of the observational influence are useful for the understanding of performance of the data assimilation system. The Forecast sensitivity to observation provides practical and useful metric for the assessment of observations. Quite often complex data assimilation systems use a simplified version of the forecast sensitivity for-

mulation based on ensembles. In this talk, we first present the comparison of forecast sensitivity for 4DVar, Hybrid-4DEnVar, and 4DEnKF with or without such simplifications using a highly nonlinear model. We then present the results of ensemble forecast sensitivity to satellite radiance observations for Hybrid-4DEnVar using a global data assimilation system.

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## MS20

### Why and How Feature-based Data Assimilation Can Be Useful

Many applications in science require that computational models and data be combined. In a Bayesian framework, this is usually done by defining likelihoods based on the mismatch of model outputs and data. However, matching model outputs and data in this way can be unnecessary or impossible. For example, using large amounts of steady state data is unnecessary because these data are redundant. It is often impossible to assimilate data of a complex system into a low-dimensional model. As a specific example, consider a low-dimensional stochastic model for the dipole of Earth's geomagnetic field, while other field components are neglected in the model. The above issues can be addressed by selecting features of the data, and defining likelihoods based on the features, rather than by the usual mismatch of model output and data. Our goal is to contribute to a fundamental understanding of such a feature-based approach that allows us to assimilate selected aspects of data into models. Numerical implementations of these ideas are illustrated in three examples.

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## MS20

### On Proposal, Mapping, and Localisation Methods for Particle Filtering in High-Dimensional Geophysical Applications

Particle filters provide an approximate solution of the fully nonlinear sequential Bayesian Inference problem using samples. Rapid recent progress allows the application of particle filters to high-dimensional geophysical systems, avoiding the weight collapse due to the curse of dimensionality. Borrowed from Ensemble Kalman Filtering, so-called localisation, in which the problem is divided up in a large number of smaller problems, has become popular in the geoscience community, even leading to a localized particle filter implementation in an operational weather prediction system. Strong progress has also been made on proposal densities, that allow for moving the particles towards future observations during their time integration. Exciting new formulations have been found that are more efficient than the so-called optimal proposal density, and have been applied to high-dimensional systems. Finally, the new kids on the block are transportation methods that aim at transforming samples from the prior to samples from the posterior, but extended to be feasible in sequential high-dimensional systems. I will provide an overview of these methods and their pros and cons, as far as understood in

the community.

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## MS21

### Noise-induced Tipping in a Periodically Forced System: The Noise-drift Balanced Regime

We consider a simple periodically-forced 1-D Langevin equation which possesses two stable periodic orbits in the absence of noise. We ask the question: is there a most likely transition path between the stable orbits that would allow us to identify a preferred phase of the periodic forcing for which tipping occurs? The regime where the forcing period is long compared to the adiabatic relaxation time has been well studied. Our work complements this by focusing on the regime where the forcing period is comparable to the relaxation time. We compute optimal paths using the least action method which involves the Onsager-Machlup functional and validate results with Monte Carlo simulations in a regime where noise and drift are balanced. Results for the preferred tipping phase are compared with the deterministic aspects of the problem. We identify parameter regimes where nullclines, associated with the deterministic problem in a 2-D extended phase space, form passageways through which the optimal paths transit. As the nullclines are independent of the relaxation time and the noise strength, this leads to a robust deterministic predictor of a preferred tipping phase for the noise and drift balanced regime.

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## MS21

### Bifurcations and Multi-Frequency Tipping in a Delay Differential Equation Model for El Niño

We consider a conceptual model for the El Niño Southern Oscillation system in the form of a delay differential equation that includes feedback loops between the ocean and atmosphere. A bifurcation analysis is conducted to investigate the extent to which the interplay between delayed feedback and seasonal forcing can produce qualitatively realistic behaviour. The model features the phenomenon of folding invariant tori, which may be interpreted as a generic form of climate tipping with previously unconsidered tipping signatures.

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## MS21

### Hurricanes and Rate-Induced Tipping

Rate induced tipping, the phenomenon in which the end behavior of a system changes drastically when parameters change quickly enough, has been well studied in one dimensional systems. However, not much is known about when rate induced tipping can happen in higher dimensional systems. In this talk, we will look at Kerry Emanuel's two-dimensional hurricane model and demonstrate how rate-induced tipping can happen through a variety of parameter changes, as well as classify some types of parameter changes for which rate induced tipping is impossible.

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## MS21

### Detecting Rate-Induced Tipping in An Ecological Resource-Consumer Model

We discuss the phenomenon of rate-induced tipping in an ecological resource consumer model. In this model, changing a parameter past a critical rate causes the system to 'tip,' i.e. solutions diverge from a spiral sink. Previous methods for identifying rate-induced tipping when applied to this system do not capture the nuanced behavior of solutions as the tipping parameter approaches and passes its critical rate. Instead, the authors explore rate-induced tipping in this and several model nonautonomous systems using Steklov averages and other stability spectra. Our results show that these numerical stability spectra are effective diagnostics for determining rate-induced tipping points in systems with time-dependent parameters with linear growth or that are asymptotically constant.

