Abstract and Titles of Talks for Scientific Grand Challenges …
Conference to celebrate Andrew J. Majda's 70th birthday

Noah Brenowitz
University of Washington
Title: Peering into the Black Box of Machine Learning Parametrization
Abstract:
Most current climate models only explicitly resolve atmospheric motions larger than about 100 km, and any smaller process, such as thunderstorms or turbulence, must be approximated, a task known as parameterization. Machine learning (ML) promises to improve such parametrizations by leveraging observations or high-resolution simulations that are too expensive for climate-scale simulation. However, training an ML parameterization to perform well when coupled to a PDE-based model over multiple time steps is an unsolved problem---ML schemes often cause numerical instability. In this talk, I discuss this numerical instability and present several tools for interpreting the behavior of ML parameterizations that can help us design stable parametrizations in the future.

Antoine Cerfon
Courant Institute, New York University
Title: Andy and the Fusionauts
Abstract:
The high level of energy transport towards the edge observed in magnetic fusion experiments is responsible for the unsatisfying power balance and insufficient gain factors measured in current fusion devices. It has been found experimentally and confirmed computationally that the strong transport is due to complex turbulent processes driven by plasma microinstabilities. A quantitatively accurate description of turbulence driven transport requires extremely expensive kinetic simulations, with simulation times measured in weeks when they are run on the largest supercomputers. The high computational cost of the kinetic simulations makes it challenging to conduct parametric studies, to quantify uncertainty and sensitivities, and to investigate innovative methods to improve the energy confinement time in magnetically confined plasmas.

In that context, reduced fluid models can play a major role, as effective tools to qualitatively understand the fundamental nonlinear processes regulating the turbulence, determine the dependence of energy transport on the key experimental parameters, and identify strategies to reduce the level of transport. In this talk, we will present new reduced fluid models Andy recently proposed to answer some of these questions, and highlight the connections he was able to make between geophysical fluid dynamics and plasma physics to gain new insight into the mechanisms for turbulence saturation in magnetic confinement fusion experiments.

Nan Chen – Note: Nan Chen’s talk given by Qiu Yang
New York University, CIMS

Title: Simple Stochastic Dynamical Models Capturing the Statistical Diversity of El Nino Southern Oscillation

Abstract:
The El Nino Southern Oscillation (ENSO) has significant impact on global climate and seasonal prediction. A simple modeling framework is developed here that automatically captures the statistical diversity of ENSO. First, a stochastic parameterization of the wind bursts including both westerly and easterly winds is coupled to a simple ocean-atmosphere model that is otherwise deterministic, linear and stable. Secondly, a simple nonlinear zonal advection with no ad-hoc parameterization of the background sea surface temperature (SST) gradient and a mean easterly trade wind anomaly representing the multidecadal acceleration of the trade wind are both incorporated into the coupled model that enable anomalous warm SST in the central Pacific.

Then a three-state stochastic Markov jump process is utilized to drive the wind burst activity that depends on the strength of the western Pacific warm pool in a simple and effective fashion. It allows the coupled model to simulate the quasi-regular moderate traditional El Nino, the super El Nino, the central Pacific (CP) El Nino as well as the La Nina with realistic features. In addition to the anomalous SST, the Walker circulation anomalies at different ENSO phases all resemble those in nature. In particular, the coupled model succeeds in reproducing the observed episode during 1990s, where a series of 5-year CP El Nino is followed by a super El Nino and then a La Nina.

Importantly, both the variance and the non-Gaussian statistical features in different Nino regions spanning from the western to the eastern Pacific are captured by the coupled model.

Peter Constantin
Princeton University

Title: On the inviscid limit

Abstract:
The high Reynolds number limit, or "inviscid limit" is a basic question of fluid mechanics. In a smooth Euler regime and in the absence of boundary layers it is well known that solutions of Navier-Stokes equations converge pathwise to solutions of Euler equations. The pathwise limit in two dimensions in non-smooth regimes was known to hold only for short time, and it is not known if it holds if boundary layers are allowed to form. I will present a result of global unconditional pathwise strong limit in the non-smooth Yudovich class with no boundary layers in two dimensions. I will also present sufficient conditions away from the boundary for the existence of a non-pathwise weak limit to possibly dissipative weak solutions of Euler equations in the presence of boundaries in both two and three dimensions.

