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New Radar Interferometric Time Series Analysis Toolbox Released

Interferometric synthetic aperture radar (InSAR) has become an important geodetic tool for measuring deformation of Earth's surface due to various geophysical phenomena, including slip on earthquake faults, subsurface migration of magma, slow-moving landslides, movement of shallow crustal fluids (e.g., water and oil), and glacier flow. Airborne and spaceborne synthetic aperture radar (SAR) instruments transmit microwaves toward Earth's surface and detect the returning reflected waves. The phase of the returned wave depends on the distance between the satellite and the surface, but it is also altered by atmospheric and other effects. InSAR provides measurements of surface deformation by combining amplitude and phase information from two SAR images of the same location taken at different times to create an interferogram. Several existing open-source analysis tools [*Rosen et al.,* 2004; *Rosen et al.,* 2011; *Kampes et al.,* 2003; *Sandwell et al.,* 2011] enable scientists to exploit observations from radar satellites acquired at two different epochs to produce a surface displacement map.

The past decade has seen the development and verification of numerous algorithms that combine phase information from multiple radar interferograms to produce internally consistent time series of land surface deformation [e.g., *Ferretti et al.,* 2001; *Berardino et al.,* 2002; *López-Quiroz et al.,* 2009; *Hetland et al.,* 2012]. Combining multiple interferograms allows detection and quantification of both secular and transient displacements. These methods also help to mitigate the effects of change in scatterer properties and phase delay introduced by the atmosphere between SAR acquisitions, resulting in measurements of surface deformation with subcentimeter accuracy.

A new repeat interferometry time series analysis toolbox, Generic InSAR Analysis Toolbox (GIAnT) 1.0, was released in December 2012. GIAnT 1.0 is a user-friendly, open-source, documented framework for rapid generation of time series of surface displacement using InSAR data. GIAnT 1.0 includes numerous published time series techniques, in some cases with improvements, allowing geophysicists to efficiently analyze the large and ever-increasing archive of SAR data acquired over the past 2 decades as well as allowing scientists to test the sensitivity of results to different analysis approaches.

A typical processing chain for generating InSAR time series products consists of (1) assembling a stack of phase-unwrapped interferograms; (2) optionally applying corrections, also known as atmospheric phase screens (APS), to mitigate the differential path delay effects due to the stratified atmosphere; (3) optionally estimating residual long-wavelength errors (e.g., due to imprecise orbits) empirically or through the use of other prior information such as surface displacement fields provided by dense GPS networks; and (4) estimating time series of line-of-sight displacements and residual turbulent APS using one of several time series analysis methods.

GIAnT 1.0 addresses steps 2 to 4 in the processing chain and includes implementations of various time series analysis methods for step 4, while allowing users to implement step 1 using their favorite processing tools [e.g., *Rosen et al.,* 2004; *Rosen et al.,* 2011; *Kampes et al.,* 2003; *Doin et al.,* 2011; *Sandwell et al.*, 2011].

GIAnT 1.0 enables mitigation of the effects of signal delays due to the stratified troposphere in each interferogram using either an empirical approach or estimates from global atmospheric models. Empirical estimates are based on the evaluation of the dependency of interferometric phase on topography and the stratification of the lower atmosphere [e.g., *Lin et al.,* 2010]. Alternatively, global atmospheric models provide daily estimates of atmospheric variables, including temperature, pressure, and water vapor partial pressure, which in turn can be used to derive the phase delay related to spatial and temporal variations in the refractivity index of air [e.g., *Jolivet et al.,* 2011]. GIAnT 1.0 implements atmospheric corrections as a stand-alone Python module named PyAPS (Python-based Atmospheric Phase Screen) and includes support for automatic download of meteorological data sets (European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA) Interim, North American Regional Reanalysis (NARR), and Modern-Era Retrospective Analysis for Research and Applications (MERRA)). GIAnT 1.0 can optionally correct each interferogram from residual orbit errors by removing a simple parametric function determined empirically or using GPS-derived time series of displacements or velocities. All corrections are consistently applied within a given interferometric data set and generally increase the signal-to-noise ratio of inferred time series.