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## MS22

### A Multivariate Approach Using Short Simulation Ensembles to Evaluate Reproducibility of Climate Model Simulations on Hybrid Architectures

Solution reproducibility is a challenge in earth system modeling as we march towards exascale computing. Model

source code and the programming environment are continually being adapted to efficiently use hybrid architectures on leadership class computers. These changes, however, may not reproduce the original solution bit-for-bit (bfb). The non-linear chaotic nature of the climate system results in exponential growth of these machine-level round-off differences making it hard to isolate bugs in a non-bit-for-bit change. The challenges will persist as model developers increasingly utilize deep learning technologies. Here, we present the application of advanced multivariate statistical methods adopted from the machine learning community to evaluate if a perturbed model with a non-bit-for-bit change reproduces the original climate simulation. Noise statistics (natural variability) of the perturbed and the original model, quantified by short simulation ensembles, are used for such evaluations. Preliminary analyses with these techniques, using US DOE's Energy Exascale Earth System Model, reveal that these methods can detect subtle changes to the simulation introduced by perturbing a model tuning parameter or aggressive compiler optimizations and ensure that simulations from an old frozen model configuration can be reproduced with the latest model version. We will present an exhaustive evaluation of some of these methods under various controlled model perturbation scenarios. ?

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## MS22

### A Novel Approach for Detecting Unexpected Model Results in E3SM Climate Model

Comprehensive model testing can be a challenging task for complex numerical models such as those used for climate simulation. Traditional approaches such as unit tests or system level testing (e.g. regression testing) do not give any insights into whether the source code modifications have changed the overall simulation results in an unexpected way. A resource intensive approach (computationally expensive as well as involving significant number of man hours) to find these unexpected cases is to run ensembles of long simulations and analyze model output to characterize the statistical similarity of those simulations compared to previous model behavior every time a source code modification is made. Rosinski and Williamson (1997) suggested that many pathologies could be detected when models are changed (by changing compilers, optimization levels, code refactoring, hardware, etc.) by comparing two very short simulations, and evaluating their solution divergence, which is much less expensive than a statistical evaluation of long simulations. In this talk, we will describe a new and even faster method to detect such issues in a very complex E3SM (Energy Exascale Earth System Model) climate model. Our method is based on the technique described by Rosinski and Williamson (1997) but it differs by using an ensemble of single time step simulations.

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## MS22

### Mathematical Aspects of the Terrestrial Carbon Dynamics

Terrestrial ecosystems absorb roughly 30% of anthropogenic CO<sub>2</sub> emissions since pre-industrial era, but it is unclear whether this carbon (C) sink will endure into the future. In this talk, I will introduce a linear compartmental model, which is a system of non-autonomous ordinary differential equations (ODEs), and discuss the long-term behavior (equilibrium) and the transit times and mean ages of the terrestrial carbon cycle. This is a joint work with Yiqi Luo et al.

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## MS23

### Quantifying the Skill in Probabilistic Forecast for the Sea Breeze Deriving from Large-Scale Variables

High resolution (kilometre-scale) regional models can represent the dynamics of mesoscale phenomena that cannot be captured currently in global simulations. They can generate flow structures that are qualitatively similar to observations. However, for kilometre-scale ensemble forecasts downscaled from global ensemble members, there is no additional observational information, so any improvement in probabilistic forecast skill must derive from small scale dynamics and the differences between large-scale members. Here, the prediction of the probability of sea breeze occurrence by the Met Office 2.2 km ensemble (MOGREPS-UK) is compared to a Bayesian statistical model driven by physical parameters derived from the parent global 33 km ensemble (MOGREPS-G). The question is what proportion of forecast skill is derived solely from knowledge of the large-scale environment and what information is gained from downscaling that cannot be represented by this reduction of the problem? A new method for identifying sea breezes is proposed for deriving the probabilistic forecast of sea breeze occurrence from the MOGREPS-UK ensemble. The Bayesian statistical forecast was created using paired MOGREPS-UK and MOGREPS-G ensemble members as a training dataset.

Reliability and resolution are evaluated using appropriate statistical tests. Preliminary results do not show significant differences between the forecast systems in this respect.

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## MS23

### Rate-Induced Tipping in Nonautonomous Dynamical Systems with Bounded Noise

Tipping points describe bifurcations where the output of a dynamical system changes disproportionately compared to the change in the parameter. A classification of differ-

ent mechanism of tipping in dynamical systems has been proposed in literature and a new behaviour has been identified: the so-called rate-induced tipping, R-tipping or rate-induced bifurcation. This work aims at providing a mathematical framework for rate-induced tipping in one dimensional nonautonomous dynamical systems in the presence of bounded noise and to give a necessary condition for such behaviour to occur. It is given an autonomous dynamical system depending on a parameter. The system is generally not undergoing any classical bifurcation under changes in the parameter. We consider the parameter changing in time at a positive rate so that the system is now nonautonomous but asymptotically autonomous. Moreover, consider a bounded time-dependent perturbation so that the system can be regarded as a nonautonomous set-valued (or general) dynamical system. A rate-induced tipping describes a destabilisation of such system due to a rapid change in the parameter, i.e. the existence of a critical rate. A precise definition of rate-induced tipping as a discontinuity in the limiting behaviour of a local pullback attractor is proposed. Under appropriate assumptions, an attractor-repeller collision is shown to be a necessary condition for such tipping to occur.