Dale Durran
University of Washington
Title: Can machines learn to predict weather? Exploring the use of deep learning with historical gridded weather data, Authors: Dale Durran, Jonathan Weyn, Rich Caruana
Abstract:
In the early 1900's, Lewis Richardson attempted the first numerical weather forecast by manually integrating a numerical approximation to the dynamical and physical equations governing atmospheric motion. Richardson was not successful, and the first useful weather forecasts had to await the development of electronic computers and a more sophisticated understanding of numerical methods. Those first successful weather forecasts occurred in the early 1950's and were based on the barotropic model, which will serve as a benchmark in this paper. In a similar way, the development of machine learning methods capable of forecasting the weather based solely on historical weather data have had to await the development of sufficiently powerful computers and advances in deep learning. As will be demonstrated in this paper, Deep Learning Weather Prediction (DLWP) models are now capable of producing weather forecasts that are far superior to those of the early 1950's.

We develop DWLP models using deep convolutional neural networks (CNNs) trained on past observed weather data to forecast basic weather variables on an entire northern-hemisphere grid with no explicit knowledge about physical processes. At lead times up to 3 days CNNs trained to predict only 500-hPa geopotential height easily outperform persistence, climatology, and the physics-based barotropic vorticity model, but do not beat an operational dynamical weather prediction model. These CNNs are capable of forecasting significant changes in the intensity of weather systems, which is surprising, because this is beyond the capability of dynamical forecast models that rely solely on 500-hPa data. Modest improvements to the CNN forecasts can be made by adding 700--300-hPa thickness to the input data. Our best-performing CNN does a good job of capturing the climatology and annual variability of 500-hPa heights and is capable of forecasting realistic atmospheric states at lead times of 14 days.

Christian Franzke
University of Hamburg
Title: Energy consistent stochastic modelling strategies
Abstract:
Current climate models still suffer from many biases which are partly due to excessive subgrid-scale dissipation.

In my talk I will present results in developing energy consistent kinetic energy backscatter schemes in atmospheric circulation models. Both, deterministic and stochastic backscatter schemes improve low-resolution compared with high-resolution simulations. I will also present a method to compute state-dependent co-variance matrices for the stochastic backscatter scheme.

Dimitris Giannakis
New York University
Title: Forecasting observables of dynamical systems with kernel analog techniques
Abstract:
Analog forecasting is a classical nonparametric forecasting technique introduced by Lorenz in the late 1960s, which involves identifying states in historical observations that closely resemble the current initial conditions, and forecasting the future evolution of observables of interest by following the evolution of those "analog" states. In this talk, we describe how kernel methods for machine learning, combined with operator-theoretic ergodic theory, lead to a generalization of Lorenz's original approach that rigorously approximates the conditional expectation of observables under partially observed, nonlinear dynamics, while also providing useful uncertainty quantification through estimates of conditional variance and conditional probability. We present applications to forecasting in low-dimensional dynamical systems, as well as the El Nino Southern Oscillation of the climate system in models and observations.

Colin Goldblatt
University Of Victoria
Title: Clouds stabilize Earth's long term climate
Abstract:
The Sun was dimmer earlier in Earth history, but glaciation was rare in the Precambrian: this is the "Faint Young Sun Problem". Most solutions rely on changes to the chemical composition of the atmosphere to compensate via a stronger greenhouse effect, whilst physical feedbacks have received less attention. Here we show that a strong negative feedback from low clouds has had a major role in stabilizing climate through Earth's history. We perform Global Climate Model experiments in which a reduced solar constant is offset by higher CO_2, and find a substantial decrease in low clouds and hence planetary albedo, which contributes 40% of the required forcing to offset the faint Sun. Through time, the climatically important stratocumulus decks have grown in response to a brightening Sun and decreasing greenhouse effect, driven by stronger cloud-top radiative cooling (which drives low-cloud formation) a stronger inversion (which sustains clouds against dry air entrainment from above). This demonstrates the importance of physical feedbacks on long-term climate stabilization, and a reduced role for geochemical feedbacks.

