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## Math of Planet Earth 2013 Set to Debut at JMM

*Polar melt ponds, April 2012. The launch of Mathematics of Planet Earth 2013 is slated for January at the Joint Math Meetings in San Diego, where a highlight of the scheduled events is the Porter Public Lecture by Ken Golden of the University of Utah. Golden has been to Antarctica seven times and the Arctic eight times in pursuit of career-long scientific interest in sea ice; among his other research interests are climate change, composite materials, phase transitions, and inverse problems. He will devote the Porter lecture in part to a discussion of "how mathematical models of composite materials and statistical physics are being used to study key sea ice processes, such as freezing and melting." A better understanding of such processes, he says, is needed "to improve projections of the fate of Earth's sea ice packs, and the response of polar ecosystems."*
*Named a SIAM Fellow in 2009 "for extraordinary interdisciplinary work on sea ice," Golden sent SIAM a selection of photos from some of his recent expeditions, including the one shown here. Another, showing him at work in the field, appears on page 6, along with a brief introduction to MPE2013.*

# What's So Special About Complex Variables?

FROM THE SIAM PRESIDENT
*By Nick Trefethen*

I'd like to return to a topic I raised in my first column last year. I believe that the subject of complex variables gets too little attention in our curriculums, and is not as familiar as it should be to applied mathematicians.

Let's start with a quiz.

1. What's the difference between $C^\infty$ and analytic?
2. How fast does the Maclaurin series of $\tanh(z)$ converge for $z = 1$?
3. What is $i^i$?

OK, time's up. Here are the answers, with modest editorial addenda.

Question 1 is a matter of fundamental *ideas*. Both $C^\infty$ and analytic functions have infinitely many derivatives, but an analytic function has the additional property that the Taylor series at each point converges to the function in some neighborhood. For a mathematician not to know this distinction is like a linguist not knowing the difference between French and Italian.

Question 2 relates to basic *applications* of analytic functions. $\tanh(z)$ is analytic near $z = 0$, but has poles in the complex plane at $\pm\pi i/2$. So the Maclaurin coefficients decay at the rate $(2/\pi)^n$, and that will be the rate of convergence of the series for $z = 1$. For a mathematician not to be able to work this out is like a physicist not being able to work out when a stone dropped from a height of 10 meters will hit the ground.

Question 3 touches upon *behavior* of analytic functions. Most mathematicians don't know the value of $i^i$ off the top of their heads; I certainly don't. But what this question gets at is that although an analytic function may be single-valued locally, its values globally will depend on what paths you follow around branch points. $i^i$ is the same as $\exp(i\log(i))$, and $\log(z)$ has a branch point at $z = 0$, so $\log(i)$ has infinitely many values, namely $\pi i/2$ plus any multiple of $2\pi i$. Therefore, $i^i$ has infinitely many values too, an infinite set of geometrically spaced positive real numbers. For a mathematician not to know how to figure

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*__Uncertainty Quantification 2012__*

# Simulation-based Volcanic Hazard Assessment

*By Elaine Spiller, Abani Patra, Bruce Pitman, Eliza Calder, Susie Bayarri, Jim Berger, and Robert Wolpert*

Large granular volcanic events—pyroclastic flows—are rare yet potentially devastating for communities situated near volcanoes. The typical process for assessing pyroclastic flow hazards for areas downstream from a volcano relies almost exclusively on expert opinion and historical record. To expect behavior we have seen previously is human nature, but it is a poor basis for hazard assessment and can seriously underestimate the hazard potential.

Over the last decade, experts have begun to supplement their understanding of volcanic hazards with realistic geophysical flow simulations. One widely used software implementation of a granular flow model, TITAN-2D, simulates course, depth, and velocity for a pyroclastic flow of specified volume and initial direction over a region whose topography is available as a digital elevation map. (You can run it yourself at www.vhub.org.)

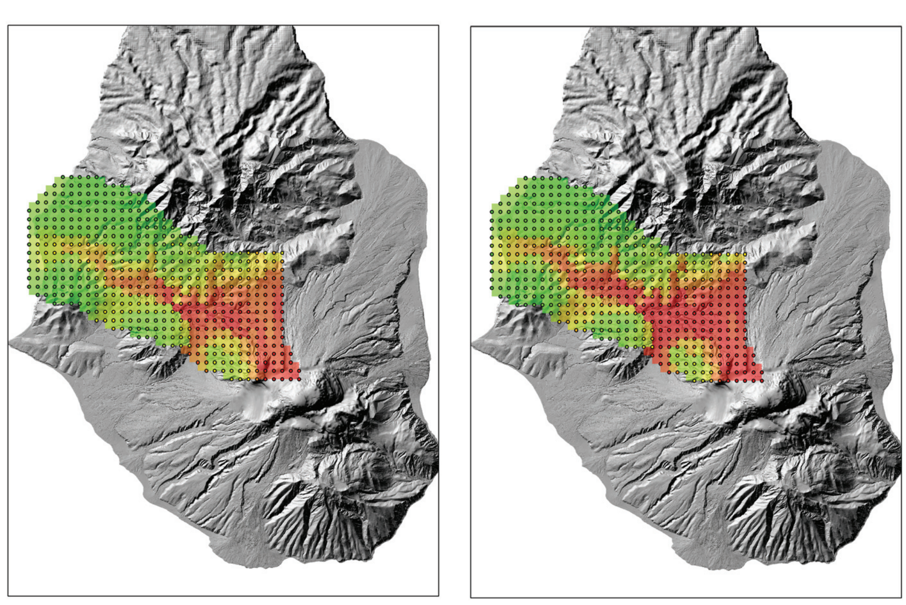
Flow simulations are not computationally cheap, and very-large-volume events that lead to inundation in regions not previously affected are extremely rare. For these reasons, we must consider certain questions: *What are the right scenarios to simulate? What are the right values of physical parameters, such as basal and internal friction, to use in flow simulations?*

Ultimately, these are questions of uncertainty quantification. In the framework of quantifying uncertainties through probability distributions, we can state the questions more precisely: *How can we reflect aleatoric variability (natural randomness) of physical scenarios and epistemic uncertainty (uncertainty in model characterization) of such probability distributions in the output of flow simulations? How can we use flow simulations to calculate the probability of volcanic hazards and ultimately produce a probabilistic hazard map? How can we achieve these objectives in a computationally efficient manner?*

A common approach to simulation-based geophysical hazard assessment first characterizes the aleatoric variability of physical scenarios by fitting a probability distribution; from this distribution, it draws "sample" scenarios for which the geophysical simulations are run, and computes the probability of a resulting hazard. (The term "samples" is used loosely—they could be collocation points for a polynomial chaos scheme, inputs for statistical emulators, or traditional Monte Carlo samples.)

There are two significant, confounding problems with this approach. First, it results in sample scenarios and simulations that are tied to a single probability distribution. To update this distribution as new data or information comes online, or to integrate the distribution over a prior distribution of parameter values as in a Bayesian uncertainty analysis, samples from a different distribution, and hence new simulations, are required. Secondly, it is the rare tail-events from the physical scenario distribution that lead to hazards. The strategy used, therefore, must be careful to target simulations on the tail. The nature of rare events, however, dictates that there is little to no data in this region; epistemic uncertainty remains large in this region of interest, even if not over the rest of the distribution. Furthermore, as large-scale geophysical simulations are precious (in terms of man hours and computation hours), there

*See* **Volcanic Hazards** *on page 2*



*Probabilistic hazard maps for the Belham Valley on the island of Montserrat generated with the hazard-assessment strategy described in the article. The color map, from red to green, represents probabilities from 1 to 0 of inundation from a pyroclastic flow over the next 2.5 years. Probabilities were calculated at the map points marked with circles. The two sets of calculations use the same set of 2048 TITAN-2D runs, with $O(10^5)$ Monte Carlo samples for each map point. A uniform distribution (left) and a delta distribution to the north/northwest (right) are used to describe aleatoric variability in the initiation angle; the distributions describing variability in frequency and flow volume of events were identical for the two cases. Once emulators are constructed, producing these hazard maps takes roughly five minutes on a cluster.*

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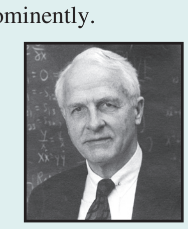
Reviewing three recent books that trace "an important part of intellectual history through the medium of equations," James Case welcomes the "great equations" genre. The three authors come at their great equations from different perspectives: historical (frequent *SIAM News* contributor Dana Mackenzie), applications (Ian Stewart), and philosophical (Robert Crease).

7 **My Poincaré, Recollected**
Among the events marking the 100th anniversary of Poincaré's death is a new biography, which elicits from Philip Davis the tale of his thesis on the three-body problem in which Poincaré could have—but did not—figure prominently.



8 **Fifteen Ways to Fool the Masses When Presenting your Work in UQ**

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Wrapping up coverage of SIAM's first UQ conference, Hari Viswanathan and colleagues consider "migration of $CO_2$ from deep storage formations into shallow drinking water aquifers," which could lead to increased levels of contaminants like arsenic, lead, and uranium. For arsenic, their model shows amelioration via a "scavenging" mechanism.

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# Obituaries

The applied and computational mathematics community lost one of its most talented and thoughtful researchers on April 30, 2012, when Royal Bruce Kellogg passed away at the age of 81, soon after he was diagnosed with a brain tumor. He spent 34 years at the University of Maryland, College Park, from 1966, when he took a position at the university's Institute for Fluid Dynamics and Applied Mathematics (IFDAM), until his retirement in 2000.

Bruce Kellogg was born in Chicago in 1930. He earned his bachelor's degree from MIT, and completed his PhD at the University of Chicago in 1958 under the supervision of Marshall Stone and Lars Garding. He worked as a research scientist in the nuclear power industry before moving to Maryland, where for the most part he held a joint appointment in the Department of Mathematics and the Institute for Physical Science and Technology, or IPST, which succeeded IFDAM. After his retirement, Bruce and his wife moved to an old family home in Landrum, South Carolina, and he took a position as adjunct professor at the University of South Carolina, Columbia. He served as editor of the book review section of *SIAM Review* from 1996 through 1999.

In the early 1960s Bruce worked on the development of the alternating direction implicit methods. While at Westinghouse's Bettis Atomic Power Laboratory, he presented one of the earliest convergence analyses of an ADI method, which was published in 1963 in the *Journal of the Society for Industrial and Applied Mathematics*, SIAM's first journal. During the 1970s, he became one of the leading figures in the development of the mathematical theory for finite element methods.

A major theme in Bruce's opus is the numerical solution of singular perturbation problems. His 1978 paper with A. Tsan on difference approximations for such problems is a seminal work in the field, and he continued this research until the end of his life. Another major theme of his research was the behavior of solutions to partial differential equations near corners and interfaces. His 1976 regularity result (with John Osborn) for the Stokes equations in a convex polygon is still frequently referenced today.

In the course of his career he published more than 100 papers, primarily in numerical analysis and partial differential equations, with substantial forays into such areas of application as renal physiology and fluid mechanics.

Bruce kept abreast of developments across a broad swath of pure and applied mathematics. He enjoyed discussions with researchers of all ages and backgrounds, to whom he gave freely of his time and ideas.

Photo by Lisa Tucker-Kellogg

*Royal Bruce Kellogg, 1930–2012*

His vast knowledge of various areas of mathematics, and beyond mathematics, together with his selfless attitude, made him an ideal colleague, collaborator, editor, and mentor, and inspired great affection in the many people who had the pleasure of interacting with him.—*Douglas N. Arnold, University of Minnesota; Susanne C. Brenner, Louisiana State University; and Martin Stynes, National University of Ireland, Cork.*

## Volcanic Hazards

*continued from page 1*

is a natural desire to avoid "wasting" them on scenarios that seem quite unlikely.

In our minisymposium at the first SIAM uncertainty quantification conference, we proposed a rather different strategy that is computationally efficient, naturally handles rare events, and allows a flexible approach to quantifying epistemic uncertainties in geophysical hazard assessment. Our impetus for devising this approach was the realization that a TITAN-2D run for a given physical scenario and set of physical model parameters will result in flow inundation at a map point of interest (or not) regardless of how probable that scenario and parameterization are.

Our approach seeks to separate state space into regions that result in inundation at a specific map point and regions that do not. The first step in solving this inverse problem is to run TITAN-2D with inputs chosen by a space-filling design, which samples over large swaths of scenario and parameter space. We then fit a statistical emulator to these flow heights (TITAN-2D outputs). A statistical emulator can be thought of as a cheap surrogate that approximates flow height for all scenarios between those of the TITAN-2D runs; the statistical emulator simultaneously provides estimates of the error incurred by using such an approximation.

With a low, threshold height as an indication of inundation, we can invert this emulated response surface to obtain an inundation contour—which separates state space into "dangerous" and "safe" scenarios. Because the evaluation of emulators is effectively free in a computational sense, we can easily generate contours over a wide range of physical parameters. Doing so gives us samples from a probability distribution on these contours, so that this uncertainty can also be quantified and propagated. These contours then replace indicator functions in probability calculations, which means that any Monte Carlo scheme will automatically sample the important regions of state space. Moreover, for a probability calculation with a different distribution representing aleatoric variability, no new geophysical simulations are required. Such calculations can thus be done in minutes instead of hours or days. In effect, this methodology allows efficient comparisons of different models of aleatoric variability.