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## MS23

### Potential Vorticity Redistribution by Localised Transient Forcing in the Shallow-Water Model

Mesoscale eddies are ubiquitous in the world's oceans, and play a crucial role in driving the large-scale circulation. To dynamically resolve these eddies in numerical simulations, general circulation models (GCMs) require grid resolutions on the order of 1 km, which is often computationally unfeasible. The solution is to define a parameterisation which accounts for the unresolved mesoscale eddy effects in a coarse-resolution GCM. We progress towards such a parameterisation by developing an understanding of flow responses to localised 'plunger' forcings intended to represent transient eddy flux divergences. Specifically, we consider the behaviour of the footprint, i.e. the time-averaged potential vorticity (PV) flux convergence in the linearised single-layer shallow-water system, with an emphasis on understanding the role of the large-scale background flow. It is found that the footprint has a robust dependence on the magnitude and direction of a zonal uniform background flow, a useful quality for the footprint to provide a basis for a parameterisation of eddy PV fluxes. I will present further details regarding the properties of the footprint and how we may apply our findings to the development of eddy parameterisations.

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## MS23

### Parameterising Eddy-Induced Lagrangian Transport in An Idealised Oceanic Jet

It has long been understood that eddying structures contribute significantly towards ocean circulation and the distribution of passive tracers in the ocean. However, as most ocean general circulation models (OGCMs) currently operate at grid resolutions greater than the size of mesoscale eddies and so are not eddy-resolving, eddying effects must be parameterised, in particular that of Lagrangian transport. Most commonly, eddy-induced transport is parameterised according to down-gradient diffusion. The eddy diffusivity constant  $K$  quantifies the efficiency of tracer transport. This constant is frequently taken to be isotropic and homogeneous. However, previous studies have suggested that this is not the case. A Quasi-geostrophic model simulating a meandering jet will be used as a simple test case. Different parameter regimes will be explored which will determine the strength and size of meanders of the jet and Lagrangian particles will be advected using these velocity fields. We will argue that the eddy-diffusivity tensor is not the most appropriate parameter to quantify oceanic transport and will suggest an alternative parameter. New parameterisation methods will be explored. The analysis of this simple test case will hopefully be the ground work in deriving a new a more suitable approach to parameterising eddy-induced transport in OGCMs.

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## MS24

### Risk Structured Model of Cholera Infections In Cameroon

In this talk, we will introduce a high and low risk structured model of cholera infection dynamics in Cameroon. The model has direct (human-to-human) transmission and indirect (contaminated water-to-human) transmission. We will use our model's demographic equation to 'fit' the population of Cameroon, and then use the fitted cholera model to capture cholera cases in Cameroon from 1990 to 2017. Furthermore, we will use our model to study the impact of various cholera control strategies on the number of cholera infections in Cameroon.

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## MS24

### Outbreak Size and Intervention on Discrete Spatial Networks

Understanding disease spread on networks is important when making decisions on intervention. We consider a discrete spatial network with SIR-type dynamics, coupled by environmental pathogen movement through a weighted, directed, strongly connected graph. We discuss how patch characteristics, network structure, and coupling strength influence disease outbreak size as well as intervention efforts on the domain. A case study in Cameroon will be discussed. This is joint work with Karly Jacobsen and

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## MS24

### Modeling the Opioid Epidemic

Opioid addiction has become a global epidemic and a national health crisis in recent years, with the number of opioid overdose fatalities steadily increasing since the 1990s. In contrast to the dynamics of a typical illicit drug or disease epidemic, opioid addiction has its roots in legal, prescription medication a fact which greatly increases the exposed population and provides additional drug availability for addicts. In this talk, I will present a first epidemic model for opioid addiction and treatment. Through analysis of our model, we show that no addiction-free equilibrium exists without stringent control over how opioids are administered and prescribed, effectively transforming the dynamics of the drug crisis into those of a classic illicit drug epidemic. Finally, numerical sensitivity and parameter space analysis suggest several focal points for control, including a nonlinear balance between writing fewer opioid prescriptions and increasing treatment of addicted individuals after the fact.

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## MS24

### Application and Modeling of a Tick-killing Robot to Protect Humans and Livestock

Ticks are known vectors of disease-causing pathogens that affect humans, wildlife, and domestic animals. Effective control measures are needed to reduce the risk of encountering ticks, and thus reduce risk of tick-borne disease. To control ticks, a variety of methods have been used including a tick-killing robot, TickBot. TickBot lures ticks, using movement and carbon dioxide, to a permethrin treated cloth as it circles a predetermined perimeter. Previous studies have shown TickBot's ability to protect a treated area from tick encounters for approximately 24 hours. Mathematical models can be used as part of the One Health approach to explore tick population dynamics, quantify risk of tick-borne disease, and identify strategies to reduce that risk. Using the data from our surveillance project, along with the results from TickBot field studies,

a mathematical model was developed to explore ideal usage of the TickBot as an integrated tick management tool. Results from the model will be presented and discussed.

