Taylor Asher
University of North Carolina

“Coastal Flooding Uncertainty, Attribution, and Communication”

Coastal flood hazards are amongst the deadliest and most costly natural disasters on the planet. Their underlying processes are, in some regards, in an advanced state of knowledge. Yet, the scale and variety of both causes and effects leave open many challenging questions. And our advanced state of knowledge has failed to realize a reduction in deaths or damages. In this talk, I will address the underlying physical processes of coastal flooding and knowledge gaps, with an eye toward current research and the overarching issue of turning knowledge to action.

James Berger
Duke University

“Coupling Computer Models through Linking their Statistical Emulators”

Direct coupling of computer models is often difficult for computational and logistical reasons. We propose coupling computer models by linking independently developed Gaussian process emulators (GaSPs) of these models. Linked emulators are developed that are closed form, namely normally distributed with closed form predictive mean and variance functions. These are compared with a more direct emulation strategy, namely running the coupled computer models and directly emulating the system; perhaps surprisingly, this direct emulator was inferior in all illustrations. Pedagogical examples are given as well as an application to coupling of real computer models.

Authors: Ksenia Kyzyurova, James Berger, and Robert Wolpert
Numerical simulation represents one of the basic tools used to improve our understanding of the dynamics of pyroclastic density currents (PDCs), and to predict the impact of future pyroclastic eruption scenarios on the natural and anthropic environment. This is required for hazard and risk assessment, and for design of risk mitigation measures. However, the predictive capability of numerical models is currently limited by: 1) incomplete knowledge of the physical processes taking place during eruptions; 2) insufficient numerical model resolution and difficulty of estimating the related numerical error; 3) large epistemic uncertainty associated to initial and boundary conditions. This work is part of a collaborative study focusing on developing a conceptual physical/sedimentological model of PDCs, and a consensual validation and benchmarking procedure to assess the performance of numerical models used to simulate PDCs. The general approach to validation is based on an iterative process of integrating data (from field, monitoring, remote sensing and laboratory), with theoretical and numerical models. In this process, synthetic benchmarks are designed to evaluate, through inter-comparison studies, model-related uncertainties associated to initial and boundary conditions, physical approximations, and numerical discretization and solution algorithms. Complementary to this, experimental benchmark data serve as a quantitative basis to test and assess numerical models.

Preliminary studies compare the performance of various numerical modeling approaches used to simulate the movement of both dilute and concentrated PDCs generated by the break of a dam on a slope. While this represents a simplified prototype of granular and particle-laden pyroclastic currents, this integrated effort is fundamental in order to achieve three overarching goals: 1) developing a general physical/sedimentological model applicable to all types of PDCs; 2) consensually evaluate the accuracy of numerical models in representing PDC-related phenomena, and the uncertainty on the results; and 3) drive future research on PDC dynamics and hazard assessment.

Charles Connor
University of South Florida

“Coupled Lava Flow Hazards: Literally a cascading event!”

Lavas are effusive flows of magma at the surface. That is, they occur when magma reaches the surface of the Earth or other planetary body as a bubbly flow, without experiencing fragmentation. On Earth, lavas are almost always silicates in composition, but lava flows of sulfur and carbon-rich magmas also occur. On land, lava flows are massive volcanic phenomena that inundate areas at high temperature (800-1250 °C), destroying structures, even whole towns, by entombing them within meters of rock. Forecasting lava flows involves forecasting vent location, modifications to the terrain, and lava flow parameters (e.g., volume). During eruptions, new vents can create hazards in unexpected areas, and so the probability of new vent formation is assessed. We use kernel density estimation (KDE) to estimate the spatial density of future volcanic events, with the probability modified and updated with geophysical data. Application of these methods relies on several assumptions about the definition of volcanic events, independence of events, the type of kernel function used, and the selection of kernel bandwidth. Each new vents and lava flows modify
the terrain, and so change the flow-path of subsequent flows. With the MOLASSES code, an asynchronous cellular automata model, we model constructional topography associated with lava flow efficiently, building entire volcano edifices, and updating probabilistic models of lava inundation.

Colton Conroy
Columbia University

“Quantifying Lava ‘Breakouts’”

When molten lava effuses from an active volcano and spreads into the surrounding terrain it immediately begins to cool and degas; this effectively changes the lava's rheology and can cause it to crystallize and develop a crust that resists the momentum of its spreading. If the crust and crystal structure of the lava gets strong enough, it will eventually cease to advance; internal pressure will increase as lava continues to effuse from the vent. Over time, this build-up of internal pressure can cause the lava to inflate, and ultimately to “breakout” from its original emplacement and become free to interact with new terrain and spread to areas outside of its initial path.