David Goluskin
University Of Victoria
Title: Studying dynamics using polynomial optimization
Abstract:
Various global properties of nonlinear ODEs and PDEs can be inferred by constructing functions that satisfying suitable inequalities. Although the most familiar example is proving stability by constructing Lyapunov functions, similar approaches can produce many other types of mathematical statements, including for systems with chaotic or otherwise complicated behavior. Such statements include bounds on attractor properties or transient behavior, estimates of basins of attraction, and design of optimal controls. Analytical results of these types often trade precision for tractability. Much greater precision can be achieved by using computational methods of polynomial optimization to construct functions that satisfy the suitable inequalities. This talk will describe several ways in which polynomial optimization can be used to study dynamics. Several examples will be shown in which polynomial optimization produces arbitrarily sharp results while other methods do not. These examples include the estimation of average and extreme quantities on the attractors of the Kuramoto-Sivashinsky equation.

John Harlim
Penn State University
Title: Data-Driven Model for Missing Dynamical Systems
Abstract:
In this talk, I will discuss a data-driven method for modeling missing dynamics. The proposed approach is formulated using the theory of kernel embedding of conditional distribution on appropriate Reproducing Kernel Hilbert Space (RKHS), equipped with an orthonormal basis functions. Depending on the choice of the basis functions, the resulting closure from this nonparametric modeling formulation is in the form of parametric models. This suggests that the successes of various parametric modeling approaches that were proposed in various domain of applications can be understood through the RKHS representation. Supporting numerical results on instructive nonlinear dynamics show that the proposed approach is able to replicate high-dimensional missing dynamical terms on problems with and without separation of temporal scales.

Markos A. Katsoulakis
Mathematics & Statistics,UMass Amherst
Title: Uncertainty Quantification for Probabilistic Graphical Models: information theory, causality and heterogeneous data
Abstract:
In this talk we present information-theoretic methods for uncertainty quantification in Probabilistic Graphical Models (PGM).PGMs are one of the fundamental tools in probabilistic machine learning and artificial intelligence, that allows to incorporate in probabilistic models multiple data sources, correlations and causal relationships. We illustrate the proposed mathematical and computational methods with an application in materials design for fuel cells. There PGMs allow us to build systematically models with (a) multiple physical mechanisms at scales ranging from the quantum to the mesoscale, and (b) incorporate available data, expert knowledge and modeling uncertainties. In the end the proposed tools provide insights on how to identify and rank experiment and modeling uncertainties, update individual PGM components that underperform in predictive capability and ultimately select materials for near optimal performance

Boualem Khouider
University Of Victoria
Title: Stochasticity and organization of tropical convection
Abstract:
I will review recent developments in these and practice of stochastic particle interacting systems from statistical mechanics for organized tropical convection as part of Andy's vision and influence on the field. I'll begin with a simple Ising model for convective inhibition and explain how this has led to the creation of the stochastic mulitcloud model (SMCM). The SMCM has been implemented in many climate models by various groups in the climate modelling world and has been successfully behind the improved fidelity of these models in representing the modes of variability of the tropical atmosphere. After illustrating this success, I will switch gears into showing how such models can be used to explain the various organization regimes of shallow cumulus as the phase transition and pattern formation in reaction-diffusion systems.