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## MS25

### A New Discretisation for the Stochastic Quasi-Geostrophic Equations

One of the challenges for numerical models of geophysical fluids is how to represent the effect of processes that are smaller than the model resolution. Traditionally this is done through adding parametrizations to the model. However these parametrizations can mean that the model may no longer preserve important properties of the fluid: for example they may not be a Kelvin Circulation theorem. However recent work by Professor Holm at Imperial College London has proposed a stochastic representation of fluid dynamics that does preserve the circulation theorem. For this work, we will be interested in a stochastic form of the quasi-geostrophic equations, a simple model of large scale atmospheric and oceanic flow. I will begin this talk by presenting the features of the stochastic quasi-geostrophic equations proposed by Professor Holm. Then I will introduce a new enstrophy-preserving discretisation for these equations, before discussing the statistical properties of our discretisation.

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## MS25

### Reflection of Rossby Waves in the Stratosphere: The Role of Critical Layer Nonlinearity

There exists a two-way coupling between the troposphere and the stratosphere; atmospheric waves are generated through a variety of mechanisms in the troposphere and they propagate upwards in to the otherwise stable stratosphere. Here, they may break down or they may be reflected downwards back in to the troposphere, thereby influencing tropospheric dynamics and forming a closed loop two-way coupling. Placing this coupling in an appropriate mathematical framework is crucial to improving climate and weather predictions, and this is investigated by first understanding the reflection of Rossby waves. The mechanism by which Rossby waves are reflected is studied in terms of a nonlinear critical layer. Critical layers exist where the base flow velocity equals the phase speed, and it is here that nonlinear effects may become significant, and Rossby waves reflected. This work takes in to account the presence of all harmonics within the critical layer, and attempts to identify the reflected and transmitted waves as well as the consequential disturbances within the critical

layer using multiple-scale techniques.

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## MS25

### Optimisation of Tidal Turbine Arrays in the Alderney Race

Planet Earth is facing a rise in energy demand, decline in fossil fuel reserves and damaging climate change. Harnessing renewable energy is imperative. To support the high and fluctuating demand, a broad portfolio of clean energy sources is needed. Predictability of supply hinders the uptake of renewables, but the regularity of tides makes them an attractive option. The UK has around 50% of Europe's tidal energy capacity and a technical resource supply of about 116 TWh/year. However, tidal energy is a fledgling industry, with the world's first array only recently installed. The first full-sized arrays will only be developed if shown to be viable from economic, engineering and environmental perspectives. Advanced numerical tools are needed to predict and maximise power yields in arrays of up to hundreds of turbines, to assess viability of new sites and aid array design. To demonstrate our ability to optimise design, we focus on the Alderney Race; a potential array location for both France and the UK. It contains the majority of the Channel Islands resource. We have set up a shallow water model of the English Channel and validated it with tide gauge data. We employ finite-element based numerical methods to solve the hydrodynamics along with adjoint technology for optimisation of the location of turbines within an array. We will show the impact that different functionals, e.g. power or Levelised Cost of Energy, have on optimal array design.

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## MS25

### A Novel Scaling Indicator of Early Warning Signals Helps Anticipate Tropical Cyclones

Tipping events have been studied in many climatological and ecological contexts, often modelled by the decay of stable equilibria, or critical modes. It is possible to detect the presence of a critical mode by estimating its decay rate, and indicators of changes in these properties may therefore be used to provide an early warning signal for an impending tipping event. The lag-1 autocorrelation function indicator and the detrended fluctuation analysis (DFA) indicator have previously been used in such a way. We shall discuss a novel scaling indicator based on the decay rate of the power spectrum, introduced in a recent paper\*, and compare this with existing indicators. Besides considering artificial and model data, we shall also demonstrate the possible use of this new method to anticipate impending tropical cyclones

using sea-level pressure data. In this case, we see that the new method appears to offer an improvement over the ACF(1) and DFA indicators. \* J. Prettyman, et al.. submitted to Europhysics Letters.

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## MS26

### Scalable in Time Algorithms for Large Scale Predictive Science

We address the design and development of innovative mathematical models for Predictive Science simulations described by Variational Data Assimilation (DA) methods tightly coupled with time-dependent Partial Differential Equations (PDEs). The result is a PDE-based variational problem that is extremely large scale. The innovation refers to the simultaneous introduction of space-and-time decomposition approaches, consisting of Parallel in Time (PinT)-based approaches for solving the PDEs and functional decomposition for solving the Variational DA model; finally, domain is decomposed both along the space and the time dimension. The core of our approach is that the DA model acts as coarse-propagator/predictor for local PDEs, by providing the background values for the local initial conditions. The main outcome of this approach is that, in contrast to other PinT-based approaches, local solvers run concurrently, so that the resulting algorithm only requires exchange of boundary conditions between adjacent sub-domains. This work is carried on in collaboration with E. Constantinescu (ANL) and L. Carracciolo (CNR-IT).