Any attempt to quantify the risk associated with these “breakouts” is difficult; to date, no existing flow models include them. Nonetheless, recent advances in observational techniques and the numerical study of differential equations have the laid the ground work for new insight into this phenomenon. Commensurate with this development, we formulate a three-dimensional lava flow model with a foundation built on experiments and observations, as well as rigorous mathematical theory that aims to predict the spatial and temporal dynamics of lava breakouts.

The mathematical model is built on a simplified version of the Navier-Stokes equations and makes use of dynamic boundary conditions and effusion rates that allow the lava to emplace, inflate and evolve organically. Numerically, the model utilizes novel discontinuous Galerkin (DG) finite element methods that leverage high-order integration techniques to accurately calculate pressure gradients and resolve terrain variations that drive lava flow advance. Model results are evaluated against molten basalt and analog laboratory experiments as well as natural flow examples, and a path forward in terms of predicting lava “breakouts” and assessing the risk associated with them is discussed.

Robert Erhardt
Wake Forest University

“Actuarial Risk Measures and the Propagation of Uncertainty for Index-based Insurance”

Actuarial risk measures are used to quantify risk as computed from the distribution of a loss random variable. They incorporate expected loss, variability of loses, tail thickness, and other features of loss distributions. Once computed, they inform how risks should be managed in advance through insurance products or other financial programs. In this talk we present an example from index-based insurance based on weather risk, in which neighboring locations display positive dependence in losses due to spatial dependence in the weather. Risk measures are computed, with particular attention to how uncertainty in parameter estimates flows through levels of the model into the final loss distribution and therefore risk measure computation.
“Calibration of Imperfect Mathematical Models by Multiple Sources of Data with Measurement Bias”

Model calibration involves using experimental or field data to estimate the unknown parameters of a mathematical model. This task is complicated by discrepancy between the model and reality, and by possible bias in the data. We consider model calibration in the presence of both model discrepancy and measurement bias using multiple sources of data. Model discrepancy is often estimated using a Gaussian stochastic process (GaSP), but it has been observed in many studies that the calibrated mathematical model can be far from the reality. Here we show that modeling the discrepancy function via a GaSP often leads to an inconsistent estimation of the calibration parameters even if one has an infinite number of repeated experiments and infinite number of observations in a fixed input domain in each experiment. We introduce the scaled Gaussian stochastic process (S-GaSP) to model the discrepancy function. Unlike the GaSP, the S-GaSP utilizes a non-increasing scaling function which assigns more probability mass on the smaller L2 loss between the mathematical model and reality, preventing the calibrated mathematical model from deviating too much from reality.

We apply our technique to the calibration of a geophysical model of Kilauea Volcano, Hawaii, using multiple radar satellite interferograms. We compare the use of models calibrated using multiple data sets simultaneously with results obtained using stacks (averages). We derive distributions for the maximum likelihood estimator and Bayesian inference, both implemented in the RobustCalibration package available on CRAN. Analysis of both simulated and real data confirm that our approach can identify the measurement bias and model discrepancy using multiple sources of data, and provide better estimates of model parameters.

“Uncertainties in Coupling a Tsunami Model to Earthquake and Landslide Source Models for the Makran Subduction Zone”

In this talk, we first examine future tsunami hazard from the Makran subduction zone in the Western Indian Ocean. Since tsunamis present a high risk to ports in the form of high velocities and vorticity, we capture these phenomena in high resolution (10-30m) using carefully constructed unstructured meshes for the port of Karachi. The seabed deformations triggered by the earthquake sources vary in magnitude. A parametrization of these sources is done via geometric descriptions and a newly introduced amplification parameter of the vertical deformation due to sediments. An emulator approximates the functional relationship between inputs and outputs maximum velocity and free surface elevation. A hazard assessment is performed using the emulator.

Second, we use recently gathered observations from the 1945 Makran tsunami, which was due to a joint source of an earthquake and a submarine landslide. In this first attempt to infer the landslide characteristics, we only invert 3 parameters of a submarine mass failure (latitude, longitude, distance travelled by the slide) using a Bayesian calibration framework. We report uncertainties in this inversion and discuss what data and modelling challenges explain these uncertainties.
Larry Mastin
U.S. Geological Survey

"Developing 21st-Century Probabilistic Maps of Volcanic Ashfall Hazards from U.S. Volcanoes"