GIAnT 1.0 implements four existing InSAR time series approaches, and new ones are easily added to the toolbox. These approaches are the Small Baseline Subset (SBAS) [*Berardino et al.,* 2002], the New-SBAS (NSBAS) [*López-Quiroz et al.,* 2009], a temporally parameterized inversion (Time-Fun), and the Multiscale Interferometric Time-Series (MInTS) [*Hetland et al.,* 2012] algorithms. In SBAS and NSBAS algorithms the temporal evolution of the phase is derived assuming each interferogram is the linear combination of each SAR acquisition's

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Beyond Point Measurements: Sea Ice Floes Characterized in 3-D

A new methodology for coincident floe-scale measurements of the surface elevation, snow depth, and ice draft (the thickness below the water line) of Antarctic sea ice has been demonstrated during two recent research voyages: the Australian-led Sea Ice Physics and Ecosystem Experiment II (SIPEX II) to East Antarctica in September–November 2012 and the United Kingdom–led Ice Mass Balance in the Bellingshausen Sea (ICEBell) voyage to the Weddell and Bellingshausen Seas in November 2010 (Figure 1a).

This methodology centered on the use of a SeaBED-class autonomous underwater vehicle (AUV; Figure 1b) from the Woods Hole Oceanographic Institution (WHOI), equipped with a swath multibeam sonar to obtain the first high-resolution geolocated three-dimensional (3-D) maps of Antarctic sea ice draft. Coincident, high-resolution 3-D measurements of snow and ice surface morphology were obtained using terrestrial laser scanners (TLS) and an automated snow probe (Figure 1d). Together, these data provide a complete and coincident characterization of the floe's snow surface, ice surface, and ice bottom. Such data move beyond traditional point-based measurements, providing a wealth of additional information on the spatial variability of sea ice characteristics such as ridging, snow accumulation, and freeboard (the height of ice above the water line).

The Need for In Situ Floe-Scale Characterization

Traditionally, sea ice voyages have predominantly featured on-ice experiments (ice stations) collecting point measurements such as ice core sampling or drill lines of about 100 or so drill holes. The limited scope of these measurements has made comparison with methods that can monitor large spatial extent—such as airborne or satellite surveys—difficult. Moreover, logistical and technical challenges have made direct measurement of under-ice characteristics and processes particularly difficult to obtain except at a few isolated locations. Detailed observations of spatial variations in ice thickness, an understanding of the processes that cause and are affected by this variability, and the influence of this variability on sea ice biogeochemistry and ecology remain particularly elusive.

Simultaneous and coincident mapping of both the upper and lower surfaces of individual floes is needed to capture the morphological relationships between the ice and snow cover. To meet these needs, the new 3-D data sets will inform and provide spatial context to a variety of studies, including satellite and airborne efforts to remotely determine large-scale sea ice and snow thicknesses (e.g., NASA's Ice, Cloud, and land Elevation Satellite (ICESat) and IceBridge missions [*Koenig et al.*, 2010]), the effect of ice deformation on sea ice volume, and process-based biological and biogeochemical measurements and models.

Floe-scale surveys provide the richness of a complete spatial characterization of the sampled ice floe while at the same time offering versatility of integration with a wide variety of process studies. Such surveys can be scaled up to provide a direct comparison for airborne surveys, which bridge the gap between in situ and large-scale satellite estimates of sea ice thickness. In addition, floe-scale measurements can be downscaled to smaller scales, such as those necessary in biological studies of sea ice algal distribution.