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## MS26

### 4dvar with Model Errors

Data assimilation in the variational approach (4DVar) is often implemented as a strong constraint algorithm (SC4DVar). This assumes that the observations over the time window are consistent (within a margin of observation errors) with the model, if initialized by the true state. However, the error in the model is often large enough to be non-negligible and this has the effect of SC4DVar scheme resulting in an analysis that is inconsistent with the observations. The effect of model error is even more pronounced when the assimilation window is large. Weak constraint 4DVar (WC4DVar) is one approach to relax the perfect model assumption. This assumes that model error is present in each time step. However, in order to implement any flavor of the WC4DVar algorithm, estimates of model-error statistics are necessary. In this work, we compare the performance of variational algorithms with different model-error statistics.

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## MS26

### A Line Search Method For Non-Linear Data Assimilation Via Random Descent Directions

In this work, we propose an efficient line search method for non-linear data assimilation in the 3D-Var context. The iterative method works as follows: initially, an ensemble of model realizations is used in order to estimate the moments of the prior error distribution, having the ensemble mean as the initial seed, an iterative method is performed in which, among iterations, the observation operator is linearized about the current solution, a convex approximation of the 3D-Var cost function is obtained, and the negative of its gradient serves as a descent approximation to the 3D-Var optimization problem. This gradient approximation is multiplied by a set of random-generated positive definite matrices from which a set of basis vectors is obtained. The optimization problem is constrained to the space spanned by such random directions and by solving a convex optimization problem, optimal weights for those basis vectors are obtained. The posterior ensemble is then built similar to that of the Posterior Ensemble Kalman Filter. Experimental tests are performed making use of the Lorenz 96 model. The results reveal that, the proposed method is able to decrease the initial gradient norm in several order of magnitudes and even more, to provide efficient assimilation states in a root-mean-square-error sense for different assimilation windows.

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## MS26

### Ice Sheet Model Initialization as Bayesian Inverse Problem

Due to the amount of water stored in the Antarctica and Greenland ice sheets, they play a crucial role in predictions of future sea level change. Estimation of the present day ice sheet state from surface satellite (and other) observations is crucial for these predictions. I will present this ice sheet model initialization problem as a Bayesian inverse problem. This problem is challenging due to the high dimension of the inversion field and the expensive-to-solve governing equations, namely a nonlinear Stokes equations describing the gravity-driven viscous flow of ice. These challenges increase if one is interested in quantifying the degree of uncertainty—due to limited surface observations and the imperfect model equations—in the model initialization. These uncertainties translate to uncertainties in predictions of sea level change. I will discuss approximations and solution methods for the inverse problem, and solvers for the governing nonlinear Stokes equations.

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## MS27

### Optimal Groundwater Remediation with PSO and the Filter Method

Particle Swarm Optimization (PSO) is one of the most highly demanded Derivative-Free methods emerging in the last two decades for solving applied optimization problems, especially when the derivatives are not available or hard to compute due to a black-box or simulation-based formulation in many applications. The Hydraulic Capture Problem (HCP) is a simulation-based problem to determine where to place wells to control the movement of a contaminant plume. It is considered a challenging problem for many DFO solvers since the objective function is nonlinear, nonconvex, has jump-discontinuities, and replete with a local minimum. In this work, we apply a hybrid of the filter method for constraint handling with PSO to the HCP and compared with other popular DFO solvers performances.

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## MS27

### Optimization of a Retention Basin Using a Hybridized Pso-Aco Method for Mixed-Integer Problems

The drought of California has led to a need for better water treatment and conservation methods. Groundwater levels have greatly suffered and have inspired researchers to find ways to recharge the aquifer. A proposed method is through the use of a retention basin system that captures rainfall for aquifer recharge. Such a construction depends upon not only the land shape, but on soil properties and government regulations as well. The purpose of this talk is to discuss the volumes of the needed basins as constrained by the topography. The original problem used a dynamic programming approach, while this research focused on two mixed integer algorithms. One of these algorithms is a new hybridization of two swarm algorithms to use a mixed integer formulation of the problem. The binary integer variables determine if a basin should be built or not and are optimized using ant colony optimization. The real-valued basin sizes are optimized using particle swarm optimization. Both algorithms give comparable results with significantly different configurations, which allows for deeper understanding and design flexibility.

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## MS27

### Simulation Based Optimization Using the Implicit Filtering Genetic Algorithm for Optimal Placement of Slow Release Oxidant Cylinders in Groundwater Remediation

The use of Slow Release Oxidant Cylinders (SROCs) is an emerging long term management strategy for the remediation of contaminated groundwater sites. The fate and transport of the oxidant, contaminant, and Natural Oxidant Demand (NOD), is modeled in 2D (top-down) using a coupled system of PDEs. A Fortran simulator is employed to solve the system using a Radial Basis Function Collocation Method (RBFCM). The hybrid Implicit Filtering Genetic Algorithm (IFEGA) is used to optimize the number, placement, and replacement of oxidant cylinders for minimal cost, subject to Environmental Protection Agency (EPA) compliance constraints. A theoretical site is considered and the cost of the optimal solution using SROCs is compared with the cost of the currently favored method of using oxidant injections.