George Kiladis
NOAA
Title: Vertical Dependence of the Scale and Structure of Stratospheric Equatorial Waves in Various Reanalysis Datasets.
Authors: George N. Kiladis, John R. Albers and Juliana Dias
Abstract:
The three-dimensional structure of free stratospheric equatorial waves and their vertical dependence are studied in various reanalysis datasets. The structure and temporal variability of the waves are isolated through space-time spectra and EOF analyses of space-time filtered equatorial wind, temperature and geopotential fields. The Principal Components (PCs) associated with each mode can be used to establish its statistical structure by projecting global multilevel dynamical fields from reanalysis onto the PCs in the time domain at lag using linear regression. Here we study the change in the activity, structure, and scale of the waves from the lower to the upper stratosphere. The spectral signals of Kelvin, n=0 mixed-Rossby/eastward inertia-gravity (MRG/EIG), and n=1 westward inertia-gravity (WIG) waves of Matsuno's (1966) theory can all be readily detected from the tropical tropopause layer (TTL) at 100 hPa all the way to the upper stratosphere at 1 hPa in the reanalysis data.

The activity of the equatorially-trapped modes is related to changes in basic state circulation including the seasonal cycle and the stratospheric Quasi-Biennial Oscillation (QBO). At the tropopause, these waves scale to around an 50m equivalent depth, and the corresponding equivalent depths increase monotonically with height, reaching values of around 300 m at 1 hPa. These shifts are assumed to be due to wave damping and filtering of lower frequency (slower) waves by the zonal wind. Correspondingly, the waves become faster and they become less progressively trapped about the equator with height, as expected from linear theory. Additionally, the well-documented variability of many of the modes associated with the stratospheric QBO is also evident.

Rupert Klein
Freie Universitat Berlin
Title: An asymptotic theory for hurricane development
Abstract:
Paeschke et al, JFM (2012) proposed a new theory for the evolution of tropical storms into the hurricane regime. By asymptotic analysis they constructed a three-dimensional model for the response of a strongly tilted and, at every height, nearly axisymmetric vortex to symmetric and asymmetric heating profiles.
This model consists of a coupled system of evolution equations for the vortex centerline and the primary circulation.
This presentation will report on recent model extensions to include both multiscale moist physics processes and the bottom boundary layer as well as on comparisons of the reduced model with idealized three-dimensional simulations aimed at independent corroboration of the asymptotic theory

Yoonsang Lee
Dartmouth College
Title: Stochastic superparameterization through local data generation
Abstract: Stochastic superparameterization is a class of multiscale methods that approximate large-scale dynamics of complex dynamical systems such as turbulent flows. Unresolved sub-grid scales are modeled by a cheap but robust stochastic system that mimics the true dynamics of the sub-grid scales, which is crucial to model non-trivial and non-equilibrium dynamics. In this talk, we propose a numerical procedure to estimate the modeling parameters, which avoids the use of climatological data

Richard M. Mclaughin
University of North Carolina at Chapel Hill
Title: Cluster formation and self-assembly in stratified fluids: a novel mechanism for particulate aggregation
Abstract:
We experimentally observe and mathematically rationalize a new fundamental attractive mechanism we have found in our laboratory by which particles suspended within stratification may self-assemble and form large aggregates without need for short range binding effects (adhesion). This phenomenon arises through a complex interplay involving solute diffusion, impermeable boundaries, and the geometry of the aggregate, which produces toroidal flows. We show that these toroidal flows yield attractive horizontal forces between particles. We experimentally observe that many particles demonstrate a collective motion revealing a system which self-assembles, appearing to solve jigsaw-like puzzles on its way to organizing into a large scale disc-like shape, with the effective force increasing as the collective disc radius grows. Control experiments with two objects (spheres and oblate spheroids) isolate the individual dynamics, which are quantitatively predicted through numerical integration of the underlying equations of motion. With this two-body information, we present simulations with hundreds of spheres which we observe reproduces many of the features of our self-assembly experiments.