Measuring the Underside of Ice

AUVs have recently opened the door to detailed measurements of the spatial

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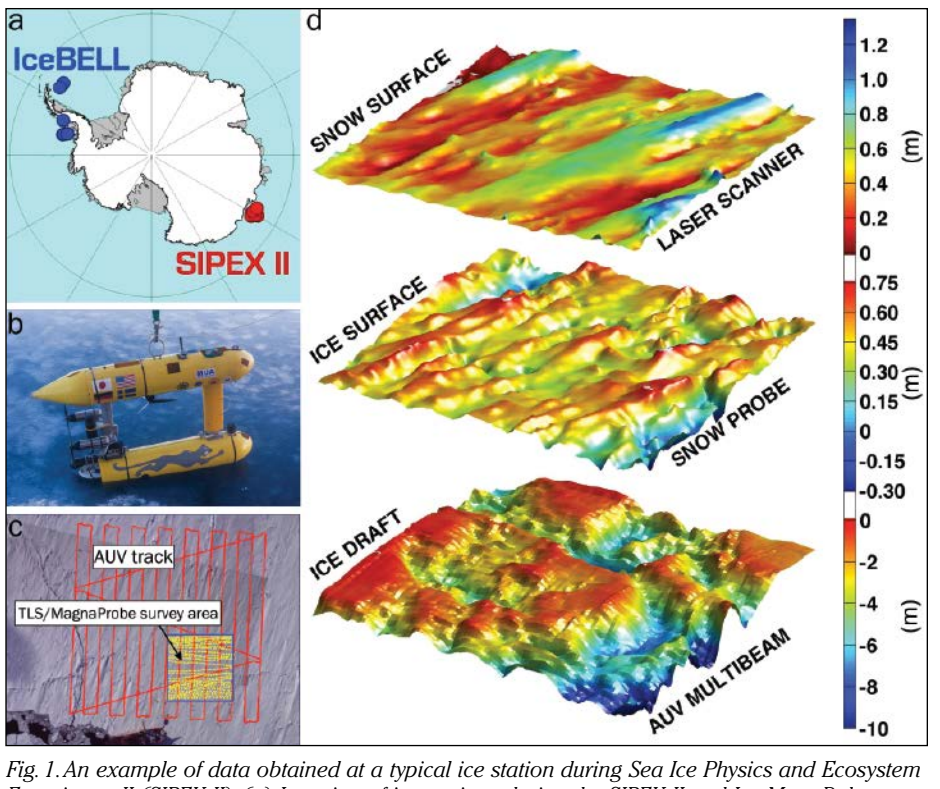

Fig. 1. An example of data obtained at a typical ice station during Sea Ice Physics and Ecosystem Experiment II (SIPEX II). (a) Location of ice stations during the SIPEX II and Ice Mass Balance in the Bellingshausen Sea (ICEBell) research voyages. (b) The Woods Hole Oceanographic Institution (WHOI) SeaBED-class autonomous underwater vehicle (AUV) Jaguar (~2 meters long) being deployed during SIPEX II. (c) Aerial photograph of an ice station from SIPEX II overlaid with AUV (300- × 300-meter, red track) and surface measurement (100- × 100-meter, yellow points and blue line) grids. (d) Corresponding ice floe maps that show, from top to bottom, snow surface (meters) from terrestrial laser scanners, with height relative to sea level; ice surface (meters) from MagnaProbe relative to sea level, corresponding to ice freeboard; and ice draft (meters) from AUV multibeam sonar relative to sea level, colocated using the GPS and total robotic station (TRS) reference grid described in the text. Note the varying vertical scale between surfaces.

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phase value. Additionally, the NSBAS method takes advantage of a user-defined functional form of the phase evolution to overcome the issue of missing links in the interferometric network due to temporal and spatial decorrelation. The MInTS approach allows the characterization of the temporal behavior of surface deformation using a dictionary of user-defined functions, including linear trends, seasonal oscillations, steps, exponential and logarithmic decays, and various splines [*Hetland et al.,* 2012]. MInTS also transforms InSAR observations into the spatial wavelet domain and allows for distinction between different spatial scales of deformation and atmospheric noise. Within GIAnT 1.0 the temporal inversion component of MInTS has also been adapted to the conventional nonwavelet approaches (TimeFun).