*Elaine Spiller is an assistant professor in the Department of Mathematics, Statistics, and Computer Science at Marquette University. Abani Patra is a professor in the Department of Mechanical Engineering at the University at Buffalo. Bruce Pitman is a professor in the Department of Mathematics and dean of the College of Arts and Sciences at the University at Buffalo. Eliza Calder is an associate professor in the Department of Geology at the University at Buffalo. Susie Bayarri is a professor in the Department of Statistics at the University of Valencia. Jim Berger and Robert Wolpert are professors in the Department of Statistics at Duke University.*

## No Name Change for NSF's Division of Math Sciences

A year ago, the mathematical sciences community was embroiled in discussions of a proposal to include statistics in the name of the National Science Foundation's Division of Mathematical Sciences. SIAM president Nick Trefethen weighed in with a *SIAM News* column (November 2011) titled "What's in a Name?" "As you can imagine," he wrote, "people have opinions on this. . . . "We are nervous about the implications of the proposed name change."

SIAM and its sister societies became involved in the discussions through the NSF advisory committee for the Mathematical and Physical Sciences. Each of the societies sought opinions from its community and transmitted comments received to the advisory committee.

In an August 16, 2012, letter to the advisory committee, Ed Seidel, then NSF assistant director for MPS, announced his decision: DMS would retain its name. The division would take other steps, he continued, to recognize the important role of statistics in the mathematical sciences. In particular, "whenever appropriate, we will specifically mention 'statistics' alongside 'mathematics' in budget requests and in solicitations in order to recognize the unique and pervasive role of statistical sciences, and to ensure that relevant solicitations reach the statistical sciences community." He also announced the formation of a subgroup of MPSAC that will examine funding for statistical sciences research at NSF, including organizational alternatives and new initiatives. (Seidel's letter is posted at http://www.nsf.gov/attachments/124926/public/Response_MPSAC_Subcommittee_Report_on_Name_of_Division_of_Mathematical_Sciences_8-16-2012.pdf.)

Further information on the issue, including a summary of comments received from the community, can be found at http://www.nsf.gov/events/event_summ.jsp?cntn_id=124926&org=MPS.

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# A Guided Tour of DMS/NSF Programs for Math Scientists

Henry Warchall, deputy director of the Division of Mathematical Sciences at the National Science Foundation, crafted his presentation for the Funding Agency Panel at the 2012 SIAM Annual Meeting by imagining himself in the shoes of a member of the SIAM community: "Which NSF programs," he wondered, "fund the kind of research I have in mind?"

Warchall, who actually constituted a one-member panel, began with a helpful tip: Prospective proposal submitters can use www.nsf.gov/awardsearch/ to search existing NSF grants on keywords, e.g., "algebraic topology large data." "You can do serious data mining with this URL," he said.

After pointing out that the bulk (3/4) of the DMS budget goes to small-group and individual grants in disciplinary research programs, he devoted the remainder of the presentation to an overview of many special research opportunities, some of them NSF-wide, also available to mathematical scientists:

**Computational and Data-enabled Research.** Looming large in this category is Computational Data-enabled Science and Engineering in Mathematical and Statistical Sciences (CDS&E-MSS), funded jointly by DMS and the Office of Cyberinfrastructure to promote the next generation of tools for research on challenges arising in CSE with the ongoing explosion of data. Several NSF-wide programs may be of interest as well, including Software Infrastructure for Sustained Innovation; Secure and Trustworthy Cyberspace, in which the focus is on encryption and privacy (as for medical datasets); Core Techniques and Technologies for Advancing Big Data Science and Engineering, known as BIGDATA; and IGERT-CIF 21, an IGERT track introduced to meet educational needs in CDS&E and cyberinfrastructure.

**Materials-related Research.** After pointing out that NSF's Mathematical and Physical Sciences Directorate is the home of DMS as well as of the Division of Materials Research, Warchall mentioned opportunities in the Materials Genome initiative program Designing Materials to Revolutionize and Engineer our Future (DMREF).

**Research Related to Sustainable Civilization.** Within the SEES (Science, Engineering, and Education for Sustainability) portfolio, Warchall identified some of the areas of particular interest to the SIAM community: earth system models for decadal and regional climate prediction (EaSM); sustainable energy pathways (SEP); and sustainable chemistry, energy, and materials (SusChEM).

**Opportunities Related to Biology.** DMS has a mathematical biology program that supports the development of mathematical and statistical tools. Warchall also mentioned a joint DMS/NIGMS (National Institute of General Medical Sciences) program; opportunities for collaborative research in computational neuroscience (with a new initiative in neuroscience to come); opportunities for work on algorithms for the detection of threats (biological and other); and the interdisciplinary BioMaPS partnership.

**Research Networks in the Math Sciences.** This program supports five- to ten-year collaborations of researchers addressing complex problems that cross intellectual, institutional, national, and other boundaries; an example is the Mathematics and Climate Research Network (Chris Jones, director; Mary Lou Zeeman and Hans Kaper, co-directors). The next deadline for proposals is in 2015. Warchall also referred the audience to the list of other special research programs available at http://www.nsf.gov/div/index.jsp?div=DMS.

**The NSF Graduate Research Fellowship Program.** See accompanying article.

*NSF's Division of Mathematical Sciences was well represented in Minneapolis. Shown here are DMS deputy director Henry Warchall (left), whose presentation of special funding opportunities for the SIAM community is outlined in the accompanying article, and DMS director Sastry Pantula, who was a member of another panel, convened to discuss big data.*

■■■

The discussion that followed Warchall's presentation included a request from the audience: Do you have suggestions for first-time proposal submitters? Get advice or help from someone who has been successful, Warchall suggested. Most proposals are reviewed by panels, he added, not all members of which will be expert in the area of a proposal. "You need to put your work in context: Why should anyone care about the project you propose?"

Citing common errors made by inexperienced grant seekers, he mentioned the preparation of exciting proposals that relate exciting challenges, but do not state what the researcher plans to do. Deborah Lockhart, formerly of DMS and currently deputy director of the Division of Information and Intelligent Systems in the CISE directorate, pointed out that junior researchers need to give themselves credibility. "Show that you know what's being done in your area, how your work ties in" to the big picture, she said.

SIAM president-elect Irene Fonseca, also in the audience, pointed out that PIRE (Partnerships for International Research and Education), a large grant of which she is the PI, holds one-day grant-writing workshops. Other programs and institutions, she said, hold similar (and similarly well-attended) events.

# Thinking of Graduate School? Check Out NSF Fellowships

*By Meredith K. Berthelson and Jennifer Slimowitz Pearl*

Many students about to graduate with baccalaureate degrees contemplate going on to graduate studies. One of the major obstacles can be funding: Students who have just finished their undergraduate education may not want to add more tuition bills to the pile. If only they had a way to continue their education and do some of the research they have in mind. Well, there is a way! And one of the most valuable funding mechanisms for mathematics and statistics graduate students is the National Science Foundation's Graduate Research Fellowship Program (GRFP).

"[The] NSF Graduate Research Fellowship (or an Honorable Mention in the competition) is certainly a feather in any future scientist's cap!" says Sastry Pantula, director of the Division of Mathematical Sciences at NSF. "There are many well-qualified mathematics and statistics students in this country, and I would love to see many, many more of them take advantage of this excellent opportunity." To put Pantula's remark in context: In 2012, the NSF-wide GRFP, which embraces all science and engineering disciplines, awarded 2000 fellowships. Of them, only 75 (3.75%) were to students in mathematics and statistics, directly reflecting the proportion of mathematics and statistics applicants; visit GRFP Awardee and Honorable Mention list (https://www.fastlane.nsf.gov/grfp/AwardeeList.do?method=loadAwardeeList).

What are the key elements of the fellowship? It is a five-year award, worth a total of $126,000. An NSF graduate fellow receives three years of support (useable over a five-year period). For each of the three years, the fellow receives a $30,000 stipend and the graduate institution receives a $12,000 educational allowance to cover tuition and all required fees. The fellow also has access to information about international research opportunities and to supercomputing resources.

Eligibility is limited to U.S. citizens, nationals, or permanent residents; an applicant should be an early-career graduate student pursuing a research-based master's or doctoral degree in an NSF-supported field. In the mathematical and statistical sciences, the following categories are included: Algebra, Number Theory, and Combinatorics; Analysis; Applied Mathematics; Biostatistics; Computational and Data-enabled Science; Computational Mathematics; Computational Statistics; Geometric Analysis; Logic or Foundations of Mathematics; Mathematical Biology; Probability; Statistics; Topology; and related fields not included in the list. An applicant must be planning to enroll in an accredited institution in the U.S. by the fall following announcement of the award. Those who have already received graduate degrees are not eligible. According to the program solicitation (NSF 12–599), "Categories of applicants that are ineligible include: Those who have earned any graduate or professional degree by August 1, 2012, except applicants who have completed a joint BS/MS program and have not completed any further graduate study outside the joint program."

Nicholas Brubaker and Gina-Maria Pomann, two current NSF graduate fellows, hammer home the importance of some of these requirements. Brubaker is on track to graduate in 2013 with a PhD in applied mathematics from the University of Delaware. His research focuses on the modeling of soap films interacting with electric, magnetic, and gravitational fields. The GRF has given him not only time and the independence to do his research, but also the opportunity to publish two papers and to have another two manuscripts in review. His advice to prospective GRF applicants: Give yourself time, and keep trying. "Apply as many times as you can! If you don't get it the first time, don't get discouraged." He also points out even if your GRF application isn't successful, the application process can help you as you plan your graduate career.

Gina-Maria Pomann is pursuing a PhD in statistics at North Carolina State University. Her research interests are functional data analysis with applications to magnetic resonance imaging and dynamic treatment regimens. She credits the GRF, in combination with her AT&T Labs Fellowship, for allowing her to work on an array of different projects, as well as with different mentors. Pomann first considered graduate school and learned about the GRF through the Mathematical Sciences Research Institute Undergraduate Program. MSRI-UP also led her and her fellow participants to a SACNAS (Society for Advancement of Chicanos and Native Americans in Science) conference, where the students were further informed about the GRF as well as other opportunities. Her advice to students seeking a GRF: "Get as much undergraduate research experience as possible!" Her early research experiences, she says, helped her to focus her research interests and to write her GRF application.

*The official NSF solicitation can be found at http://www.nsf.gov/pubs/2012/nsf12599/nsf12599.pdf. For more information, and tips from awardees and reviewers, go to the GRFP website at http://www.nsfgrfp.org or contact 1–866–NSF–GRFP (673–4737); info@nsfgradfellows.org. For access to online applications, user guides, and other official announcements, log on to the FastLane website at https://www.fastlane.nsf.gov/grfp/. The deadline for full proposals for 2013 is November 14, 2012.*

*Meredith Berthelson is pursuing a PhD in Interdisciplinary Studies at the University of Montana; with a Quality Education for Minorities/Tribal Colleges and University Programs fellowship, she is spending six months at the National Science Foundation. Jennifer Slimowitz Pearl, a program director in the Division of Mathematical Sciences at NSF, manages the Infrastructure Program.*

## Tips for Students

To enter the competition for an NSF graduate research fellowship, you need to submit a complete application via NSF FastLane (https://www.fastlane.nsf.gov/grfp/Login.do). The application asks for a personal statement, description of research experience, proposed plan of research, and transcripts. You will also need to arrange for three letters of reference, submitted separately via FastLane by the reference writers.

Reviewers evaluate GRF applications on the basis of two National Science Board-specified criteria: intellectual merit and broader impacts. For intellectual merit, you will need to demonstrate your academic capability and other conventional requisites for scholarly, scientific study. You could comment on your ability to plan and conduct research, work in a team as well as independently, and interpret and communicate your research findings. To demonstrate broader impacts, you need to convey how your research will contribute on a larger scale to society and the breadth of its audience. Will it encourage diversity, broaden opportunities, and allow participation of all citizens in science and research? If so, you should make this evident to the reviewer. You can access examples of "broader impact" activities at http://www.nsf.gov/pubs/gpg/broaderimpacts.pdf.

Be clear and specific in preparing your application—the reviewer shouldn't have to struggle to read it. Describe experiences—whether personal, professional, or educational—that have been factors in your preparation and that have driven you to pursue graduate study. Be detailed about your involvement in any scientific research activities and what you learned from those experiences. If you have not been directly involved in research, you should describe any activities that you believe have prepared you to start doing research. Don't leave it to the reviewer to glean from your writing that you "could" be a leader in some capacity—instead, describe your leadership potential directly. How do you see yourself contributing to research, education, and innovation? Let the reviewers know your career aspirations and specific goals you hope to accomplish. Your application is a chance to sell yourself!

*Uncertainty Quantification 2012*

# Probabilistic UQ for PDEs with Random Data: A Case Study

*By Oliver G. Ernst and K. Andrew Cliffe*

At the first SIAM Conference on Uncertainty Quantification, held in April in Raleigh, North Carolina, a distinguished statistician observed, "UQ—I thought that's what I had been doing for the past 30 years!" Indeed, one might argue that the origins of mathematical statistics and probability theory, dating back to Laplace and Gauss, were motivated in part by the need to deal with uncertainty from measurement errors.