Volcanoes in the Cascade Range of North America produce about one large plinian eruption per century. The most recent one, on May 18, 1980 at Mount St. Helens, deposited more than a cubic kilometer of tephra across Washington, Idaho, and western Montana. Airborne ash disrupted air traffic and ground transportation, power supplies, caused respiratory problems, and impacted agriculture over nearly 100,000 square kilometers. The impact during a future eruption is likely to be greater given the higher regional population. To prepare for such an event, the USGS Volcano Hazards Programs is developing a new generation of probabilistic tephra hazard products, derived from thousands of Monte-Carlo-style simulations of tephra dispersal from each volcano under varying wind and eruptive conditions. Model inputs will include expert-derived estimates of the likely eruption sizes and recurrence intervals at each volcano. Products will include hazard maps showing the probability of ashfall around each volcano during the next eruption, along with a regional map showing the annual probability of tephra fall throughout the Northwest U.S. This presentation describes the methodology being developed to derive these products.

Sarah Ogburn
USGS-USAID

“Volcano Disaster Assistance Program (VDAP) Eruption Forecasting: methods, data, and challenges”

The U.S. Geological Survey/USAID Volcano Disaster Assistance Program (VDAP), in conjunction with foreign observatory partners, uses probabilistic event trees to assess volcanic unrest, activity, and hazards before and during volcanic crises. Event trees are frequently used to facilitate discussion, reach consensus, evaluate uncertainty, and to help scientists assess the likelihood of different hazardous phenomena before and during volcanic crises (Newhall & Hoblitt, 2002). VDAP has been involved in the creation of over 35 event trees, from the 1991 Pinatubo, Philippines eruption to the 2017- ongoing Agung, Indonesia eruption. VDAP uses a consensus method based on discussion of multiple datasets to populate event trees (Newhall & Pallister, 2015). This method relies upon expert interpretation of different data, such as conceptual models of the volcanic system, local eruptive history, current and past local monitoring data, physical or empirical models of volcanic hazard impacts, and global statistical data from analog volcanos. VDAP increasingly utilizes global databases to inform our conceptual models, to fill in gaps where local information is sparse, to explore the full range of possible behavior, to compare volcanic activity to that at analogous volcanos, and to improve uncertainty estimates by leveraging larger. VDAP also uses models to estimate the areal dispersion and inundation of hazardous phenomena such as tephra, lahars, and pyroclastic density currents. Both local data and global databases help inform our choices of model input parameters. This contribution will describe the method employed by VDAP for eruption forecasting, discuss available data and limitations, and explore some of the many challenges faced by VDAP and partners when forecasting eruptions.
Jeremy Phillips  
University of Bristol

“Challenges to Predicting Hazards and Impacts from Sediment Flows”

Sediment Flows including flash floods, volcanic lahars and debris flows are typically energetic and destructive hydrometeorological hazards, and their dynamics are strongly affected by substrate erosion and sediment deposition. In this talk, we will highlight some of the challenges to predicting their hazards and impacts, with examples from case studies using the LaharFlow model (www.laharflow.bristol.ac.uk). LaharFlow is a shallow-water formulation for predicting dynamics of sediment flows on topography, with basal resisting stress parameterisations that evolve with particle concentration to reflect the key processes of erosion and deposition. We will use case study examples of lahars at Nevado del Ruiz in Colombia and at Tungurahua in Ecuador to highlight difficulties in model calibration including using often sparse observations with the risk of overfitting model parameters, and with the use of uncertain topographic forcing data. We will also present simulations of energetic flash floods (locally-termed ‘huaicos’) at Chosica in Perú to highlight consequences of uncertain initial conditions and the need to predict impacts at high spatial resolution necessary for urban scales. The talk will draw together these examples to open discussion on critical challenges for application of models for large geophysical flow events.

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Gavin Smith  
North Carolina State University

“Adapting to Climate Change: Lessons from Natural Hazards Planning”

This presentation, which is derived from the text *Adapting to Climate Change: Lessons from Natural Hazards Planning* (Glavovic and Smith 2014), identifies lessons from natural hazard experiences to help communities plan for and adapt to climate change. Case studies are used to examine diverse experiences, from severe storms to sea-level related hazards, droughts, heat waves, wildfires, floods, earthquakes and tsunami, in North America, Europe, Australasia, Asia, Africa and Small Island Developing States. The 264 lessons (findings) are grouped according to four imperatives: (i) Develop collaborative governance networks; (ii) build adaptive capabilities; (iii) invest in pre-event planning; and (iv) the moral imperative to undertake adaptive actions that advance resilience and sustainability. The findings are intended to provide climate change policy-makers, scholars, students and practitioners with a rigorous understanding of lessons from natural hazards planning scholarship and experience that can help to overcome barriers and unlock opportunities for building communities that are sustainable and resilient to climate change.
Gabriel Terejanu  
University of North Carolina, Charlotte