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## MS27

### Simulation-Based Optimization and Agricultural Water Management

Managing existing water supplies has become critically important in recent years, as overuse, in conjunction with severe levels of drought, have placed aquifers in jeopardy. The imbalances in aquifer levels are especially dire in regions whose economies are heavily dependent on agriculture, as irrigation of crops accounts for more than 80% of the usage of groundwater resources. In California, for instance, the effects of a several-year, severe drought are exacerbated by the heavy agriculture production throughout the state. In particular, farmers in this region produce a significant amount of the produce consumed in the U.S. Thus, water policy decisions, and limited availability of water, have a drastic effect on the livelihood of local residents as well as the U.S. as a whole. Our multidisciplinary research team has worked to develop a software environment that can be used to help water management agencies evaluate strategies for water conservation and water supplementation efforts. We use simulation-based optimization to evaluate a suite of options available to members of an agricultural community and provide analytics on possible solutions. These data can be used to help water management agencies make decisions that will have community support. The talk will include information on case studies we have conducted over agricultural regions in California and discuss our path forward.

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## MS28

### Modeling Differential Transmission Mechanisms in Vector-Borne Viral Cassava Diseases in Africa

The whitefly, *Bemisia tabaci*, is one of the most economically important insect vectors of plant viruses. It transmits over 200 viruses through either semi-persistent or persistent mechanisms. Cassava mosaic geminiviruses and Cassava brown streak viruses have been associated with region-wide spread of a dual pandemic of cassava mosaic disease and cassava brown streak disease. Although both diseases are spreading through East and Central Africa, their epidemiological characteristics differ greatly. We compare local transmission characteristics of both viruses using mathematical modeling techniques, to derive novel insights into factors driving these epidemics.

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## MS28

### Stochastic Modeling of Infectious Diseases

In an infectious disease outbreak, individuals who transmit the disease to a large number of susceptible individuals are known as superspreaders. To investigate the role superspreaders play in an outbreak, we construct both deterministic and stochastic models with two classes of individuals, superspreaders and nonsuperspreaders. We analyze these models and then run numerical simulations for the cases of Middle East respiratory syndrome (MERS) and Ebola. From the analysis and simulations, we gain insight into superspreaders' role in the outbreak timeline and severity of the outbreak.

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## MS28

### A Discrete Data-Driven Pseudorabies Model for Feral Hogs in Great Smoky Mountains National Park

Pseudorabies, or Aujeszky's Disease, was first identified in 1902. This herpes viral infection is highly contagious and causes respiratory illness in adults and high mortality rates for piglets in domestic swine. Feral hogs in Great Smoky Mountains National Park are a reservoir for the disease, making the population a serious threat for the local domestic swine industry. As a result, feral hogs in the Park have been surveyed for pseudorabies starting in 2001, and the prevalence has been as high as 57% of the population. In this project we model pseudorabies in the population in order to better understand transmission routes and important dynamics of the disease. This is achieved by building a compartmental disease model into our existing metapopulation model for the population. Using available data to drive our model, we explore possible transmission routes, estimate transmission parameters, and model the spread of the disease in the population.

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## MS28

### Managing the Commons Against Infectious Diseases

Despite a romantic predilection toward individualism, it is hard to deny the interconnectedness of human existence in 2018. Each day, we rely on a commons of interwoven economies, infrastructures, and ecosystems for our health and happiness. These interconnections mean that we share not only resources, but also risks. A fruit bat roost may pose a health risk not only to the children of the neighboring village, but those of us thousands of miles away. In this talk, I'll illuminate how emerging diseases, population migrations, and health poverty traps pose health challenges to rich and poor alike that we should all work to mitigate.

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## PP1

### Detecting Spatiotemporal Critical Transitions, "Information-Theoretic Catastrophe Alarm"

This paper introduces a spatiotemporal information flow affinity that will infer critical changes in spatiotemporally evolving systems that are only remotely observable. The proposed method represents a spectral method built on information theoretic measures to describe an underlying geometry describing the observed spatiotemporal states, using mutual information and also Kulback-Liebler divergence, in a manner inspired by transfer entropy and also spatial information flow. The proposed method will allow to design a geometry that has the potential to partition into like (coherent) sets with similar spatial evolving statistics, whereas, developing boundaries can serve as spatiotemporal critical transitions early warning signs.