Three factors have contributed to the explosive growth in the emerging field of modern UQ: an abundance of data resulting from advances in sensor technology, the widespread availability of affordable high-performance computing, and the development and analysis of new algorithms for solving differential equations with random inputs. It is these developments that have enabled the application of UQ techniques to the engineering sciences and other fields, where the point of departure is typically PDE-based modelling of some interesting phenomenon. For many such problems, existing numerical techniques can be used to obtain a solution to essentially any desired accuracy, assuming knowledge of problem inputs, such as the modelling domain, boundary and initial data, coefficients, and source terms. When any of these are uncertain, it becomes necessary to quantify the effect of the uncertainty on the solution of the PDE, or on any quantity of interest, or QoI, derived from the solution. The complete UQ task then consists of determining the uncertainty in the inputs and propagating it to the outputs.

A tried and true approach for approximating statistics of QoIs is Monte Carlo sampling, in which realizations of the random PDE inputs are obtained via random number generators following a postulated probability law. For each generated realization, the QoI is obtained by solution of the resulting deterministic PDE. While simple and robust, MC sampling is plagued by slow convergence, a deficiency that can render it unuseable when the underlying deterministic PDE is computationally expensive. Initiated by the work of Ghanem and Spanos [1] in the early 1990s, new solution techniques, now known as stochastic Galerkin and stochastic collocation methods, have been developed and analyzed by the numerical analysis community; these techniques can exploit smoothness in the dependence of the solution on a (possibly large) number of random parameters to yield algorithms that often outperform MC sampling. (See [2] for a survey.)

■ ■ ■

Radioactive waste disposal is an application area in which UQ is a vital instrument for regulatory agencies and other decision-makers. The safe long-term disposal of radioactive waste is an important problem that has implications for the future use of nuclear power. The solution favoured by most countries that have civil nuclear power programs is disposal deep within stable geological formations. The rocks between the repository and the earth's surface are important in two ways: First, they isolate the waste from the immediate human environment. Second, if radioactive wastes should leak from their containers and escape from the engineered repository, the rocks between the repository and the surface form a barrier that can delay the arrival of harmful radionuclides. If the time for travel from the repository to the surface is sufficiently long, many of the radionuclides will have decayed and the impact, in terms of dose to humans, will have been reduced. This travel time is therefore a crucial parameter in assessing a potential repository.

The basic physics of flow and transport in porous media is reasonably well understood. Because the rock properties cannot be measured everywhere relevant to a calculation, however, uncertainty is inherent in any calculation of travel time. This uncertainty must be represented and its impact quantified as part of a repository assessment. One way to carry out UQ is to use probabilistic methods. We present here a case study in which probabilistic UQ was applied to groundwater flow and radionuclide transport in the assessment of a radioactive waste disposal site, based on data from the site, the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico.

The primary QoI is the time needed for transport of a radioactive particle by groundwater from the repository to the human environment. The most transmissive feature in the region of WIPP is a thin, but laterally extensive layer called the Culebra Dolomite. Figure 1 shows a cross-section of the geological environment of WIPP.

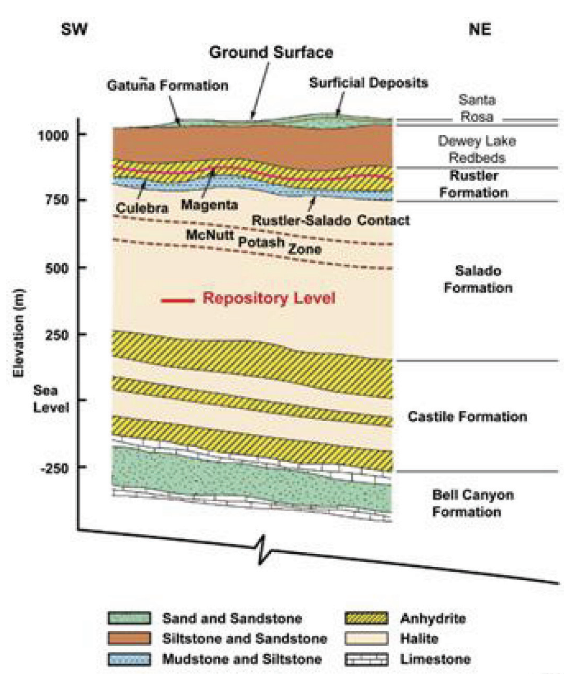


**Figure 1.** *Cross-section of the geological structure surrounding the WIPP repository.*

The rocks above and below the Culebra are relatively impermeable. The scenario studied is the release of radionuclides from the repository to the Culebra via a man-made borehole. The mathematical model consists of a stationary two-dimensional diffusion equation, based on Darcy's law and mass conservation, for the hydraulic head; the hydraulic conductivity is modelled as a random field.

Classical geostatistical techniques are used to determine the parameters for the input random field's probability law. Figure 2 shows the 2D transmissivity field obtained by *kriging*, a statistical estimation technique based on a set of measurement data. Numerical solutions are obtained with a mixed finite-element discretization of the Darcy flow problem; once the (stochastic) hydraulic head is computed, contaminant transport can be modelled by particle tracing in the associated velocity field.

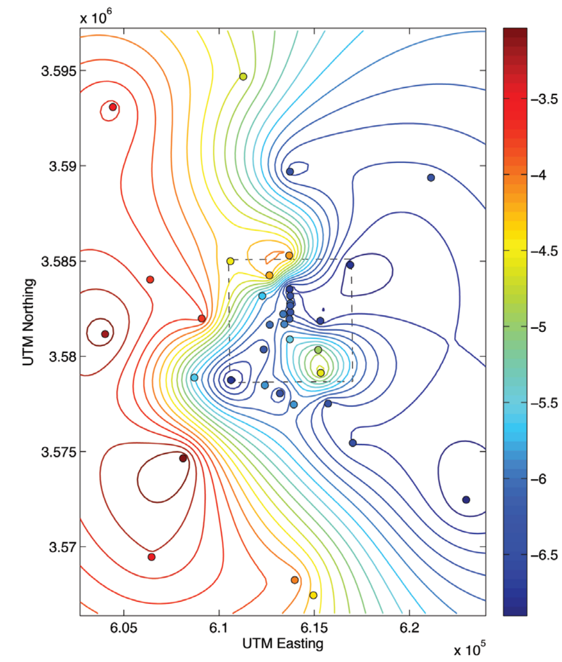


**Figure 2.** *The colored dots indicate the location and value of transmissivity measurements taken in the WIPP area (dashed box) and nearby. The contour lines represent the kriging interpolant used to generate the input of the UQ simulation.*

In our case study, we compared three approaches: classical brute-force MC simulation, Gaussian process emulators, and stochastic collocation. Gaussian process emulators can provide a stochastic approximation to the output of a computer program as a function of its inputs—in this case the particle travel time is the output, and the parameters determining a finite-dimensional approximation to the random field are the inputs. The third approach involves the numerical solution of the PDE with random data as a parametrized deterministic system. Sparse grid collocation methods are used to discretize the parameter space. This approach is computationally efficient because the spatial problems that have to be solved at each collocation point are independent and the approximation properties of the sparse grid are good.

We calculated the statistical travel time from the stochastic model for each of the methods studied, and compared the results. For a given finite truncation of the random field, the three methods produce very similar results for the cumulative distribution function for travel time. The brute-force MC method is the most expensive, the stochastic collocation method the most efficient.

The limitations of methods based on explicit parametrization in terms of random quantities (such as collocation) are encountered when the random fields have very short correlation lengths, as in the rough fields encountered in many geophysical settings. It is often observed, however, that although the solution of the random PDE may have a complicated dependence on a large number of random parameters, certain QoIs lie on a low-dimensional manifold in this parameter space. Much current research in UQ methodology centers on the adaptive capture of this manifold with numerical methods.

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## Complex Variables

*continued from page 1*

this out is like a driver not knowing how to parallel park.

But mathematics has a thousand beautiful topics that we all wish we knew better! What's so special about complex variables?

Weierstrass, Kelvin, Hardy, or von Neumann could have told you the answer. Numbers and functions are at the heart of mathematics, and you can't properly understand them if you see them only on the real line. That's why the other name for complex analysis is *function theory*. Ask Stokes, or Rayleigh, or Painlevé, who wrote that "The shortest path between two truths of the real domain often passes through the complex one." (The original French quote is given in the marvelous new book by Lax and Zalcman, *Complex Proofs of Real Theorems*.)

I'd like to propose three explanations of how complex variables have been pushed to the sidelines.

*Curriculums.* What has replaced function theory in mathematics education over the years? I think the answer may be linear algebra, which students spend much more time with now than they used to. Alas, I believe deeply in the importance of linear algebra, so I can't pretend that this hypothesis, if valid, points the way to a solution.

*Mission creep.* When I ask colleagues about complex analysis, they mention daunting topics like Riemann–Hilbert problems and Phragmén–Lindelöf theory. At least in some perceptions, it would seem that these fine advanced subjects have pushed aside basics like series, branch cuts, and contour integrals. To tell the truth, I suspect conformal mapping also gets too much attention, though I'm a card-carrying conformal mapper myself.

*The oasis and the jungle.* Let me finish with a couple of metaphors. Analytic functions are all the same, like Tolstoy's happy families: You can differentiate them as often as you like, their Taylor series converge absolutely and uniformly, you can manipulate the series term by term, and on and on in a symphony of tractability. Is $f(z)$ analytic in the unit disk? Then there's not much more to say about it! That disk of analyticity is an oasis of fully understood mathematics and powerful applied mathematical methods. The basic ideas had been worked out by the time Cauchy and Riemann were gone in 1866.

But now consider the boundary of that disk of analyticity, the unit circle. Is $f$ continuous there, or differentiable, or what? Is it even defined as a function, or a distribution, or is it not defined at all? Almost anything is possible! The boundary circle is the jungle at the edge of the oasis. It's a dangerous, exciting place. And by the turn of the 20th century, that's where the research action was moving. Lebesgue and his successors exploded our notion of function, and the amazing subject of real analysis was created, right there at the edge of complex analysis. Why is real analysis a bigger specialty than complex analysis for research mathematicians? Because unhappy families are all different.

But theoretical complexity has little to do with whether a tool is *useful*. Most functions we encounter in practice are analytic or piecewise-analytic. Students should learn how to work with them right from the start. Every numerical analysis textbook should tell its readers that if the integrand is analytic, then Gauss quadrature converges geometrically. At the moment none of them do, at least none that I have seen—because "analytic" is considered too advanced a notion. Astonishing.

# Birth of a Literary Genre

**The Great Equations: Breakthroughs in Science from Pythagoras to Heisenberg.** *By Robert P. Crease, W.W. Norton, New York, 2008, 224 pages, $25.95; paperback, 2010, 315 pages, $16.95.*

**In Pursuit of the Unknown: 17 Equations that Changed the World.** *By Ian Stewart, Basic Books, New York, 2012, 352 pages, $26.99.*

**The Universe in Zero Words: The Story of Mathematics as Told Through Equations.** *By Dana Mackenzie, Princeton University Press, Princeton, New Jersey, and Elwin Street Productions, London, UK, 2012, 224 pages, $27.95.*

BOOK REVIEW
*By James Case*

If three quite different books by quite different authors with quite similar titles can be said to constitute a new literary genre—call it the "great equations" genre—it may be time for a birth announcement. Each of the three books reviewed here undertakes to explain an important part of intellectual history through the medium of equations.

Two of the authors are well known to the SIAM community. Ian Stewart, a professor emeritus of mathematics at Warwick University, is among the most prolific popular mathematics writers of all time. Dana Mackenzie, who received the JPBM Communications Award last year (following its presentation to Stewart by more than a decade), has written for *Discover*, *Smithsonian*, *Science*, *New Scientist,* and *SIAM News*.

Robert Crease, who chairs the philosophy department at Stony Brook University, is the author of several popular science books. He is also the official historian of the Brookhaven National Laboratory.

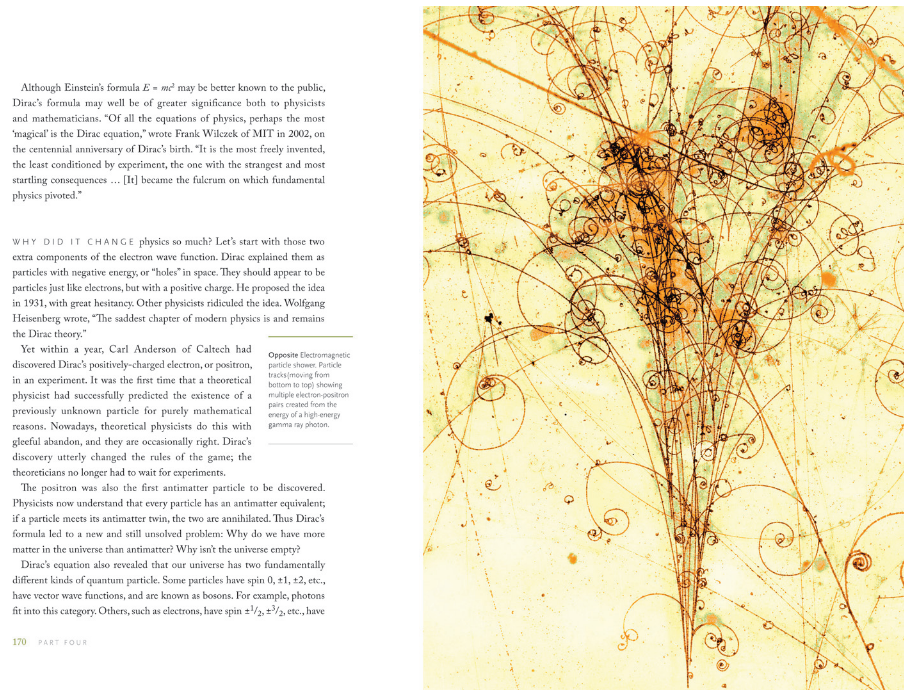
The three authors make use of a common format. A sequence of "equation chapters"—each devoted to a single equation or system of equations—is preceded by a brief introduction and/or preface and followed by a single chapter of "conclusions." Each equation chapter begins with a display of the featured equation(s), followed by a discussion of meaning and content, and a discourse on historical significance. Crease offers ten such chapters, and relegates his commentary to brief "Interludes" separating his substantive chapters. Stewart presents 17 equation chapters, and Mackenzie, 24.