“Geospatial Uncertainty Modeling using Stacked Gaussian Processes”

A network of independently trained Gaussian processes (StackedGP) is introduced to obtain predictions of geospatial quantities of interest with quantified uncertainties. The main applications of the StackedGP framework are to support component-based modeling in environmental science, enhance predictions of quantities of interest through a cascade of intermediate predictions usually addressed by cokriging, and to propagate uncertainties through emulated dynamical systems driven by uncertain forcing variables. By using analytical first and second-order moments of a Gaussian process with uncertain inputs using squared exponential and polynomial kernels, approximated expectations of quantities of interests that require an arbitrary composition of functions can be obtained. The performance of the proposed nonparametric stacked model in model composition and cascading predictions is measured in a wildfire and mineral resource problem using real data. The stacked Gaussian process is also applied to predict aflatoxin concentrations in corn in South Carolina by integrating both field and wet-lab measurements.

Anne Tillery and Dennis Staley  
USGS

“Post-wildfire Debris Flow Hazard Modeling and Associated Sources of Uncertainty”

Rainfall intensity and duration are critical forcing mechanism to debris flows, potentially hazardous and destructive forms of mass wasting. Wildfire can substantially increase the likelihood of debris flows in mountainous areas of the western United States given the same rainfall intensity and duration. Although the exact location, extent, and severity of wildfire or subsequent rainfall intensity and duration that may trigger debris flows cannot be known, estimates of debris-flow likelihood, magnitude, and triggering rainfall thresholds for recently burned locations can be estimated using geospatial analysis of burned landscape characteristics, design storm precipitation values, and modeling. Generating these estimates in areas that have not yet burned requires estimated fire-severity data. Fire-severity data can be statistically simulated using historical data to define the range of potential fire severities for a given location based on the statistical distribution of historical fire-severity metrics obtained from remote sensing techniques. Hazard assessments in burned and unburned areas using these methods provide the first step in reducing public exposure to these events, however, uncertainties remain in the model estimates, in forecasting fire severity and extent, and in predicting timing, intensity, and locations of rainfall. As the collection of post-wildfire debris-flows data grows in quantity and quality, uncertainties associated with the post-wildfire debris-flow assessments will diminish.
Tori Tomiczek  
US Naval Academy  

“Coastal Resiliency to Extreme Events in a Changing Climate”

In 2017 Hurricanes Harvey, Irma, and Maria caused catastrophic damage to coastal regions in the Gulf of Mexico, Caribbean Sea, and Atlantic Ocean, and the 2018 season further contributed to coastal and inland damage with Hurricanes Florence and Michael. Recent forecasts suggest that these high intensity seasons may be representative of a “new normal” with a greater number of Category 3-5 storms making landfall in the U.S. (Klotzbach and Bell, 2018). These recent hurricane seasons have emphasized the need for coastal engineers, scientists, and stakeholders to seek innovative solutions to improve coastal resiliency and effectively mitigate damage during extreme events. In order to mitigate damage, it is critical to better understand the wave transformation during overland flow conditions as well as to identify relationships between wave loading and structural response. document the vulnerability of coastal residences to damage during Hurricane Ike (2008) on the Bolivar Peninsula, TX and Hurricane Irma (2016) in Key West and Big Pine Key, FL. Results identified the need to objectively characterize structural damage as well as to better understand overland wave propagation and transformation in the presence of macroroughness elements such as buildings and rigid vegetation. Natural shorelines (mangroves) were identified as effectively withstanding storm surge flooding and riding waves associated with Hurricane Irma, and further prevented damage to inland structures, showing the parcel scale benefits of natural and nature-based features. While natural and nature-based features have potential to serve as sustainable coastal engineering solutions, their engineering performance as well as limitations must be quantified.

Daniel Williamson  
University of Exeter  

“Uncertainty Quantification for Calibrating Spatio-temporal Models using Basis Methods”

When building emulators for natural hazard models or climate models, often model output is in the form of spatio-temporal fields. The two main approaches to emulating these so that the model can be calibrated with observations are either to emulate every point in space and time independently using simple Gaussian processes, or to use a basis to describe the spatio-temporal signal, project the model runs onto this and to emulate the coefficients. Conceptually, the attractions of each approach are clear. Basis methods allow us to capture large scale spatio-temporal correlation structures that have a basis in the underlying model physics and allow us to build fewer emulators. Single grid box methods are conceptually simpler and, for any given grid box, the uncertainty may be lower as there is no loss of information due to discarding low-signal basis vectors. In this talk I will present our rotated basis methods and compare their performance in calibration for emulating climate model fields with the single grid box approach.