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## PP1

### A Generalized Stefan Problem Exhibiting Two Moving Boundaries with Application to the Evo-



### Evolution of Fluvial Deltas under Sea-Level Change

Many of the world's deltas are highly populated and experiencing rapid rates of deterioration. In order to form baselines for coastal management and protection and reverse these land loss trends, we need to understand the natural processes of delta growth and long-term evolution. With this goal in mind, we present a forward model for the cross-shore evolution of a river dominated deltaic system subjected to sea-level changes. Assuming the transport of sediment is directly proportional to the fluvial slope, the model can be treated as a one-dimensional Stefan problem with two geomorphic moving boundaries: the alluvial-bedrock transition (ABT), which separates the sediment prism from the non-erodible bedrock basement, and the shoreline (SH), where the delta meets the ocean. We extend a fixed grid enthalpy-like numerical technique to compute the trajectories of the ABT and SH under sea-level changes. The mathematics of the approach are verified by comparing predictions under two specific scenarios that admit closed form solutions: square-root of time sea-level change and constant sea-level rise. The model is then used to predict the evolution of the system under sea-level cycles. Model results demonstrate that time lags in the ABT response to sea-level variations can be geologically long-lived. Moreover, these results demonstrate that numerical techniques from heat transfer, in particular enthalpy methods, can be used to better understand the dynamics of fluvial deltas.

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### PP1

#### Krylov Subspace Spectral Methods for Navier-Stokes

Existing time-stepping methods for PDEs such as Navier-Stokes equations are not as efficient or scalable as they need to be for high-resolution simulation due to stiffness. The failure of existing time-stepping methods to adapt to changes in technology presents a dilemma that is becoming even more problematic over time. By rethinking approaches to time-stepping, dramatic gains in efficiency of simulation methods can be achieved. Krylov subspace spectral (KSS) methods have proven to be effective for solving time-dependent, variable-coefficient PDEs. The objective of this research is to continue the development of KSS methods to provide numerical solution methods that are far more efficient and scalable to high resolution for Navier-Stokes equations. So far, KSS methods have been applied only on 1-dimensional, 2-dimensional, and 3-dimensional rectangular domains, but current work is extending them to polar domains using polar coordinates and expansions in Legendre polynomials instead of Fourier series. We will utilize these techniques for compressible Navier-Stokes equations on rectangular domains as well as polar domains.

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### PP1

#### Data-Driven Modeling of Phytoplankton Blooms in the Ocean

Phytoplankton are the base of the marine food web. They are also responsible for almost half of the oxygen we breathe and they remove carbon dioxide from the atmosphere. A macroscale plankton ecology model is constructed consisting of coupled, nonlinear reaction-diffusion equations with spatially and temporally changing coefficients. An example of an NPZ model, this model simulates biological interactions between nutrients, phytoplankton and zooplankton. It also incorporates seasonally varying, physically driven forces that affect the phytoplankton growth: solar radiation and depth of the ocean's upper mixed layer. The model's predictions are dependent on the parametric functional behavior of the model. The model is analyzed using seasonal oceanic data with the goals of understanding the model's dependence on its parameters and of understanding seasonal changes in plankton biomass. The model is tested on different regions of the world's oceans so that appropriate choices can be made for parameters that correspond to physical/biological quantities in those regions. A study of varying parameter values and the resulting effects on the solutions, stability, and the timing of blooms is carried out. This modeling effort can be helpful for understanding the ecological structure of plankton communities and the timing of seasonal phytoplankton blooms, which are debated topics in oceanography.

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### PP1

#### Effects of Brine Inclusions and Crystallographic Anisotropy on the Rheological Response of Sea Ice

Sea ice exhibits a highly anisotropic multi-phase polycrystalline microstructure that varies with temperature and bulk salinity. In the multi-year desalinated ice, the grains consist of isolated spheroidal brine inclusions in an anisotropic HCP matrix. As the temperature increases, the inclusions first transform into isolated cylindrical shapes, with an increase of porosity, and finally they coalesce to form an interconnected network. These microstructural changes are found to significantly impact the rheological response of sea ice. In this work, we use the recently developed iterated second-order homogenization method to model the effects of the volume fraction and shape of the inclusions on the rheological response of sea ice. Finally, we explore the effects of the crystallographic anisotropy on the effective response for various loading configurations. We also highlight the influences of the relative slip-activities in determining the rheology of sea ice.

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#### PP1

##### **Raising the Roof: Using the Uk Met Office's Unified Model to Simulate the Lower Thermosphere - Results and Validation**

Forecasting weather in the lower thermosphere (85–120 km) is of particular interest due to its impact on spacecraft re-entry and radio communications. To this end, we aim to extend the current 85 km upper boundary on the UK Met Office's Unified Model (UM) to a height of around 120 km. Thus, we shall raise the roof on current numerical weather prediction and pave the way for the development of a whole atmosphere model. This region, however, has proven to cause particular difficulties for the UM. Thus, extended UM simulations were performed to assess the model anomalies directly. With these model runs, the radiation scheme was discovered to be a significant contributing factor causing the model to crash. In particular the lack of consideration of non-Local Thermodynamic Equilibrium (LTE) effects in the thermosphere leads to anomalous shortwave radiative heating. The inclusion of non-LTE effects is still a work in progress. Thus, in order to circumvent this problem, we shall replace the radiation scheme by nudging towards a climatological temperature structure above 70 km. With this in place, we look to validate the models accuracy in the lower thermosphere by comparison to data. We present the results of this validation, and introduce steps to further improve the model in the lower thermosphere, including the improved parametrization of gravity waves at these heights.