All three authors devote entire chapters to eight equations deemed great by consensus: Pythagoras's $a^2 + b^2 = c^2$, Newton's $F = ma$ and $F = GMm/r^2$, Euler's $e^{i\pi} + 1 = 0$ and $V - E + F = 2$, Einstein's $E = mc^2$, Maxwell's equations of electromagnetism, and the fundamental equation of quantum mechanics. Crease and Stewart take the latter to be Schrödinger's equation, while Mackenzie opts for Dirac's. Each author includes at least two equations omitted by the other two.

Crease—more concerned with the equations of physics than those of pure mathematics—considers only two equations that are missing from the lists of the other two authors: Heisenberg's uncertainty principle and Einstein's field equations of general relativity. Both Mackenzie and Stewart discuss general relativity in chapters on $E = mc^2$. Stewart, in particular, extends his discussion to include current events in cosmology, beginning with the discovery that the universe appears to be expanding at an increasing rate. Cosmologists are currently unable to explain this apparent fact without assuming the presence of large quantities of unobservable (dark) matter and energy in the otherwise empty space between observable (luminescent) heavenly bodies. Even with these powerful hypotheses, Stewart writes, the available facts are proving difficult to explain.

After describing the content of the uncertainty principle, Crease chronicles the dispute it occasioned between Heisenberg and Bohr concerning the manner in which quantum mechanics is to be interpreted, as well as the uneasy truce between them that became the "Copenhagen interpretation."

Stewart includes seven great equations omitted by the other two, and Mackenzie presents 14. That is in part because Mackenzie begins nearer the origins than the others, his first two great equations being 1 + 1 = 2 and 1 – 1 = 0. In the chapter devoted to the former, titled "Why We Believe in Arithmetic," he argues that our belief is mainly empirical. The results of arithmetic computation would not be accepted if they did not conform with experience involving sheep, goats, shekels of silver, yards of cloth, and so on.


Although Einstein's formula $E = mc^2$ may be better known to the public, Dirac's formula may well be of greater significance both to physicists and mathematicians. "Of all the equations of physics, perhaps the most 'magical' is the Dirac equation," wrote Frank Wilczek of MIT in 2002, on the centennial anniversary of Dirac's birth. "It is the most freely invented, the least conditioned by experiment, the one with the strangest and most startling consequences … [It] became the fulcrum on which fundamental physics pivoted."

WHY DID IT CHANGE physics so much? Let's start with those two extra components of the electron wave function. Dirac explained them as particles with negative energy, or "holes" in space. They should appear to be particles just like electrons, but with a positive charge. He proposed the idea in 1931, with great hesitancy. Other physicists ridiculed the idea. Wolfgang Heisenberg wrote, "The saddest chapter of modern physics is and remains the Dirac theory."

Yet within a year, Carl Anderson of Caltech had discovered Dirac's positively-charged electron, or positron, in an experiment. It was the first time that a theoretical physicist had successfully predicted the existence of a previously unknown particle for purely mathematical reasons. Nowadays, theoretical physicists do this with gleeful abandon, and they are occasionally right. Dirac's discovery utterly changed the rules of the game; the theoreticians no longer had to wait for experiments.

**Opposite** Electromagnetic particle shower. Particle tracks(moving from bottom to top) showing multiple electron-positron pairs created from the energy of a high-energy gamma ray photon.

The positron was also the first antimatter particle to be discovered. Physicists now understand that every particle has an antimatter equivalent; if a particle meets its antimatter twin, the two are annihilated. Thus Dirac's formula led to a new and still unsolved problem: Why do we have more matter in the universe than antimatter? Why isn't the universe empty?

Dirac's equation also revealed that our universe has two fundamentally different kinds of quantum particle. Some particles have spin 0, ±1, ±2, etc., have vector wave functions, and are known as bosons. For example, photons fit into this category. Others, such as electrons, have spin $\pm^1/_2$, $\pm^3/_2$, etc., have

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*Electromagnetic particle shower. Particle tracks (moving from bottom to top) showing multiple electron–positron pairs created from the energy of a high-energy gamma ray photon. Two-page spread from* The Universe in Zero Words*; courtesy of Elwin Street Productions.*

It was not until the late 16th century, Mackenzie adds, that European authors began to substitute symbols for words like sum, difference, and product. The now ubiquitous equals sign made its European debut in a book called *The Whetstone of Wytte*, published in 1557 by one Robert Recorde. Although it had been known for millennia that 1 + 1 = 2, the equation was probably not written in symbolic form until some time in the 16th century. The subtler 1 – 1 = 0 took even longer, due to the resistance with which the concept of zero was met in western Europe.

Several of the equations considered, such as Crease's $\Delta x \Delta p \geq \hbar/4\pi$, Stewart's $dS \geq 0$, and Mackenzie's $\pi = 3.1415926535\ldots$ and $2\uparrow\aleph_0 = \aleph_1$, would not ordinarily be thought of as equations. Yet they help the authors describe important events in the history of mathematics briefly and understandably. (Here $S$ stands for entropy, as in the second law of thermodynamics, and $\hbar$ denotes Planck's constant.)

Crease begins his chapter on the Pythagorean theorem by rehearsing the proof of a special case of it that Socrates coaxed out of the untutored slave boy Meno (according to Plato's dialogue of that name). He then describes the dramatic effect of a chance encounter with a copy of Euclid's *Elements*—left open at the page containing Pythagoras's result—on the life and subsequent career of Thomas Hobbes, and the equally important influence of the theorem on the careers of Descartes, Einstein, and others. Indeed, Crease speculates, the theorem appears to epitomize—for Hobbes, Plato, and many others—the very *idea of mathematical proof*. By contrast, Stewart emphasizes the role of the theorem in the development of trigonometry, cartography, coordinate geometry, and the knowledge that the earth is round, and Mackenzie focuses on the contribution of the theorem to the discovery of irrational numbers, and the failure of the Chinese and Babylonians (both of whom knew the theorem before Pythagoras) to discover that $\sqrt{2}$ is irrational.

Mackenzie's chapter "The Great Explorer: Euler's Theorems" describes what Euler accomplished while maintained at various courts of 18th-century Europe. In addition to the fact that $e^{i\pi} + 1 = 0$ and $V - E + F = 2$, Mackenzie includes the identities $\zeta(x) = \Sigma\ 1/n^x = \Pi\ (1 - p^{-x})^{-1}$ and $\zeta(2) = \Sigma\ 1/n^2 = \pi^2/6$, in which the infinite sums are to extend over all positive integers $n \geq 1$, and the infinite product over all primes $p > 1$. Why, one wonders, did he omit Euler's equations of motion for perfect fluids and rigid bodies? Euler, incidentally, never actually wrote $e^{i\pi} + 1 = 0$. The closest he came was $\exp(ix) = \cos x + i \sin x$.

In his chapter on Maxwell's equations, Stewart traces their development from Faraday's notion of a field and deduces from them (in an endnote) that both the electric and magnetic fields satisfy the generalized (three-dimensional) wave equation. He then recounts the detection—in 1886 by Heinrich Hertz—of the waves predicted by Maxwell, their transmission a decade later over a distance of 16 kilometers by Guglielmo Marconi, and the revolution in entertainment and communication made possible by those achievements. Crease, in contrast, focuses on the more complicated form of the equations in the presence of electric charge distributions, and their development by Oliver Heaviside into a tool useful in the design of electrical circuits, while Mackenzie summarizes the evidence indicating that light is an electromagnetic wave.

In his chapter on the Navier–Stokes equations—omitted by both Crease and Mackenzie—Stewart focuses on recent developments in computational fluid dynamics and their relevance to modern automobile

*See* **Great Equations** *on page 7*

# Math of Planet Earth 2013

You have probably heard that 2013 is the year of Mathematics of Planet Earth, but do you know what that means?

MPE2013 began as an initiative of North American math institutes, a way of highlighting contributions of the mathematical sciences to understanding our planet and biosphere. In the short time since MPE2013 was founded, more than 100 organizations in the mathematical sciences, including SIAM, have become partners in this worldwide effort to promote the contributions of mathematics to areas of the geosciences, biology, climate, and related fields.

The U.S. kickoff for MPE2013 will occur in January at the Joint Math Meetings in San Diego. Among the many MPE2013-related sessions on the program is the Porter Public Lecture, a joint project of the AMS, MAA, and SIAM that was chosen to fit the MPE2013 theme. Ken Golden (who in 2009 gave the SIAM invited lecture at the JMM) will speak about his team's work in Antarctica, including the study of sea ice and its role in climate modeling. Many additional special sessions at the Joint Math Meetings will be related to MPE2013.


*A recent request from Jim Crowley for details about the 2013 Porter lecture brought the following reply: "Ken Golden is on an Australian icebreaker in Antarctica until November 5. . . ." Shown here coring ice during an earlier polar expedition, Golden is clearly a hands-on applied mathematician. The Porter lecture promises to be both visually spectacular (with video from recent Antarctic expeditions to be shown) and completely up to date!*

Events scheduled for the year include sponsored public lectures, workshops, and summer schools on MPE2013-related themes. In addition, many conferences in the mathematical sciences have elected to make Math of Planet Earth a major theme; among them are the 2013 SIAM Annual Meeting (San Diego, July 8–12) and the SIAM Conference on Geosciences (June 17–20 in Padova, Italy).

The organizers hope that MPE2013 will attract the attention of the media and, with plans for a daily blog, hope to enlist people from the community to serve as bloggers (go to http://mpe2013.org/ to volunteer).

An example of an activity scheduled for MPE2013 is a series of public lectures to be given around the world. Held in traditional lecture format in a public hall, each of the lectures will be streamed live to viewers around the world. Topics include biodiversity ("Motility: Molecules, Mechanics, Mathematics and Machines," by L. Mahadevan), epidemiology ("Puzzles in the Pattern of Plagues," by David Earn), and climate ("Using Mathematics to Combat Climate Change," by Ron Dembo).

Stay tuned. You may see MPE2103 featured on public television in the U.S. or highlighted in the media. We hope that readers will seek ways to participate and help show the contributions that our community makes to understanding our world and the living things around us.—*JMC*

# My Poincaré, Recollected

*By Philip J. Davis*

A review copy of Jeremy Gray's biography of Poincaré,* absolutely magisterial in both scope and treatment, threw me back to my undergraduate and graduate years. Rather than write a conventional review, I prefer to take a cue from the historian and essayist Thomas Babbington Macaulay (1800–1859), who, in dealing with a book, pretty much ignored what the author said and wrote what he himself wanted to say about the topic.

So Speak, Memory: In my junior year in college, I took Advanced Calculus with George David Birkhoff (1884–1944). It was during the first semester that I learned of the existence of the great French mathematician Jules Henri Poincaré (1854–1912). A decade and a half earlier, Birkhoff had been putting the final touches on his proof (circa 1913–1925) of what is now known as the Poincaré–Birkhoff fixed-point theorem (discussed in Gray's book). This achievement immediately earned Birkhoff the reputation of a world-class mathematician.

This theorem asserts that a bijective, continuous, area-preserving mapping of the ring between two concentric circles onto itself that moves one circle in the positive sense and the other in the negative sense has at least two fixed points. I call this the merry-go-round theorem, and my simplified formulation of it is as follows: Two concentric circles of merry-go-round horses rotate at the same angular speed, one in the positive sense and the other in the negative. Two friends mount horses on different circles. How often do they meet?

Not what might be called a rigid lecturer, Birkhoff did not follow our class text, Osgood's *Advanced Calculus*, with punctilio. But when a topic in Osgood caught his attention, he would free associate out of his vast knowledge and experience. At a departmental tea one afternoon to which math majors were invited, I asked him a question. His answer: Go to the *Rendiconti di Palermo*, such and such a volume. I never did check it out, but that was my first inkling of a world of professional mathematics that extended far beyond Lancelot Hogben's popular *Mathematics for the Million*, a best seller that I received as a high school graduation gift. Yes, in class the morning of the tea, Poincaré was rattling around in Birkhoff's brain. This was 13 years after the appearance of Birkhoff's *Dynamical Systems*, a book with a chapter devoted to Poincaré's geometrical theorem and with 15 index listings for the man.