Each of these methods includes a data-driven bootstrapping approach to estimate uncertainties associated with time series products. While numerous variants of published time series algorithms exist, GIAnT provides several tools in a simple and efficient framework so that users can test a variety of techniques and customize their processing chain, specific to a given data set. Users are encouraged to make their modifications or even new algorithms available for inclusion in future distributions of GIAnT. The goal is to make GIAnT an open collaborative environment for InSAR time series analysis.

GIAnT 1.0 is primarily an ensemble of Python routines but includes an interface for some optimized C and Fortran 90 routines. GIAnT 1.0 relies extensively on numerical Python libraries to develop an object-oriented, flexible, and generalized framework for InSAR time series applications. The user manual describes available scripts and functions and includes detailed instructions for installing the set of prerequisite libraries using standard repository management tools on Linux and OS X platforms. The developers are heavy users of GIAnT for their own geophysical projects, and they will attempt to fix software bugs as they arise.

GIAnT 1.0 is available from http://earthdef.caltech.edu. The Web site includes details regarding access to the version-controlled software repository and a user discussion forum and wiki. Other related packages can also be obtained from the same Web site. While not designed to match the standards of a well-maintained commercial package, GIAnT 1.0 provides a set of tools to be used by researchers who need the flexibility and access to various stages of processing in InSAR time series applications. Future versions of GIAnT will include support for working directly with wrapped interferometric data, persistent scatterer algorithms, improved constrained and regularized solvers, automatic correction of elastic ocean tidal load response, and direct download of APS maps from third-party projects. An immediate gain from using GIAnT is the ability for able and willing users to easily share large interferometric data sets in a standard format and to compare the performance of various time series approaches on any data set in a common framework. The rich suite of library functions that is distributed with GIAnT 1.0 should also facilitate faster development and prototyping of new InSAR time series processing algorithms.

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References

Berardino, P., G. Fornaro, R. Lanari, and E. Sansosti (2002), A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms, *IEEE Trans. Geosci. Remote Sens., 40*(11), 2375–2383.

Doin, M. P., S. Guillaso, R. Jolivet, C. Lasserre, F. Lodge, G. Ducret, and R. Grandin (2011), Presentation of the small baseline NSBAS processing chain on a case example: The Etna deformation monitoring from 2003 to 2010 using Envisat data, paper SP-697 presented at FRINGE Symposium, Eur. Space Agency, Frascati, Italy.

Ferretti, A., C. Prati, and F. Rocca (2001), Permanent scatterers in SAR interferometry, *IEEE Trans. Geosci. Remote Sens., 39*(1), 8–20.

Hetland, E. A., P. Muse, M. Simons, Y. N. Lin, P. S. Agram, and C. J. DiCaprio (2012), Multiscale InSAR Time Series (MInTS) analysis of surface deformation, *J. Geophys. Res., 117,* B02404, doi:10.1029/2011JB008731.

Jolivet, R., R. Grandin, C. Lasserre, M. P. Doin, and G. Peltzer (2011), Systematic InSAR tropospheric phase delay corrections from global meteorological reanalysis data, *Geophys. Res. Lett., 38,* L17311, doi:10.1029/2011GL048757.

Kampes, B., R. Hanssen, and Z Perski (2003), Radar interferometry with public domain tools, paper presented at FRINGE Symposium, Eur. Space Agency, Frascati, Italy.

Lin, Y. N., M. Simons, E. A. Hetland, P. Muse, and C. DiCaprio (2010), A multiscale approach to estimating topographically correlated propagation delays in radar interferograms, *Geochem. Geophys. Geosyst., 11,* Q09002, doi:10.1029/2010GC003228.

López-Quiroz, P., M.-P. Doin, F. Tupin, P. Briole, and J.-M. Nicolas (2009), Time series analysis of Mexico City subsidence constrained by radar interferometry, *J. Appl. Geophys., 69,* 1–15, doi:10.1016/j.jappgeo.2009.02.006.