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#### PP1

##### **Assessing the Health of Tampa Bay Through a Time Series Analysis of the Cpue**

We investigated the catch per unit effort of a spectrum of fish in Tampa Bay including Gulf Flounder, Gray Snapper, Pinfish, Red Drum, Sheepshead, Spotted Seatrout, and Striped Mullet. We analyzed the robustness of these populations over a twenty year span, and the reaction of different species to known environmental and anthropogenic factors such as temperature, salinity and the harmful algal bloom *Karenia brevis*. We used a generalized least squares model with bootstrapping without replacement to control for outliers. The model delineated the species into those that have maintained a steady population, those that have declined and those that have flourished over the study period.

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#### PP1

##### **A Dynamical Systems Approach to the Pleistocene**

#### Climate

In 1990, K. Maasch and B. Saltzman proposed a conceptual model for Earth's climate during the Pleistocene Epoch. The model emphasizes the role of CO<sub>2</sub> and accounts for interactions between the oceans, atmosphere, and cryosphere. We show that, in most parameter regimes, the long-term system dynamics occur on certain intrinsic two-dimensional invariant manifolds in the three-dimensional state space. These invariant manifolds are slow manifolds when the characteristic time scales for the total global ice mass and the volume of North Atlantic Deep Water are well separated, or center manifolds when the characteristic time scales for the total global ice mass and the volume of North Atlantic Deep Water are comparable.

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#### PP1

##### **Modelling the Enzoitic Cycle of the Black-Legged Tick and *Borrelia burgorferi***

We present reasonable modifications of an existing model of the enzootic cycle of the black-legged tick (*Ixodes scapularis*). We modify a model presented by Caraco et. al. to more accurately describe the underlying ecology of *Ixodes scapularis*. Our modified model maintains many qualitative results and mathematically verifies a mechanism by which the *Ixodes scapularis* population self-regulates. We have shown that acquired resistance in small mammalian hosts for *Ixodes scapularis* can have a bounding effect on the population. Additionally, we discuss conditions for persistence of the species and persistence of *Borrelia burgorferi* (the spirochete that causes Lyme Disease in humans) within the tick's enzootic cycle.

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#### PP1

##### **On the Interactions Between Topography, Land-Sea Contrast and Diurnal Cycle During the Passage of An MJO Event in the Maritime Continent**

Understanding the multi-scale interactions between topography, land-sea contrast and diurnal cycle in the Maritime Continent (MC) remain a challenge to the atmospheric community. In particular, how such interactions influence the amplitude and propagation of the Madden-Julian Oscillation (MJO) is not known. Interactions between topography, land-sea contrast, and the diurnal cycle are revealed

using a unique set of regional model simulations and set theory that allows us to quantify such interactions. The amplitude and propagation of the MJO in the absence of one component (e.g., topography or land-sea contrast or diurnal cycle), two components (e.g., topography and diurnal cycle), and all three components are revealed. The implications of the results in the context of MJO dynamics is discussed.

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## PP1

### Vector-Valued Spectral Analysis of Indo-Pacific Ocean Variability

We study Indo-Pacific Ocean variability using a recently developed framework for spatiotemporal pattern extraction called Vector-Valued Spectral Analysis (VSA). This approach is based on the eigendecomposition of a kernel integral operator acting on vector-valued observables (spatially extended fields) of the dynamical system generating the data, constructed by combining elements of the theory of operator-valued kernels for multitask machine learning with delay-coordinate maps of dynamical systems. A key aspect of this method is that it utilizes a kernel measure of similarity that takes into account both temporal and spatial degrees of freedom (whereas classical techniques such as EOF analysis are based on aggregate measures of similarity between snapshots). As a result, VSA has high skill in extracting physically meaningful patterns with intermittency in both space and time, while factoring out any symmetries present in the data. We demonstrate the efficacy of this method with applications to various model and observational datasets of oceanic variability in the Indo-Pacific sector. In particular, the recovered VSA patterns provide a more realistic representation of ENSO diversity than conventional kernel algorithms.

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## PP1

### An Iterative Coupling Scheme in Modeling Rate and State Dynamic Ruptures in the Self-Gravitational Prestressed Earth

We consider the dynamic evolution of rate- and state-dependent frictional rupture embedded in prestressed elastic-gravitational deforming body. An splitting iterative coupling scheme is proposed based on the mixed variational form with nonlinear interior boundary conditions, for both continuous and with implicit discretization in time. The convergence of the scheme to unique viscous solutions of both cases are shown rigorously, and the artificial viscosity coefficient can be choose arbitrarily small in the time-continuous case, and proportional to time stepping in the

discretized case. Numerical implementations are based on a discontinuous Galerkin method with modified penalty flux, adapted for unstructured tetrahedral mesh with hp-refinements, and the rate- and state-dependent friction is weakly enforced across the fault surface as numerical flux. A nonlinearly constrained optimization problem is set up based on the force equilibrium, and solved by Gauss-Newton method.

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