This is joint work with Roberto Camassa, Dan Harris, Robert Hunt, and Zeliha Kilic

Mustafa Mohamad
MIT
Title: Predicting the Eulerian energy spectrum from Lagrangian drifters
Abstract:
The assimilation and prediction of a flow field given a stream of measurements provided by passively advected Lagrangian drifters is discussed. We quantify recovery of the Eulerian energy spectra from observations of Lagrangian drifters by special Lagrangian data assimilation algorithms, based on conditionally Gaussian Kalman filters. Prediction of the Eulerian energy slope is demonstrated through combined assimilation and parameter estimation, and recovery skill of the spectrum in various regimes is demonstrated.

Nick Moore
Florida State University
Title: Experiments and theory for anomalous waves induced by abrupt changes in topography
Abstract:
I will discuss both laboratory experiments and a newly developed theory for randomized surface waves propagating over variable bathymetry. The experiments show that an abrupt depth change can qualitatively alter wave statistics, transforming an initially Gaussian wave field into a highly skewed one. In our experiments, the probability of a rogue wave can increase by a factor of 50 compared to what would be expected from normal statistics. I will discuss a theoretical framework based on dynamical and statistical analysis of the truncated KdV equations. This theory accurately captures many key features of the experiments, such as the skewed wave distributions that emerge downstream and the associated excitation of higher frequencies in the spectrum

David Neelin
Department of Atmospheric and Oceanic Sciences, UCLA
Title: From stochastic process models to climate model diagnostics for precipitation processes
J David Neelin, Yi-Hung Kuo, Cristian Martinez-Villalobos, Fiaz Ahmed
Abstract:
Stochastic process models based on simplifications of climate model equations — and motivated by observational analysis — suggest that economical assumptions can yield simple connections between underlying physics and important aspects of observed precipitation statistics. These include characteristic shapes of probability distributions of precipitation accumulations, time averaged intensities and spatial clusters, relationships between wet regime and dry regime probabilities, and factors affecting changes in extremes. A dialogue between such theoretical underpinnings and pragmatic diagnostics for climate models aims to help understand biases in the models and aspects of the process models that should be expanded.

Di Qi
New York University
Title: Statistical Reduced Models and Rigorous Analysis for Uncertainty Quantification of Turbulent Geophysical Flows
Abstract:
The capability of using imperfect statistical reduced-order models to capture crucial statistics in turbulent flows is investigated.
Much simpler and more tractable block-diagonal models are proposed to approximate the complex and high-dimensional turbulent flow equations. A systematic framework of correcting model errors with empirical information theory is introduced, and optimal model parameters under this unbiased information measure can be achieved in a training phase before the prediction. It is demonstrated that crucial principal statistical quantities in the most important large scales can be captured efficiently with accuracy using the reduced-order model in various dynamical regimes of the flow field with distinct statistical structures.

John Scinocca
CCCma, ECCC, University of Victoria
Title: The Search for Added Value in RCM Climate Change Experiments
Abstract:
When a regional climate model is used to investigate and understand an issue related to climate change, it is necessarily the case that an understanding of that issue will already be available from the global model simulations that provided the RCM driving data. The downscaling exercise, then, is inherently one of adding understanding, or value, to an existing GCM result. Consequently, any statements made regarding the value added by RCM downscaling must be made in the context of GCM results. While such added understanding is central to the downscaling exercise, its evaluation is an intrinsically difficult undertaking for a variety of reasons, not least of which is the lack of a consensus on how added value should be defined. Irrespective of the definition of added value, however, one can still make progress on this problem if it is recognized that added value can only exist where appreciable differences occur in the climate change predictions made between a regional model and its global parent model. In this presentation, a framework is introduced to define and evaluate appreciable differences between GCM and RCM results in the context of climate change problems and an initial application of the method to CanESM2 CMIP5 and CanRCM4 CORDEX model output is presented