Rosen, P., S. Hensley, G. Peltzer, and M. Simons (2004), Updated repeat orbit interferometry package released, *Eos Trans. AGU, 85*(5), 47, doi:10.1029/2004EO050004.

Rosen, P., E. Gurrola, G. Sacco, and H. A. Zebker (2011), InSAR scientific computing environment—The home stretch, poster IN43B-1397 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13–17 Dec.

Sandwell, D., R. Mellors, X. Tong, M. Wei, and P. Wessel (2011), Open radar interferometry software for mapping surface deformation, *Eos Trans. AGU, 92*(28), 234, doi:10.1029/2011EO280002.

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Sea Ice Floes

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variability of sea ice draft using multibeam sonars [*Wadhams et al.*, 2006]. A vehicle with advanced navigational capability and easy deployment and recovery is essential when operating in a compact sea ice cover. The WHOI SeaBED-class AUV offers great flexibility in sensor integration, deployment, and operation. Its twin-hulled design and three-thruster layout provide a stable and highly maneuverable platform for deployment and recovery through small openings in the sea ice. An acoustic link between the AUV and the ship provides vehicle and mission progress information and the ability for operators to direct the vehicle to open water for recovery.

Operating at a depth of 20 to 30 meters and driving in a lawnmower pattern with overlapping swaths, a 245-kilohertz Imagenex multibeam sonar mounted on the AUV provided ice draft maps with a horizontal resolution better than 0.25 meter. This resolution enables the discrimination of individual ridge keels and rafted ice blocks in the resulting map. The AUV missions (up to 6 hours for a 400- × 400-meter grid) efficiently return preliminary maps of the underside of the ice floe that can inform other on-ice experiments conducted during the ice station.

Measuring the Ice and Snow Surface

Complete characterization of ice floe morphology required coincident spatial measurements of the surface topography and snow depth at a resolution and accuracy comparable to that of the AUV ice draft maps. High-precision snow surface topographic information was obtained using a portable TLS. By acquiring scans from several locations on the floe to eliminate scan shade behind ridges and other surface features, an integrated 3-D elevation model with tens of millions of data points for areas of tens to hundreds of meters can be achieved. This operation is efficient and cost-effective, achievable by a single operator in a few hours. The snow depth distribution was measured with a GPS snow probe (SnowHydro MagnaProbe) that automatically logs snow depth and its position. Although still a labor-intensive operation, between 1000 and 2000 snow depths were recorded at spatial resolutions of 1–3 meters in a few hours.

Combining Coincident Spatial Data Sets

The precise coregistration of temporally displaced surface and subsurface measurements is important to correct for ice floe drift and rotation during the surveys. An advantage of coincident measurements at ice stations (as opposed to long-range AUV or airborne surveys) is the relatively straightforward combination of GPS and total robotic station (TRS) measurements. At each ice station a floe-centric coordinate system was established using a TRS to obtain floe-local coordinates of AUV navigation transponders, laser scanner targets, and ice thickness drill holes (the latter providing sea level reference and coregistration "tie points" for the topographic data sets). Precise location of the AUV data (<1 meter accuracy) can be achieved through a combination of bottom tracking, acoustic location, matching of overlapping multibeam swaths, and identification of ice thickness tie points [*Roman and Singh*, 2011]. The snow probe sites were placed in floe-local coordinates using either the TRS or a roving dual-frequency GPS to achieve positioning accuracy of a few centimeters.

Looking Forward

This methodology has delivered the first-ever complete coincident whole-of-floe measurements of sea ice. Importantly, this was achieved at modest cost and with logistics typical of a standard sea ice voyage, allowing a variety of additional sea ice studies to be conducted in concert. Such an approach could become standard in future sea ice research voyages, with specific AUV capability being considered in the operational requirements of the next generation of polar icebreakers. The success of these floe-scale missions could pave the way for a new era of field experiments that could eventually explore ocean and sea ice processes and phenomena on scales up to the mesoscale (10–100 kilometers). This increase in scale is important for the goal of directly linking in situ data with satellite sensor footprints, sea ice, and coupled climate model grid cells and ecosystem studies.