In the late '40s, when I came up for my PhD at Harvard, instead of a qualifying exam, I had to submit a "minor thesis." The "major thesis" was on a topic of one's own choosing, but the minor thesis was not and in it one was not required to present original results. I went to the office of the department chairman, who at the time was Garrett Birkhoff (1911–1996; son of G.D. Birkhoff and, in 1966–67, president of SIAM). He handed me a small box containing a number of slips of paper. "Pick one," he said. "The Three-Body Problem" was written on the one I selected. "Write on that," Birkhoff said; "you have one month to do it."

Though I'd had had a course in mechanics, this really was a challenge. How to proceed? Ask a friendly member of the faculty for advice? Forget it. I had the *Math Reviews*. I had the German equivalent: the *Zentralblatt der Mathematik*. I knew that G.D. Birkhoff had worked on the three-body problem. I got out his *Dynamical Systems* and turned to Chapter IX, "The Problem of Three Bodies." Skipping the Poincaré material: I found this quote: "It is not too much to say that the work of Sundman is one of the most remarkable contributions to the problem of three bodies which has ever been made."

That settled the matter for me. I read up on the work on the three-body problem of Karl F. Sundman (1873–1949), a great Finnish mathematician. The problem of what to present in my minor thesis was solved. I described how under certain circumstances, the bodies, considered as mathematical points, collide and pass through one another, and do so in a way that can be parameterized by conformal analytic functions.

I seem to have retained no copy of it (no great loss!), but I recall that it contained as epigraphs (1) the quotation from G.D. Birkhoff about Sundman mentioned above and (2) a statement that in those cataclysmic days, it was appropriate to study the collisions of mathematical planets. Hiroshima and Nagasaki were on many minds. I haven't thought about that work from the late 1940s to this day. No Poincaré in my minor thesis? Ah, well, the chips have to fall where they may.

Poincaré! What a man! He seems to be all over the mathematical map: analyst, probabilist, topologist, celestial mechanician, critic of mathematical logic, philosopher, quotable semi-popular author. Today we have the Institut Henri Poincaré in Paris, the Poincaré prize, Poincaré's conjectures, his vision of the mathematical future. Topping all this off are a variety of events laid on in Paris to celebrate the 100th anniversary of his passing.

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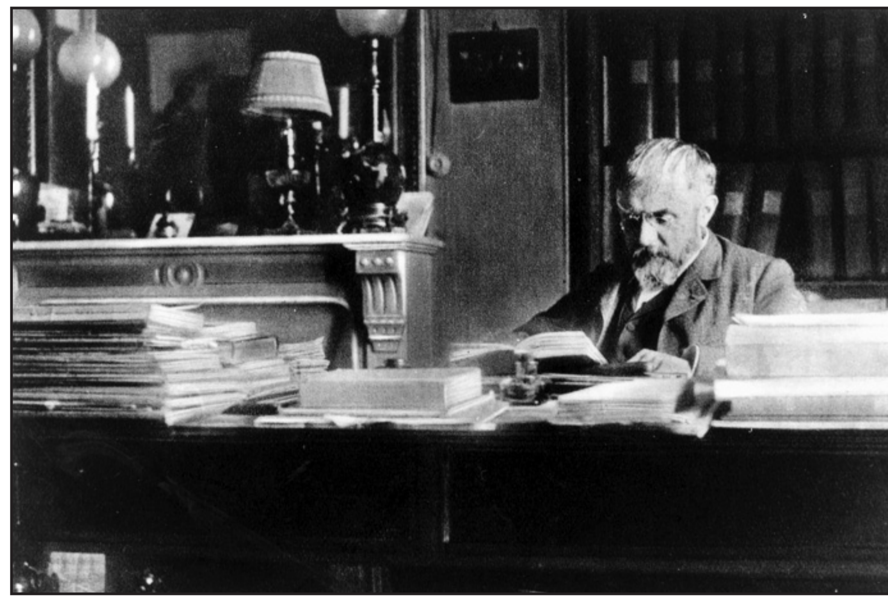
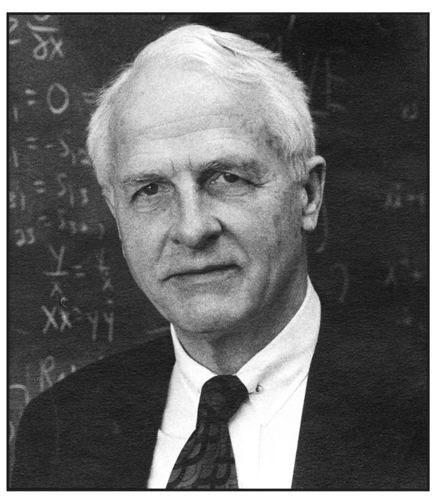
**Henri Poincaré: A Scientific Biography*, by Jeremy Gray, Princeton University Press, 2012.



*Henri Poincaré, who died 100 years ago. His work on the three-body problem could have settled the author's dilemma as to his minor thesis topic. But it wasn't to be.*



*As a graduate student, the author picked a minor thesis topic out of a hat: "The Three-Body Problem." "Write about that," math department chair Garrett Birkhoff said; "you have one month to do it."*

## Great Equations

*continued from page 6*

and aircraft design. A variety of questions either difficult or impossible to answer by wind-tunnel experiment are approachable via CFD. To emphasize the point, Stewart depicts the computed airflow around a Formula 1 race car, information almost impossible to obtain from wind-tunnel experiments. He also points out that CFD is directly applicable to climate studies, concerning which he provides a good deal of up-to-date information.

Only Mackenzie devotes a chapter to S.S. Chern's generalization $\int_M Pf(\Omega) = (2\pi)^n \chi(M)$ of the classic Gauss–Bonnet formula, in which $M$ represents an arbitrary manifold of even dimension $2n$, $\Omega$ its Gaussian curvature, $Pf$ the Pfaffian operator, and $\chi(M) = 2 - 2g$ the Euler characteristic of $M$. Because the "connectivity" $g$ of $M$ represents the number of holes in space enclosed by $M$, it can assume any of the values 0, 1, 2, . . . , meaning that $\chi(M)$ can assume any of the values 2, 0, –2, –4, . . . .

After being extricated from Japanese-held China in 1943, Chern (considered then and now to be Cartan's most gifted student) was invited to visit the Institute for Advanced Study in Princeton. While there, he learned that André Weil and Carl Allendoerfer had recently proved a version of the classic ($n = 1$) Gauss–Bonnet theorem that worked for any even-dimensional manifold $M$. Finding their proof ugly and unenlightening, Chern produced one of his own (published in a six-page paper in 1946) that was neither, and that—by introducing the concept of a fiber bundle—revitalized 20th-century geometry.

It came to light later that fiber bundles are closely related to quantum fields. "To understand the shape of a space," Mackenzie writes, "you need to know what kinds of fiber bundles—or, essentially the same thing, what kinds of quantum fields—can be erected on that space." As he adds later, "Michael Atiyah and Isidore Singer made the links between math and physics even more explicit" by giving "a proof of the Chern–Gauss–Bonnet theorem (and quite a bit more) that proceeds directly from solutions of the Dirac equation!"

Well written and entertaining, all three books are also replete with interesting details that add to what most mathematicians already know about the equations described and the events chronicled. Generally, Crease seems the most philosophically inclined of the three authors, Stewart has the most to say about applications, and Mackenzie delves most deeply into the historical development of purely mathematical ideas. All three books can be recommended to any reader with even a casual interest in mathematics and/or its history.

*James Case writes from Baltimore, Maryland.*

# Fifteen Ways to Fool the Masses When Presenting your Work in UQ*

*By Max Gunzburger*

As is true for any rapidly developing field that is attracting ever increasing numbers of participants, uncertainty quantification for complex systems (such as those governed by partial differential equations) has become quite a competitive area of research. This being so, one endeavors, in one's papers, talks, and proposals, to present one's accomplishments in UQ in as favorable a light as possible. This is often difficult, given that one's accomplishments may not, in fact, be very impressive. To help those in such difficulty, especially junior researchers just getting into the UQ business, this article provides 15 suggestions for making one's results look wonderful, when they are actually nowhere near wonderful.

*1. Compare your results with the slowest possible version of Monte Carlo, never with someone else's method;*

this way, even you will have a difficult time not looking good, as long as you don't go to a dimension higher than 3, if your method is really bad, or higher than 1, if it is a total disaster.

*2. Claim that you can do 1000-dimensional problems and that no one else can do this,*

but present results for a problem that has an effective dimension of only 4 or less; totally obfuscate what you are doing with lots of mumbo-jumbo so that a naive audience really believes you are doing a 1000-dimensional problem.

*3. Tailor your examples so that they are advantageous for your method and disadvantageous for your competitors' methods,*

even if all fair examples have the opposite result; but heed this warning: Finding such examples for a lousy method requires some cleverness on your part, so you may not be able to do so.

*4. Invent a fancy name for a method you claim to have invented and that you also claim to be new and transformational, but that really is a well-known method given a new name;*

this way, everyone will think you are really doing something new and important.

*5. Using the same problem as for the previous recommendation, invent a fancy name for another well-known method and again make outlandish claims, but completely fail to mention that your previous claims turned out to be totally unfounded;*

in fact, don't mention the previous method at all; this way, no one will be reminded of your previous failure.

*6. Tailor your claims to your audience; if the audience is made up of, say, probabilists, make outlandish claims about how good your algorithms are; if they are numerical analysts, make outlandish claims about how your results involve deep and innovative probability;*

this way, you take advantage of the audience's ignorance without revealing your own.

*7. Never show what happens as the number of samples or other degrees of freedom increase;*

this way, the lack of convergence of your method is not revealed, and, if you also follow recommendation 8, no one will care because the errors you report are so small.

*8. Without pointing out that you are doing so, show only absolute and not relative errors, making sure to neglect to mention that the solution you use for comparison has a minuscule norm, certainly no bigger than $10^{-5}$;*

this way, you can make your non-convergent method look really good by showing that, using only a handful of samples, you can get an error of order $10^{-5}$.

*9. Blame the data, and not the shortcomings of your method, for its poor performance;*

most people will believe you when you say that if you had better data, your results would be better.

*10. Always do your calculations on a supercomputer, even if you just use one processor;*

this allows you to use any of David Bailey's stratagems to hide the poorness of your results.

*11. When comparing your results with experiments, make sure to pick experimental data that comes with huge error bars—so huge, in fact, that your bad results still fit within them;*

you can then claim that your results always fall within "experimental error."

*12. Give plots that show your method converging to a tolerance of less than $10^{-12}$ with just a few samples, but do not mention the preprocessing step that required a humongous number of samples, and certainly do not mention that the method converges to the wrong solution;*

the $10^{-12}$ figure will dazzle your audience to such an extent that they will not think of questioning your claims.

*13. Show results for only two parameter dimensions or, even better, for a single parameter, but add that your method obviously scales well to much higher dimensions;*

use of the word "obviously" will keep people from questioning you, fearful that, by missing something that is obvious to everyone else, they will look stupid.

*14. Use no math;*

that way, you won't make elementary mistakes and no one will figure out that you don't know any math.

*15. Of course, if all else fails, show lots of pretty pictures and especially movies,*

but don't mention anything about the performance of your methods.

*Max Gunzburger (gunzburg@fsu.edu) is the Frances Eppes Eminent Professor in and chair of the Department of Scientific Computing at Florida State University.*

*David Bailey of Lawrence Berkeley National Laboratory initiated a series of missives of this nature with "Twelve ways to fool the masses when giving performance results on parallel computers" (*Supercomputing Review*, 1991). That paper spawned many imitations. Apologies to him for yet another blatant echo.

# Professional Opportunities

*Send copy for classified advertisements to: Advertising Coordinator,* SIAM News*, 3600 Market Street, 6th Floor, Philadelphia, PA 19104–2688; (215) 382–9800; fax: (215) 386–7999; marketing@siam.org. The rate is $2.55 per word (minimum $295.00). Display advertising rates are available on request.*

*Advertising copy must be received at least four weeks before publication (e.g., the deadline for the December 2012 issue is October 31, 2012).*

*Advertisements with application deadlines falling within the month of publication will not be accepted (e.g., an advertisement published in the December issue must show an application deadline of January 2013 or later).*

*Students (and others) in search of information about careers in the mathematical sciences can click on "Careers and Jobs" at the SIAM website (www.siam.org) or proceed directly to*

www.siam.org/careers

### Centro de Investigación en Matemáticas, Mexico

*Visiting Positions Related to the International Year of Statistics and the Mathematics of Planet Earth*

CIMAT is seeking applicants for two six- or 12-month visiting positions (January to December 2013): one related to the "International Year of Statistics" (http://www.statistics2013.org/) and the other to "Mathematics of Planet Earth 2013" (http://www.mpe2013.org/). Candidates are sought to conduct research and activities oriented by the aims of the 2013 celebrations that will have impact on CIMAT academic programs. The expected monthly income will be $4000 U.S. currency.

Further information can be found at: http://www.cimat.mx/index.php?m=541.

### Texas Tech University

*Department of Mathematics and Statistics*

The Department of Mathematics and Statistics at Texas Tech University invites applications for three tenure-track assistant professor positions, to begin in the fall of 2013. A PhD degree at the time of appointment is required. The department is seeking candidates who will be engaged in nationally visible scholarship, establish externally funded research programs, interact with the existing research groups in the department, involve graduate students in their research, and show excellence in teaching at the undergraduate and graduate levels. It is anticipated that one of the positions will be in statistics, one in numerical analysis, and one in another area compatible with the department's existing research programs. Candidates with very strong records who will bring externally sponsored research to Texas Tech will be considered for associate or full professor ranks.