Leslie Smith
University of Wisconsin, Madison
Title: A QG Model to Investigate the Influence of Latent Heat Release and Precipitation on Mid-Latitude Dynamics
Abstract:
The phase change of water is an important driver of atmospheric circulations over a vast spectrum ranging from the cloud-scale to the global scale. Motivated by large-scale features such as frontal circulations, cyclones and atmospheric rivers, we aim to elucidate the fundamental role of water in shaping the canonical structures of the mid-latitude atmosphere. Starting from an idealized cloud resolving model, a quasi-geostrophic (QG) model with phase changes of water and precipitation is derived in the limit of rapid rotation and a stable moist thermodynamic environment. The precipitating QG (PQG) equations may be described as the evolution of a potential vorticity (PV) and a variable M including moisture effects. The PV and M fields determine all other variables by inversion of an elliptic partial differential equation with coefficients that are discontinuous at phase boundaries. The results of exploratory PQG studies suggest promise for the model to provide theoretical foundations; such results include simple exact solutions with discontinuous coefficients, and numerical simulations of saturated jets in a 2-level set-up.

Shafer Smith
New York University, Courant, CAOS
Title: Dynamical Connections between Measured Eddy Mixing Coefficients

Abstract:
The Gent-McWilliams (GM) and Redi eddy parameterizations are essential features in ocean climate models. GM helps to maintain stratification, balancing the steepening of isopycnals by Ekman forcing and convection with a relaxation that dissipates potential energy adiabatically. The Redi parametrization represents unresolved isopycnal mixing of tracers, while keeping diabatic mixing small. Due to its direct impact on the simulated circulation, research has focused more on theories for the GM than Redi coefficient, the latter typically being set equal to the former without justification. When the GM coefficient is tuned to values of O(500) m^2s^{-1}, parameterized simulations are able to reproduce observed ocean stratification. By contrast, observational estimates of along-isopycnal mesoscale diffusivity (the Redi part) are typically an order of magnitude larger. Setting the Redi coefficient equal to the GM value can result in serious errors in biogeochemical tracers like oxygen.

Here we investigate possible dynamical relationships between these coefficients, with an eye towards understanding their apparent difference in magnitude, as well as their spatial structure and connection to mixing theories. The analyzed fluxes are `measured' using the method of multiple tracers, applied to eddy-resolving simulations set in a zonally-reentrant channel, with a meridional ridge, and forced by steady winds and surface buoyancy. The simulations and measurement method are described in a separate talk by the coauthors.

The analysis reveals a number of interesting connections and new behaviors, discussed in our companion presentation. Here we focus on the degree of consistency of the results with quasigeostrophic (QG) theory, and how the results can be used to inform GM and Redi coefficient choices. The reconstructed fluxes generically reveal the following: (1) in a significant fraction of the simulated flow, variance transport appears to be small, rationalizing local parameterization theory; (2) the mixing rate of tracers and QG potential vorticity (QGPV) are very similar; (3) the eddy QGPV flux is dominated by the vertical derivative of the buoyancy flux (the momentum and anisotropy terms are generally small); (4) as a result of the above, in most regions a theory for the Redi coefficient predicts the GM coefficient, and visa versa, thereby reducing the need for separate theories for each. Lastly, the Redi diffusivity shows a mid-depth maximum and is large compared to the inferred GM coefficient.

Sam Stechmann
University of Wisconsin-Madison
Title: Atmospheric Fluid Dynamics with Moisture and Phase Changes: Energetics and Balanced-Unbalanced Decompositions
Abstract:
Water vapor, clouds, and precipitation are among the most challenging aspects of weather and climate prediction. The difficulty is at least in part due to our relatively poor understanding of "moist" dynamics compared to "dry" dynamics. In this talk, two new contributions will be presented toward better understanding of "moist" dynamics, as well as connections with Andy Majda's seminal work in these areas.

First, it is shown that the Boussinesq equations, with moisture and phase changes, have a conserved energy that is piecewise quadratic. The piecewise quadratic energy provides a generalization of the quadratic energy of a dry system; and it has an extension to the moist anelastic equations, although it is not quadratic for an anelastic system. Second, it is shown that moist dynamics has a second balanced component, in addition to the familiar potential vorticity (PV) component of dry dynamics, and the second balanced component (called M) is related to moisture. A balanced-unbalanced decomposition can then be carried out for moist dynamics with phase changes, in the form of a new elliptic PDE for PV-and-M inversion, by accounting for both of the moist balanced components. These two results – on energetics and balanced-unbalanced decompositions -- are both made possible by recognizing an additional moist eigenmode that is not present for a dry system.