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References

Koenig, L., S. Martin, M. Studinger, and J. Sonntag (2010), Polar airborne observations fill gap in satellite data, *Eos Trans. AGU, 91*(38), 333–334, doi:10.1029/2010EO380002.

Roman, C., and H. Singh (2011), Improved vehicle based multibeam bathymetry using sub-maps and SLAM, in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 3662–3669, IEEE Press, Piscataway, N. J., doi:10.1109/IROS.2005.1545340.

Wadhams, P., J. P. Wilkinson, and S. D. McPhail (2006), A new view of the underside of Arctic sea ice, *Geophys. Res. Lett., 33,* L04501, doi:10.1029/2005GL025131.

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NEWS

Native Communities in the Arctic Face Climate Change Impacts

Warming temperatures, sea ice loss, permafrost melting, and other impacts of climate change are adding to the stresses indigenous communities already face in several Arctic countries, prompting some communities to consider relocating to safer areas. Native communities in Alaska, Russia, and Scandinavia are among those dealing with climate change impacts, according to researchers at a forum entitled "Arctic Indigenous Peoples, Displacement, and Climate Change" held at the Brookings Institution in Washington, D. C. on 30 January.

In Alaska, dozens of native communities are threatened by flooding and erosion, and some have started the process of trying to relocate to other areas after typical disaster relief efforts such as building sea walls have failed to protect them, according to Robin Bronen, executive director of the Alaska Immigration Justice Project. Bronen, a human rights attorney, cited a U.S. Government Accountability Office (GAO) report from 2009, its most recent report on the topic, which noted that 31 communities are imminently threatened and 12 are hoping to relocate; an earlier 2003 GAO report noted that more than 180 communities were being affected by flooding and erosion at that time.

Bronen said the issue of relocation is complex, in part because of a history of some native communities' having been moved against their wishes. She said relocations should be decided by the affected communities and should be based in human rights principles.

In her presentation, Bronen focused on several communities, including Newtok, a village of about 350 people on the Ninglick River in western Alaska that has faced repeated extreme weather events including flooding and is currently in the process of relocating to a new nearby settlement called Mertarvik. Other communities actively looking for relocation sites include the Alaskan villages of Kivalina and Shishmaref, which also have recently been affected repeatedly by extreme weather events.

Bronen said that while a few communities are on the road to relocation, the barriers to relocation "are enormous." She said Congress should amend federal disaster relief legislation to allow communities to use existing funding mechanisms for relocation and that there should be an adaptive governance framework to evaluate when communities and governments could shift to relocation efforts after typical erosion and flood control measures have been tried and have failed to protect people in place.

"What happens in Alaska is relevant to coastal communities all over the United States," Bronen said at the forum. Later she told *Eos,* "Repairing and rebuilding communities and places where sea level rise is going to inundate them is not a good decision. We need government agencies to invest in studies now to figure out what sea level predictions are expected to occur. We need to be doing excellent monitoring of the environmental changes being caused by repeated weather events so that we can make better decisions about how to adapt."

At the forum, Susan Crate, associate professor of anthropology in the Department of Environmental Science and Policy at George Mason University, Fairfax, Va., focused on the Viliui Sakha native communities in the boreal forest in the Russian north. She said that although the communities are not yet in need of relocation due to the impacts of climate change, efforts to maintain their way of life may be affected if current trends of permafrost melting and increasing precipitation continue. She cited the increasing amount of water on their land caused by a combination of changing precipitation patterns and the warming and degradation of permafrost.

Crate said that, to date, other changes have been more dramatic in affecting the villagers' way of life and their mobility, which historically had provided a way for them to flexibly adapt to annual and seasonal weather patterns. She said that previous Russian colonization and Soviet era collectivization policies are among those changes that have significantly affected the Viliui Sakha. "The impacts of those changes have to date had a far greater effect on contemporary livelihoods than climate change has so far," Crate said.