The department has active research groups in both pure and applied mathematics (see http://www.math.ttu.edu/FacultyStaff/research.shtml). The department fosters a spirit of interdisciplinary collaboration across areas of mathematics as well as with engineering and the physical and biological sciences.

Applicants should apply for position numbers T96800 for statistics, T96232 for numerical analysis, and T96376 for all other areas at: http://jobs.texastech.edu. Applications should include a completed AMS standard cover sheet and a vita. Three letters of reference and any material in addition to that completed online should be sent to: Alex Wang, Hiring Committee Chair, Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409–1042. The review of applications will begin immediately.

Texas Tech University is an affirmative action/equal opportunity employer. Texas Tech University is committed to diversity among its faculty. The university strongly encourages applications from women, minorities, persons with disabilities, and veterans, and will consider the needs of dual-career couples.

### Massachusetts Institute of Technology

*Department of Mathematics*

The Department of Mathematics at MIT is seeking to fill positions in pure and applied mathematics, and statistics, at the level of instructor, assistant professor, or higher, beginning in September 2013. The department also seeks candidates for a Schramm Postdoctoral Fellowship. Appointments are based primarily on exceptional research qualifications. Appointees will be expected to fulfill teaching duties and to pursue their own research program. A PhD is required by the employment start date.

For more information and application procedures, applicants should visit: http://www.mathjobs.org. For full consideration, applications should be submitted by December 1, 2012.

MIT is an affirmative action, equal opportunity employer.

### Indiana University Bloomington

*Department of Mathematics*

The Department of Mathematics seeks applications for a tenure-track position, with appointment beginning in the fall of 2013. Exceptionally well-qualified applicants may also be considered at the tenured level. Outstanding candidates with a PhD in any area of pure or applied mathematics and with postdoctoral or faculty-level experience are encouraged to apply, with particular emphasis in the areas of algebra and pure and applied analysis. A minimum requirement is a PhD in mathematics. Salary will be commensurate with qualifications and the level at which the position is filled. The base teaching load for research-active faculty is three courses per year.

The department maintains strong research groups in all of the principal fields of mathematics. Bloomington is located in the forested hills of southern Indiana and offers a rich variety of musical and cultural attractions.

Applicants should submit an AMS cover sheet, curriculum vitae, a research statement, and a teaching statement, using the online service provided by the AMS at http://www.mathjobs.org. Applicants should arrange for four letters of recommendation, including one evaluating teaching experience. Where applicable, applicants should ask reference writers to submit their letters electronically through http://www.mathjobs.org. If applicants or letter writers are unable to submit materials online, they can submit them to: Search Committee, Department of Mathematics, Indiana University, 831 East 3rd Street, Rawles Hall, Bloomington, IN 47405–7106. Applications should be received by November 1, 2012; however, applications will continue to be accepted until the search is filled.

Indiana University is an affirmative action/equal opportunity employer and is supportive of the needs of dual-career couples.

### Indiana University Bloomington

*Department of Mathematics*

The Department of Mathematics seeks applications for two Zorn Research Postdoctoral Fellowships, beginning in the fall of 2013. These are three-year, non-tenure-track positions with reduced teaching loads. Outstanding candidates with a recent PhD in any area of pure or applied mathematics are encouraged to apply; a minimum requirement is a PhD in mathematics. Zorn fellows are paired with mentors with whom they have compatible research interests.

The department maintains strong research groups in all of the principal fields of mathematics. Bloomington is located in the forested hills of southern Indiana and offers a rich variety of musical and cultural attractions.

Applicants should submit an AMS cover sheet, a curriculum vitae, a research statement, and a teaching statement, using the online service provided by the AMS at http://www.mathjobs.org. If unable to do so, applicants can send application materials to: Zorn Postdoctoral Fellowships Search Committee, Department of Mathematics, Indiana University, 831 East 3rd Street, Rawles Hall, Bloomington, IN 47405–7106. Applicants should arrange for four letters of recommendation, including one evaluating teaching experience. Applicants should ask reference writers to submit their letters electronically through http://www.mathjobs.org. If they are unable to do so, they can also send their letters to the previous address. Applications should be received by December 15, 2012.

Indiana University is an affirmative action/equal opportunity employer.

### Texas A&M University

*Department of Mathematics*

The Department of Mathematics anticipates several openings for tenured, tenure-eligible, and visiting faculty positions, beginning in the fall of 2013. One position at either the associate or assistant professor level is in noncommutative geometry and topology. For the others, the field is open; however, the department particularly seeks applications from individuals whose mathematical interests would augment and build on existing strengths both within the Department of Mathematics as well as in other departments at the university. The department also has several visiting positions available. Research and teaching are duties expected of all positions. Salary and start-up funds are competitive. For a tenured position, an applicant should have an outstanding research record. An established research program, including success in attracting external funding, and a demonstrated ability and interest in teaching are required. Informal inquiries are welcome. For an assistant professorship, the department seeks very strong research potential and evidence of excellence in teaching. Research productivity beyond the doctoral dissertation will normally be expected. The department's visiting assistant professor positions are three-year appointments and carry a three course per year teaching load. They are intended for those who have recently received a PhD; preference will be given to mathematicians whose research interests are close to those of the department's regular faculty members. Senior visiting positions can be for a semester or a one-year period.

Applicants should send the completed "AMS Application Cover Sheet," a vita, and a summary statement of research and teaching experience and arrange to have letters of recommendation sent to Mathjobs at: http://www.mathjobs.org. Further information can be obtained at http://www.math.tamu.edu/hiring. Complete dossiers should be received by December 15, 2012. Early applications are encouraged since the department will start the review process in October 2012.

Texas A&M University is an equal opportunity employer. The university is dedicated to the goal of building a culturally diverse and pluralistic faculty and staff committed to teaching and working in a multicultural environment and strongly encourages applications from women, minorities, individuals with disabilities, and veterans. The university is responsive to the needs of dual-career couples.

### Cornell University

*Department of Mathematics*

The Department of Mathematics at Cornell University invites applications for three tenure-track positions at the rank of assistant professor or higher, pending administrative approval, starting July 1, 2013. The searches are open to all areas of mathematics, with an emphasis on the areas of probability; algebra, in particular, number theory; analysis, in particular, PDEs; and topology.

Applicants must apply electronically at: http://www.mathjobs.org. For more information about these positions and application instructions, applicants should see http://www.math.cornell.edu/Positions/positions.html. Applicants will be automatically considered for all eligible positions. The deadline for applications is November 1, 2012. Early applications will be regarded favorably.

Cornell University is an affirmative action/equal opportunity employer and educator. The Department of Mathematics actively encourages applications from women and minority candidates.

*See* **Opportunities** *on page 10*







# Opportunities

*continued from page 9*

### National University of Singapore

*Department of Mathematics*

The Department of Mathematics at the National University of Singapore invites applications for tenured, tenure-track, and visiting positions at all levels, beginning in August 2013. The department seeks promising scholars and established mathematicians with outstanding track records in any field of pure and applied mathematics. The department, housed in a newly renovated building equipped with state-of-the-art facilities, offers internationally competitive salaries with start-up research grants, as well as an environment conducive to active research with ample opportunities for career development. The teaching load for junior faculty is kept especially light. The department is particularly interested in, but not restricted to, considering applicants specializing in any of the following areas: analysis and Ergodic theory; number theory and arithmetic geometry; computational science, especially biomedical imaging and computational material sciences; probability, stochastic processes, and financial mathematics; and combinatorics and discrete mathematics.

NUS is a research-intensive university that provides quality undergraduate and graduate education. The Department of Mathematics has about 65 faculty members and teaching staff whose expertise cover major areas of contemporary mathematical research. For further information about the department, applicants should visit http://www.math.nus.edu.sg.

Application materials should be sent via e-mail (as PDF files) to the Search Committee at: search@math.nus.edu.sg. Applicants should include the following supporting documentation in an application: (1) an American Mathematical Society Standard Cover Sheet; (2) a detailed CV, including a list of publications; (3) a statement (maximum of three pages) of research accomplishments and plans; and (4) a statement (maximum of two pages) of teaching philosophy and methodology. Applicants should attach evaluations of teaching from faculty members or students at their current institution, where applicable, and arrange for at least three letters of recommendation, including one that indicates effectiveness in and commitment to teaching. Applicants should ask their referees to send their letters directly to: search@math.nus.edu.sg; enquiries can also be sent to this e-mail address. The review process will begin on October 15, 2012, and will continue until the positions are filled.

### Alliance for Building Faculty Diversity in the Mathematical Sciences

The Alliance for Building Faculty Diversity in the Mathematical Sciences aims to increase the access of U.S. underrepresented minority groups to academic tenure-track positions. The Alliance invites applications for four NSF-funded postdoctoral fellowships, targeted at new or recent minority PhDs, beginning in the fall of 2013. Successful applicants will show strong research potential and be interested in continuing in a career at a research university. The postdoctoral fellowships are for three years. A typical three-year postdoctoral fellow will spend two years at one of the alliance universities and, if there is a suitable program, up to a year at a national institute. Each postdoc will be matched with a research mentor at his or her host university. The fellowship salary will be $60,000 per year, plus benefits; in addition, fellows will receive a travel and research allowance. To be eligible, applicants must be U.S. citizens or permanent residents who have obtained a PhD in mathematics within the last five years. Particular attention will be given to U.S. underrepresented minority candidates.

For more information about these fellowships, applicants should see http://www.math.ncsu.edu/alliance.

The Alliance is comprised of NSF Mathematical Sciences Institutes and seven major research universities that have a good record of mentoring underrepresented mathematics graduate students. The Alliance universities (listed alphabetically) are: Arizona State University, Howard University, Iowa State University, North Carolina State University, University of Arizona, University of Iowa, and University of Nebraska. The Alliance NSF Mathematical Sciences Institutes (listed alphabetically) are: American Institute of Mathematics (AIM), Institute for Computational and Experimental Research in Mathematics (ICERM), Institute for Mathematics and its Applications (IMA), Institute for Pure and Applied Mathematics (IPAM), Mathematical Biosciences Institute (MBI), Mathematical Sciences Research Institute (MSRI), National Institute for Mathematical and Biological Synthesis (NIMBioS), Park City Mathematics Institute (PCMI/IAS), and Statistical and Applied Mathematical Sciences Institute (SAMSI).

Applicants should send application materials, including a vita, at least three letters of recommendation, a description of current and planned research, and a short statement that addresses how these research plans fit with the priorities of this program, to: http://www.mathjobs.org/jobs/alliance. Applicants are encouraged to consult the Alliance website at http://www.math.ncsu.edu/alliance and provide a list of potential mentors and preferred institutions. Applicants can write to alliance@math.ncsu.edu with questions concerning these positions.

Applications received by December 15, 2012, will be given priority.

### Institute for Computational and Experimental Research in Mathematics at Brown University

*Postdoctoral Institute Fellowship Program*

ICERM invites applications for two one-year, non-renewable, salaried postdoctoral institute fellowships, to commence in September 2013. These positions are intended for mathematical scientists at an early-career stage who would like to participate in one or both of the semester programs that run at ICERM in 2013–2014. ICERM will match postdoctoral institute fellows with faculty mentors for the entire year. These programs are: Low-dimensional Topology, Geometry, and Dynamics (Fall 2013, http://icerm.brown.edu/sp-f13/) and Network Science and Graph Algorithms (Spring 2014, http://icerm.brown.edu/sp-s14/). Pref-erence will be given to applicants with a PhD awarded in 2010 or later.

All application materials must be submitted online at http://www.mathjobs.org.

Brown University is an affirmative action/equal opportunity employer and encourages applications from women and minorities.

### Institute for Computational and Experimental Research in Mathematics at Brown University

*Postdoctoral Fellowship Program*

ICERM invites applications for eight one-semester, non-renewable postdoctoral fellowships (with stipends), to commence in September 2013 or January 2014. These positions are intended for mathematical scientists at an early-career stage who would like to participate in one semester-long program at ICERM in the fall of 2013 or spring of 2014. These programs are: Low-dimensional Topology, Geometry, and Dynamics (Fall 2013, http://icerm.brown.edu/sp-f13/) and Network Science and Graph Algorithms (Spring 2014, http://icerm.brown.edu/sp-s14/). Preference will be given to applicants with a PhD awarded in 2010 or later.

All application materials must be submitted online at http://www.mathjobs.org.

Brown University is an affirmative action/equal opportunity employer and encourages applications from women and minorities.

### Brown University

*Division of Applied Mathematics*

The Division of Applied Mathematics at Brown University invites applications for two Research Training Group postdoctoral fellowships. The area of emphasis is dynamical systems, differential equations, probability, or stochastic processes.

For a full posting, applicants should see the division's website: http://www.dam.brown.edu.

### Dartmouth College

*Department of Mathematics*

The Department of Mathematics anticipates a tenure-track opening, with initial appointment at the assistant professor level in the 2013–14 academic year. The successful applicant will have a research profile with a concentration in computational or applied mathematics.