Andrew Stuart
Caltech
Title: Interacting Langevin Diffusions: Gradient Structure And Ensemble Kalman Approximation
Abstract:
We study an interesting class of interacting particle systems that may be used for optimization. By considering the mean-field limit, we obtain a nonlinear Fokker-Planck equation. This equation exhibits a novel gradient structure in probability space, based on a modified Wasserstein distance which reflects particle correlations: the Kalman-Wasserstein metric. We demonstrate how the setting gives rise to a methodology for calibrating, and quantifying uncertainty in, parameters appearing in complex computer models; the methodology arises from connecting the interacting particle system to ensemble Kalman methods for inverse problems.

Joint work with Alfredo Garbuno-Inigo (Caltech), Franca Hoffmann (Caltech), Wuchen Li (UCLA)

Edriss S. Titi
University of Cambridge and Texas A&M University
Title: On two geophysical problems with vanishing parameter limit
Abstract:
In this talk we will provide rigorous justification for the derivation of the Primitive Equations of planetary scale oceanic dynamics from the 3D incompressible Navier-Stokes equations, for small values of the aspect ratio of the depth to horizontal width. Furthermore, we will also consider the singular limit behavior of a tropical atmospheric model with moisture, as the moisture phase transition convective adjustment relaxation time parameter tends to zero. Rate of convergence will also be provided.

Xin Tong
National University of Singapore
Title: Ensemble Kalman filter in high dimensions
Abstract:
Ensemble Kalman filter (EnKF) is an algorithm designed for data assimilation of high dimensional geophysical systems. It can produce skillful forecast of nonlinear models of millions of dimension with around 100 samples. We seek rigorous explanations of such surprisingly good performance. Assuming the underlying dynamics is linear, we show the filter error can be bounded by the sample covariance, as long as there exists 1) a low effective dimension, or 2) a stable spatially localized covariance structure. We will further develop a framework that guarantees the spatially localized covariance structures, and can be applied to models such as FitzHugh-Nagumo with mean field interactions.

Bruce Turkington
University of Massachusetts Amherst
Title: Optimal closure for nonequilibrium statistical models, with applications to two-dimensional turbulence
Abstract:
Over the past several years I have developed a optimization-based approach to model reduction and coarse-graining for turbulent dynamical systems. In this lecture I will outline this approach in the general setting of reducing a high-dimensional Hamiltonian dynamics onto a selected set of observables. The key idea is to construct a nonequilibrium statistical model parameterized by the mean values of those observables, and to seek the path in model parameter space that is optimally compatible with the full dynamics. Optimality is defined in terms of the rate of information loss due to model reduction, as quantified by incremental relative entropy. The governing equations for this optimal closure have a generic thermodynamic format and properties, and are free from any tuned closure parameters. I will show how this approach can be applied to two test problems from hydrodynamics: (1) systems of many point vortices in the plane, giving a nonequilibrium mean-field model of the formation of coherent structures; and (2) spectrally-truncated, two-dimensional Euler flows, giving a nonequilibrium energy-enstrophy model in which the intrinsic dissipation operator acting on the low modes is derived from their interaction with an equilibrated spectrum of high modes. In both cases the predictions of the reduced models are validated by direct numerical simulations of the full dynamics.

Xiao Ming Wang
Southern University of Science and Technology
Title: Coupling and decoupling of free flow and porous media flow
Abstract:
Systems that involve the interaction of free flow with flow in porous media are common in nature and engineering. We present a few recent results on three inter-related topics:
1) How do the free flow and the porous media flow couple?
2) Under what circumstances the two subsystems decouple?
3) Are there accurate and efficient schemes that decouple the two subsystems at the numerical level?