"The Viliui Sakha do not have to relocate yet due to these [environmental] changes, but their refined adaptation to the extreme climate is being affected." She cited warmer weather, which now delays the communities' annual animal slaughter by about a month and also prevents their wild berries from freezing and being used as food during the winter. Crate added that there is a need for appropriate relocation plans and an early warning system to better allow communities to evacuate before any potential catastrophic events.

Marius Warg Naess and Ilan Kelman, senior research fellows at the Center for International Climate and Environmental Research in Oslo, Norway, described challenges facing the Saami, a group of people living in Scandinavia above the Arctic Circle. Naess and Kelman said that climate change is one of a number of challenges the Saami face. The researchers noted that for those Saami who still practice reindeer herding, artificial boundaries such as private property can inhibit mobility and herders' traditional ability to respond to environmental variability.

They said that climate change itself likely would not directly cause much community displacement. However, they noted that a significant impact from climate change would be the migration into the Arctic of non-Saami who are involved with resource extraction or other activities. Involving the Saami as full participants in decisions affecting them and in addressing concerns related to temporary migrants could help minimize the impacts of climate change on the Saami, they noted.

—Randy Showstack, Staff Writer

FORUM

Forgotten Merits of the Analytic Viewpoint

The early twentieth-century German scientist Ludwig Prandtl solved a problem that at first sight seems impossible to solve without a computer: What are the shear forces exerted on the wing of an airplane during flight? The governing equations for this problem are the Navier-Stokes equations, nonlinear partial differential equations for which it is not possible to obtain a general analytic solution. Prandtl solved the problem through strong physical insight, by realizing that frictional effects of the air on the wing are localized within a thin boundary layer, with airflow far from the wing behaving as if it were an ideal fluid, that is, one of zero viscosity. By separating the solution domain into a boundary layer and a far field, he was able to simplify the equations that describe the global domain enough to solve them for the case he needed. Even today, many difficult problems can be usefully approached this way, such as problems of buoyant convection adjacent to vertical walls. For a good review of these and other successes of boundary layer theory, see *Bejan* [2004].

Earlier (circa 1889), the Austrian scientist Josef Stefan faced a similarly intractable problem: If ground that is saturated with liquid water is subjected to a constant freezing temperature at the surface, what is the speed of the resulting downward migrating ice-liquid interface? Again, the physics is governed by a nonlinear partial differential equation. However, Stefan realized that on each side of the moving ice-liquid interface the relevant equations are linear. By solving the easier problems on the separate sides of the interface and pasting the solutions together, he obtained the solution for the whole domain! This solution technique is successful in many situations involving propagating interfaces that separate domains with distinct physical properties, such as penetration of oil into a water-filled reservoir or crystallization of melt in a magma chamber. For a good review of these and other "Stefan" problems, see *Rubinstein* [1967].

Numerical solutions are, of course, very often indispensable. For the purpose of this Forum, a numerical solution is defined roughly as an approximate, algorithmic solution to a differential equation, expressed as a grid of numerical values. In contrast, analytic solutions are expressed as combinations of elementary or special functions. Global analytic solutions are usually unobtainable for systems involving complex geometry and strongly coupled sets of nonlinear differential equations. Numerical routines, on the other hand, can be very good at handling such systems. In this age of powerful computers, researchers use massively parallelized codes that include nonlinear effects and multiple layers of strongly coupled physical processes. With such capability, many see the analytic approach as outmoded or, at best, as a way to validate codes in simple scenarios. It seems that many of the strengths of analytic methods have been largely forgotten. When such strengths are taken into consideration, however, it becomes clear that numerical and analytic viewpoints are deeply complementary. Based on very different kinds of fundamental assumptions, they offer strong mutual but independent support, going far beyond the use of analytical methods for code verification.