Applicants should apply online at http://www.mathjobs.org, Position ID: APACM #3874. Applications received by December 15, 2012, will receive first consideration. For more information about this position, applicants should visit the department's website: http://www.math.dartmouth.edu/activities/recruiting/.

Dartmouth is committed to diversity and encourages applications from women and minorities.

### Dartmouth College

*Department of Mathematics*

The Department of Mathematics anticipates a senior opening, with initial appointment in the 2013–14 academic year. The successful applicant will have a research profile with a concentration in computational or applied mathematics, will be appointed at the level of full professor, and is expected to have an overall record of achievement and leadership consonant with such an appointment.

Applicants should apply online at http://www.mathjobs.org, Position ID: PACM #3873. Applications received by December 15, 2012, will receive first consideration. For more information about this position, applicants should visit the department's website: http://www.math.dartmouth.edu/activities/recruiting/.

Dartmouth is committed to diversity and encourages applications from women and minorities.

### Dartmouth College

*Department of Mathematics*

The Department of Mathematics anticipates a tenure-track opening for a mathematician working in either topology or number theory, with initial appointment in the 2013–14 academic year. The appointment is for candidates at any rank.

Applicants should apply online at: http://www.mathjobs.org, Position ID: TTPTNT #3875. Applications received by December 15, 2012, will receive first consideration. For more information about this position, applicants should visit the department's website: http://www.math.dartmouth.edu/activities/recruiting/.

Dartmouth is committed to diversity and encourages applications from women and minorities.

### Portland State University

*Fariborz Maseeh Department of Mathematics and Statistics*

The Fariborz Maseeh Department of Mathematics and Statistics invites applications for two Maseeh Professorships in Mathematical Sciences, to begin in the fall of 2013. The intent is to fill these faculty positions at the associate professor level, with tenure or on the tenure track; however, exceptional candidates at all levels will be seriously considered. The positions are part of a broad university initiative to develop a world-class program in computational mathematics and statistics at Portland State University. The initiative is supported by a recent $3.9 million gift from the Massiah Foundation. The gift endows three faculty positions in computational mathematics and statistics: the Maseeh Distinguished Chair in Mathematical Sciences and two Maseeh Professorships in Mathematical Sciences; it also provides support for graduate research fellowships and a colloquium and lecture series. The current search is a continuation of this initiative after the successful hiring of the Maseeh Chair in Mathematical Sciences. The new faculty members are expected to participate in the further development of a strong and highly visible research and educational program in the area of computational mathematics and statistics. The department is looking for exceptional applicants who have an outstanding record of research, external funding, and a commitment to excellence in teaching. The department is particularly interested in mathematicians and statisticians who can demonstrate the willingness and ability to expand the multidisciplinary outreach of the department into such areas as health sciences, engineering and computer science, or finance and business. Successful candidates will be expected to teach graduate and undergraduate courses, actively participate in supervising graduate students, and conduct research. In particular, it is expected that the new hires will actively contribute to the department's PhD program in mathematical sciences (http://www.pdx.edu/math/) by offering new courses and attracting outstanding students.

Candidates will be expected to create an environment that acknowledges, encourages, and celebrates differences and to function and communicate effectively and respectfully within the context of varying beliefs, behaviors, and cultural backgrounds. Candidates will also be expected to seek opportunities to gain experience working and collaborating in diverse, multicultural, and inclusive settings, with a willingness to change for continual improvement and to adhere to all of PSU's policies, including the policies on prohibited discrimination and harassment and the professional standards of conduct. Candidates should have a PhD degree (preferably in mathematical sciences or statistics). Commitment to teaching and the ability to work within a diverse research group are expected.

Portland is consistently ranked as one of the world's most livable cities, and Portland State University has established a record of excellence in research, teaching, community outreach, and sustainability. Applicants should see http://www.pdx.edu for more details.

Applicants should send a current CV, a statement of interest that contains a discussion of what he or she can bring to the position, a research agenda, a description of outreach and teaching philosophies, and at least three letters of recommendation. Applicants should address all materials to the Maseeh Professor Search Committee and send (in PDF format) to: maseeh-search@pdx.edu. Consideration of applications will begin December 1, 2012, and will continue until the positions are filled.

Portland State University is an affirmative action, equal opportunity institution and welcomes applications from diverse candidates and candidates who support diversity.

### University of Nebraska–Lincoln

*Department of Mathematics*

The Department of Mathematics at the University of Nebraska–Lincoln invites applications for one tenure-track assistant professor position in scientific computing/computational mathematics, to begin in August 2013. The successful candidate will have a PhD in mathematics or in a field with strong interdisciplinary ties to mathematics and a demonstrated potential to conduct a research program and teach mathematics at a research university. Preference will be given to applicants who: (1) have a documented research background in some area of computational mathematics, including but not limited to scientific computing and numerical analysis; (2) have the potential to interact with and strengthen existing research groups in the department of mathematics; and (3) have the potential to strengthen cross-disciplinary ties with other departments by connecting mathematical research and computational capability to applications. Applicants at an entry level as well as those with prior postdoctoral experience are encouraged to apply.

For more information on how to apply, applicants should go to: http://www.math.unl.edu/department/jobs/. The review of applications will begin November 30, 2012, and will continue until a suitable candidate is found.

The University of Nebraska has an active National Science Foundation ADVANCE gender equity program, and is committed to a pluralistic campus community through affirmative action, equal opportunity, work–life balance, and dual careers.

### University of Pennsylvania

*School of Arts and Sciences*

The School of Arts and Sciences at the University of Pennsylvania invites applications for a tenure-track assistant professor appointment in evolution, broadly interpreted. The school is interested in exceptional scientists and mathematicians who have well-developed research programs employing mathematical or computational techniques to study the evolution of dynamical processes far from equilibrium in the context of any of the following fields: biology, chemistry, materials from the molecular to the systems scale, language, geology, psychology, or the environment. The successful candidate's primary appointment will be in a single department in the natural sciences: Biology, Chemistry, Earth and Environmental Science, Linguistics, Mathematics, Physics, Astronomy, or Psychology. Secondary apointments in other departments can be arranged, as appropriate. This appointment will be the first in a cluster of appointments across the natural sciences in various aspects of evolution; the successful candidate should, therefore, have a strong interest in building such a program and in interacting with researchers from other disciplines whose research lies within the overarching theme of evolution. The successful candidate will teach courses in his or her home department and will participate in the development of curriculum pertinent to the theme of the cluster.

Applications, which should include a curriculum vitae, a research statement that includes an applicant's perspective on how she or he fits into one of the core departments, links to no more than three journal publications, and the contact information for three individuals who will be contacted by the university with instructions on how to submit a letter of recommendation, should be submitted online at: https://facultysearches.provost.upenn.edu/applicants/Central?quickFind=51089. The review of applications will begin November 16, 2012, and will continue until the position is filled.

The University of Pennsylvania is an affirmative action/equal opportunity employer and is strongly committed to establishing a diverse faculty (http://www.upenn.edu/almanac/volumes/v58/n02/diversityplan.html).

### Georgia Institute of Technology

*School of Mathematics*

The School of Mathematics is accepting applications for faculty positions at all ranks and in all areas of pure and applied mathematics and statistics. Applications from highly qualified candidates, especially those from groups under-represented in the mathematical sciences, are particularly encouraged.

For more details and application instructions, applicants should see: http://www.math.gatech.edu/resources/employment.

### Statistical and Applied Mathematical Sciences Institute

*Postdoctoral Fellowships for 2013–14*

Postdoctoral fellowships (up to 6) are available at the Statistical and Applied Mathematical Sciences Institute for either of the two SAMSI Research Programs for 2013–14: Computational Methods in the Social Sciences and Low-Dimensional Structure in High-Dimensional Systems. Appointments will begin in August 2013 and will typically be for two years. Appointments are made jointly between SAMSI and one of its partner universities, where teaching is a possibility. Extremely competitive salaries, travel stipends, and health insurance will be offered.

Further information can be found at http://www.samsi.info.

Applicants should go to: http://mathjobs.org, SAMSIPD2013 Job #3759 to apply.

*See* **Opportunities** *on page 11*

# Opportunities

*continued from page 10*

### North Carolina State University

*Chancellor's Faculty Excellence Program*

As one of the leading land-grant institutions in the nation, North Carolina State University is proud to announce its Chancellor's Faculty Excellence Program; a cluster-hire program that marks the first major initiative of the university's 2011–2020 strategic plan, "The Pathway to the Future." Starting in 2012, NC State will hire 38 faculty in 12 research areas or "clusters," to promote interdisciplinary scholarship and the development of innovative curricula in emerging areas of strategic strength; prospective applicants should see: http://www.ncsu.edu/workthatmatters.

The research cluster in Personalized Medicine (http://www.ncsu.edu/projects/personalmed) invites applications for a position in the Department of Mathematics. The Personalized Medicine Cluster is a collaboration of the Department of Mathematics, the Edward P. Fitts Department of Industrial and Systems Engineering, and the Department of Statistics, in which each department will recruit relevant faculty.

To fill its commitment to the Personalized Medicine Cluster, the department is seeking qualified applicants for a full-time faculty position, starting as early as August 2013. Strong preference will be given to candidates with a proven record of research achievements and a record of research support in related areas of interest in the cluster. A record of contributions in related disciplines as applied to personalized medicine, mathematical modeling, medical decision making, and/or health care systems analysis is essential. Applicants with strong methodological research interests are particularly encouraged to apply. The successful candidate will be expected to carry out innovative research in mathematical modeling and health systems analysis within the Personalized Medicine Cluster and to pursue relevant research funding. In addition, the candidate is expected to be active in the PhD program and to teach at the graduate and undergraduate levels.

The North Carolina Research Triangle, home of NC State, has a vast health and medical care environment. The Department of Mathematics has cutting-edge research programs in both pure and applied mathematics. Many members of the department participate in interdisciplinary programs and research groups on campus and in the broader scientific community. More than ten faculty members have been elected as Fellows by professional societies (AAAS, IoP, ACM, ASA, IEEE, and SIAM) in recent years. For the last ten years the department has ranked in the top five nationally for federally financed R&D expenditures in the mathematical sciences. The department has been recognized nationally for its excellence in graduate and undergraduate education with two successive awards: the 2010 American Mathematical Society Award for an Exemplary Program or Achievement in a Mathematics Department and the 2011 American Mathematical Society Award for Mathematics Programs that Make a Difference. The latter award cited the department for distinction in its extraordinary record in serving students who have traditionally been underrepresented in mathematics, especially African-Americans. The department is housed in the new state-of-the-art SAS Hall, and it is one of the few mathematics departments in the world with a physical/biological laboratory where students can conduct laboratory experiments for data collection and analysis.

Applicants should submit application materials to: http://www.mathjobs.org/jobs/ncsu. These materials should include: a cover letter; a complete curriculum vitae that details educational background, research and professional experience, teaching experience, and a list of publications; and the names of three references who are familiar with their work. A one-page description of past, current, and future research activities and interests should also be submitted. The review of applications will begin immediately; applications will be accepted until suitable candidates are found. For consideration for this position, applicants should also go to http://jobs.ncsu.edu/postings/12683 and complete a Faculty Profile for this position. Applicants can send questions concerning this position to: math-jobs@math.ncsu.edu with.

Individuals with disabilities desiring accommodations in the application process should contact Frankie Stephenson, executive assistant, at (919) 513–2294; fax: (919) 515–0657; frankie_stephenson@ncsu.edu.

NCSU is an affirmative action and equal opportunity employer. All qualified applicants will receive consideration for employment without regard to race, color, national origin, religion, sex, age, veteran status, or disability. In addition, NC State University welcomes all persons without regard to sexual orientation. Applications from women, minorities, and persons with disabilities are encouraged. The College of Physical and Mathematical Sciences welcomes the opportunity to work with candidates to identify suitable employment opportunities for spouses or partners.

### Rutgers University–New Brunswick

*Department of Mathematics*

The Department of Mathematics at Rutgers University–New Brunswick invites applications for the following positions, anticipated to be available in September 2013.

*Tenure-Track Assistant Professorships:* The department expects two or more openings, subject to the availability of funding, at the level of tenure-track assistant professor. In exceptional cases, there is the possibility of appointment at a higher level. Candidates must have a PhD, show a strong record of research accomplishments in pure or applied mathematics, and demonstrate concern for teaching. The department has hiring priorities in algebra (including algebraic geometry/algebraic topology), probability/stochastic analysis, and numerical analysis/scientific computation; however, outstanding candidates in any field of pure or applied mathematics will be considered. The normal annual teaching load for research-active faculty is 2–1, that is, two courses for one semester, plus one course for the other semester. The review of applications begins immediately.

*Hill Assistant Professorships and Non-Tenure-Track Assistant Professorships:* These are both three-year nonrenewable positions. The department expects several open positions of these types, subject to availability of funding. Hill assistant professorships carry a reduced teaching load of 2–1 for research; candidates for it should have received a PhD, show outstanding promise of research ability in pure or applied mathematics, and have concern for teaching. The non-tenure-track assistant professorships carries a teaching load of 2–2; candidates for it should have received a PhD, show evidence of superior teaching accomplishments, and demonstrate promise of research ability. The review of applications begins January 1, 2013.