Qiu Yang
New York Uiversity
Title: Upscale Impact of Mesoscale Convective Systems and Its Parameterization in an Idealized GCM for an MJO analog above the Equator, Author: Qiu Yang, Andrew Majda, Mitchell Moncrieff
Abstract:
The Madden-Julian oscillation (MJO) is observed to be organized in a hierarchical structure that the eastward-moving planetary-scale envelope usually contains multiple synoptic-scale superclusters with numerous embedded mesoscale convective systems (MCSs). Present-day GCMs fail to explicitly resolve MCSs due to their coarse resolutions. It is hypothesized that such inadequate treatment of MCSs and their upscale impact leads to the poorly simulated MJOs in the GCMs.

Here we used a simple 2D multicloud model to mimic typical behaviors of GCMs with clear deficiencies. Explicit expressions of eddy transfer of momentum and temperature have been obtained based on the Mesoscale Synoptic Equatorial Dynamics (MESD) model, originally derived by Majda (2007). The results show that upscale impact of westward-moving MCSs at a slow speed provides favorable conditions for eastward propagation of the MJO analog, consistent with theoretical predictions by the MESD model. When modulated by deep heating excess, this upscale impact favors well-organized planetary-scale envelopes. When modulated by vertical shear strength, the upscale impact of upshear-propagating MCSs induces significant westerly wind burst, another realistic feature of the observed MJO. Under these two modulation effects, an interesting scenario is obtained with planetary-scale envelopes switching their directions every 250 days, mainly due to the interactions among upscale impact of MCSs, MJO analog, and background state. Such zonal symmetry is broken after introducing modulation effects of deep heating excess on westward-moving MCSs. Instead, persistent eastward-moving MJO analog is simulated.

The merits of this study lie in (1) providing an idealized testbed to understand how upscale impact of MCSs influences the propagation, variability and vertical structure of the MJO above the equator, (2) providing prototype strategies for parameterizing upscale impact of MCSs in GCMs.

Laure Zanna
Oxford University
Title: Discovering Novel Eddy Parameterisations with Machine Learning
Abstract:
Current climate models do not fully resolve ocean eddies due to computational constraints, and consequently their effects on the large-scale flow must be parameterised. Recent studies have successfully used neural networks to construct eddy parameterisations.
However, this approach can sometimes sacrifice physical interpretability. Our study aims to use machine learning to accurately capture the effects of unresolved eddies, while retaining a clear physical interpretation of the end result.
Specifically, we discover a closed-form equation for a parameterisation of eddy momentum fluxes - as opposed to training a black-box function - using an iterative algorithm based on relevance vector machines.
We show that this method can reveal simple and interpretable eddy parameterisations, which capture a significant proportion of the true eddy forcing variance in idealised models. The expressions can also be constrained to respect physical conservation principles.

Francis Zwiers
Pacific Climate Impacts Consortium
Title: Some challenges in making reliable inferences about extreme precipitation
Abstract:
A broad range of applications require reliable estimates of the magnitudes of rare, extreme, precipitation. This talk describes two challenges in the context of this topic, with a particular emphasis on engineering design applications. First, it has been famously recognized that “stationarity is dead” as a consequence of the human induced climate change. Thus we are faced with the challenge of estimating historical changes in the magnitude of extreme events, and of projecting how they will continue to change in the future. This information is required, for example, to ensure that infrastructure that is built today will be resilient to future climatic loads. Secondly, as the engineering community moves from so-called uniform hazard to uniform risk design approaches, it will require estimates of extreme climatic loads for much long return periods than is currently the case. This means that extreme value analyses of precipitation and other climatic indicators will have to routinely extrapolate much further into the upper tails of extreme value distributions, raising questions about the surprises that may be lurking beyond the part of the tail that can be described with the 50-year or so instrumental record that is generally available. Both questions are explored in this talk using a large ensemble of climate simulations, which provides a wealth of data that is simply unattainable from our observed world.