Applicants for the above positions should submit a curriculum vitae (including a list of publications) and arrange for four letters of reference to be submitted, one of which evaluates teaching. Applicants should first go to the website: https://www.mathjobs.org/jobs and fill out the AMS Cover Sheet electronically. It is essential to fill out the cover sheet completely, including naming the positions being applied for (TTAP, HILL, NTTAP, respectively), giving the AMS Subject Classification numbers of areas of specialization, and answering the question about how materials are being submitted. The strongly preferred way to submit a CV, references, and any other application materials is online at: https://www.mathjobs.org/jobs. If necessary, however, application materials can instead be mailed to: Search Committee, Department of Mathematics, Hill Center, Rutgers University, 110 Frelinghuysen Road, Piscataway, NJ 08854–8019. The review of applications will begin on the dates indicated above, and will continue until openings are filled. Updates on these positions will appear on the Rutgers Department of Mathematics webpage at http://www.math.rutgers.edu.

Rutgers is an affirmative action/equal opportunity employer and encourages applications from women and minority-group members.

### Institute for Advanced Study

*School of Mathematics*

The School of Mathematics has a limited number of memberships with financial support for research in mathematics and computer science at the institute during the 2013–14 academic year. The school frequently sponsors special programs; however, these programs comprise no more than one-third of the membership so that a wide range of mathematics can be supported each year. "Non-equilibrium Dynamics and Random Matrices" will be the topic of the special program in 2013–14. Horng-Tzer Yau of Harvard and Thomas Spencer of the institute will lead the program. Juerg Froehlich of ETH and Herbert Spohn of Zentrum Mathematik will be among the senior participants. More information about the special program for the year can be found on the school's homepage (http://www.math.ias.edu/).

Several years ago the School of Mathematics established the von Neumann Fellowships. Up to eight of these fellowships will be available for each academic year. To be eligible for a von Neumann Fellowship, applicants should be at least five, but no more than 15, years after receipt of a PhD.

Veblen Research Instructorships are three-year position that were established in partnership with the Department of Mathematics at Princeton University in 1998. Three-year instructorships will be offered each year to candidates in pure and applied mathematics who have received a PhD within the last three years. The first and third years of an instructorship are usually spent at Princeton University and will carry regular teaching responsibilities. The second year is spent at the institute and dedicated to independent research of the instructor's choice.

Candidates must have given evidence of ability in research comparable with at least that expected for a PhD degree. Postdoctoral computer science and discrete mathematics applicants may be interested in applying for a joint (two-year) position with one of the following: Department of Computer Science at Princeton University, http://www.cs.princeton.edu; DIMACS at Rutgers, The State University of New Jersey, http://www.dimacs.rutgers.edu; or the Intractability Center, http://intractability.princeton.edu. For a joint appointment, applicants should apply to the School of Mathematics, as well as to one of the listed departments or centers, noting their interest in a joint appointment.

Applicants can request application materials from: Applications, School of Mathematics, Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540; applications@math.ias.edu. Applications can be made online at: https://applications.ias.edu. The deadline for all applications is December 1, 2012.

The Institute for Advanced Study is committed to diversity and strongly encourages applications from women and minorities.

### Pomona College

*Department of Mathematics*

Pomona College, in Claremont, California, seeks applicants for a tenure-track position in the Department of Mathematics, to begin in the fall semester of 2013–14. The department seeks candidates in applied mathematics, and the position is targeted at the rank of assistant professor. The department is looking for candidates who have demonstrated excellence in research and teaching, and who are interested in mentoring students and in directing students in independent work. The strongest candidates will have postdoctoral experience, have a strong research agenda, and show significant progress in their research. It is a priority of Pomona College and its Department of Mathematics to have faculty who have experience working with students from diverse backgrounds and a demonstrated commitment to improving access to and success in higher education for underrepresented students.

Pomona College is a highly selective liberal arts college with 1500 students (http://www.pomona.edu), located at the eastern edge of Los Angeles. Pomona is the founding member of the Claremont Colleges, a consortium of seven institutions with over 40 active mathematicians. The teaching load at Pomona College is 2–2.

Pomona College strongly prefers online applications submitted at: MathJobs.org (http://www.mathjobs.org). Applicants can also send applications via electronic mail to: mathsrch@pomona.edu or to: Search Committee, Department of Mathematics, Pomona College, 610 North College Avenue, Claremont, CA 91711–6348. A complete application will include a letter of application, curriculum vitae, graduate transcripts, at least three letters of recommendation (at least one of which evaluates teaching), a description (for the non-specialist) of research accomplishments and plans, and a statement of teaching philosophy. Applications completed by December 1, 2012, will receive full consideration.

Pomona College is an equal opportunity employer and especially invites applications from women and members of underrepresented groups.

*Uncertainty Quantification 2012*

# The Impact of $CO_2$ Sequestration on Shallow Groundwater

*By Hari Viswanathan, Zhenxue Dai, Christina Lopano, Elizabeth Keating, J. Alexandra Hakala, George D. Guthrie, and Rajesh Pawar*

Numerous comprehensive analyses have concluded that recent increases in average global temperature are likely a result of increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere [2]. Storing $CO_2$ in geologic formations is one approach for mitigating excess anthropogenic $CO_2$ from centralized sources, such as coal-fired power plants [1]. One concern about geologic sequestration is the possibility that $CO_2$ will leak from the sequestration reservoir, affecting overlying aquifers utilized for drinking water. For this reason, groundwater protection is of vital importance to carbon capture and storage (CCS) projects.

Migration of $CO_2$ from deep storage formations into shallow drinking water aquifers is one possible system failure of geologic $CO_2$ sequestration. Although $CO_2$ is not toxic in low concentrations, increased concentrations in the shallow subsurface could cause a decrease in pH levels. This, in turn, could result in the mobilization of trace metals from aquifer minerals and subsequently increasing levels of naturally occurring contaminants, such as arsenic, lead, and uranium [4]. Subsurface injection of large amounts of $CO_2$ could also displace large amounts of brine, which might already contain elevated concentrations of toxic metals [3]. Trace metal concentrations could exceed those specified in the National Primary Drinking Water Standards of the Environmental Protection Agency. Risk assessment for CCS requires quantitative information about the potential impact of $CO_2$ and brine leakage on overlying aquifers; this impact, however, is largely unknown.

In the study described here, a $CO_2$ sequestration site in Chimayo, New Mexico, was examined for site-specific impacts of shallow groundwater interacting with $CO_2$ from the deep storage formations. The work focuses on As, which is regulated by EPA under the Safe Drinking Water Act and which is present in some wells in the Chimayo area at concentrations above those given in the Maximum Contaminant Level (MCL). Statistical analysis of existing Chimayo groundwater data indicates that the presence of As is strongly correlated with that of trace metals U and Pb, indicating that the source of all three may be the same deep subsurface water. Batch experiments and material characterizations, as by X-ray diffraction, scanning electron microscopy, and synchrotron micro X-ray fluorescence (μ-XRF), were used to identify As association with iron-rich phases, such as clays or oxides, in the Chimayo sediments as the major factor controlling the fate of As in the subsurface. Figure 1 shows μ-XRF results in which trace metals, including U and As, were correlated with Fe in most of the shallow Chimayo sediments.

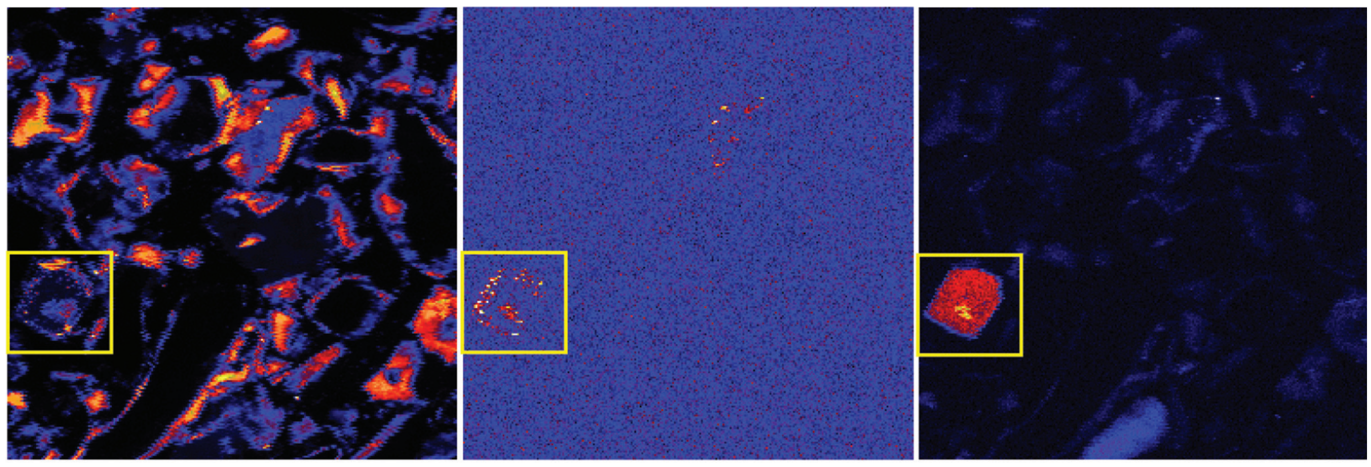


**Figure 1.** *Selected element distribution maps (iron, left; arsenic, center; uranium, right) for sample Roadcut Lithosome A illustrating that As and U trend with Fe (since they appear to be associated with iron-bearing minerals in the clay) in this portion of the Chimayo sediment. A yellow box has been drawn around an area of interest in these false-color maps (in which warmer colors correspond to higher concentrations of each element). Maps were collected at 19 keV with a step size of 2 μm. Each map area is 500 μm x 500 μm.*

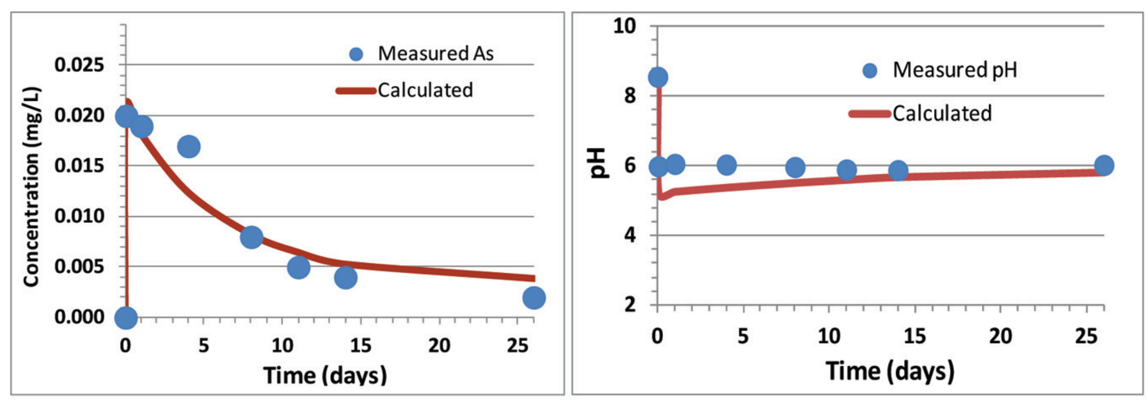



**Figure 2.** *Inverse modeling results of the batch experiment with sample Roadcut Lithosome B.*

Batch laboratory experiments with Chimayo sediments and groundwater show that pH decreases as $CO_2$ is introduced into the system and buffered by calcite (Figure 2). The introduction of $CO_2$ causes an immediate increase in As concentration, which then decreases over time. A geochemical model developed to simulate these batch experiments successfully predicted the drop in pH once $CO_2$ was introduced into the experiment. In the model, adsorption of As to illite, kaolinite, and smectite through surface complexation proved to be the key reactions in simulating the drop in As concentration as a function of time in the batch experiments. Based on analysis of the model, kaolinite precipitation is anticipated to occur during the experiment; this allows for the formation of additional adsorption sites with time, resulting in the slow decrease in As concentration (Figure 2). This mechanism can be viewed as trace metal "scavenging" resulting from adsorption-caused secondary mineral precipitation.

In summary, the data show that arsenic upwells from the deep aquifer with $CO_2$ and then (under the oxidizing conditions of the aquifer) adsorbs to iron-bearing minerals (e.g., clays) at the Chimayo site, retarding transport of As in the shallow groundwater. Other trace elements, such as U or Pb, may be controlled by completely different processes. The risk assessment of each trace element of concern will thus require fairly complex analysis to determine the key parameters affecting its fate at the site. A combination of laboratory and field observations will have to be joined with geochemical modeling to identify the key parameters of interest. Unlike major ions, trace elements exist at concentrations so low that processes like scavenging by secondary minerals can greatly affect their fate and transport in the subsurface.

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## NSF Postdoctoral Research Fellowships in the Math Sciences

The National Science Foundation has released an updated solicitation for its Mathematical Sciences Postdoctoral Research Fellowships (MSPRF) program.

Details of the solicitation can be found at http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5301&org=DMS&from=home.

The purpose of the program is to support future leaders in mathematics and statistics by facilitating their participation in postdoctoral research environments that will have maximal impact on their future scientific development. Two options are available for awardees: research fellowships and research instructorships. Awards will support research in areas of mathematics and statistics, including applications to other disciplines; 30 or more awards may be available.

Eligible individuals are encouraged to apply. The deadline for full proposals is October 17, 2012, and the third Wednesday in October annually thereafter.