The duality between analytic and numerical methods lies in the contrast between simplicity and generality—both desirable properties for a mathematical model. We would like a model to be broadly applicable and yet easy to use and understand. Unfortunately, there is a trade-off between these virtues. The more phenomena that are incorporated into a model, the more general—and complicated—that model becomes. Numerical models tend to emphasize generality at the expense of simplicity, and analytic models, vice versa.

The simplicity of analytic solutions tends to cost generality but benefit theory. Their construction forces one to engage with theory to decide what are the most important parameters in a problem. The benefit is clear: Physical insight does not result from including every effect imaginable but from knowing which effects are most important; see *Barenblatt* [1996] for many examples of complex phenomena that have been "boiled down to essentials." On the other hand, effects neglected in solution construction could turn out to be important, even crucial, in ways not knowable a priori. Creating a numerical method, in contrast, forces one to consider all the effects that might be important in many possible circumstances. This characteristic makes numerical modelers less prone to prejudging what will be important, though perhaps more prone to losing physical insight. Sensitivity analysis performed on numerical results (e.g., via a program like PEST [*Doherty*, 2002]) can serve to isolate important parameters, also allowing a model to be "stripped down" to its essentials. Such analysis, however, does not give exact functional relationships between parameters of interest; as a result, numerical solutions are much less amenable than analytic solutions for many important theoretical purposes, such as general stability

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analysis, development of new physical theories, perturbative series expansions, and the study of self-similarity through dimensionless groups.

Consider the latter example—that analytic methods give rise to key dimensionless groups of variables. Such groups commonly arise in two distinct ways. The first is through scale analysis, which consists of solving algebraic approximations of the governing differential equations [*Bejan,* 2004]. The second way is through the Buckingham Pi theorem [*Barenblatt,* 1996], which is (roughly stated) that a dimensionally homogeneous equation in n arguments with respect to m units can be expressed as a relation between n-m dimensionless groups. Dimensionless groups reduce the library of books that would be required to tabulate a function such as $f = f(x_1, x_2, ..., x_5)$ to the single page that would be required to tabulate $f = f(x)$, where x is a dimensionless combination of the arguments x_i. This compression of information is not merely an advantage of notation. Instead, it is comparable to the difference between using Roman versus Arabic numerals—the latter system leading to physical insights that were inaccessible using the former [*Bolster et al.,* 2011]. For example, it allows one to determine when the behavior of one system is exactly the rescaled behavior of another system that may appear on the surface to be quite different from the first. Moreover, dimensionless groups are not necessarily invalidated by nonlinearity or complex problem geometry. A dimensionless group is the compact expression of the results of countless possible numerical runs or experiments. Dimensionless groups allow one to exploit dynamical similarity, provide insight that would aid in the construction/extension of physical theories, facilitate intermodel comparisons, and enable one to perform useful back-of-the-envelope calculations.

As mentioned above, complex system geometry, multiple strongly coupled physical processes, and strong nonlinearity rule out the use of global analytic solutions; however, they certainly do not, as is commonly thought, rule out the use of analytic methods altogether. Global numerical simulations of complex phenomena usually display local features such as boundary layers, planar fractures, and repeated patterns of thermal convection cells, which are quite accessible to local methods of analysis. It is true that local analysis frequently assumes linearity in the governing differential equations; however, as the Josef Stefan story illustrates, such an assumption can be reasonable even when the system is nonlinear globally. Moreover, it is frequently not known ahead of time what the strength of nonlinearity in a problem will be. In such cases, comparison with linear analytical results is never a waste of time—if there is a close match between the solutions, then the nonlinearity is not important after all, i.e., the system is simpler than it at first seems; if there is not a close match, then it has been demonstrated rigorously that nonlinearity is important in the problem.

In summary, complicated system geometry, strongly coupled processes, and nonlinearity are usually seen as precluding the use of analytic methods, but it is exactly when these factors are at play that a combination of analytic and numerical approaches can be most powerful. There are similarities between numerical simulations and experiments done in a laboratory, hence the commonly used expression "numerical experiment." The analogy suggests that just as experimental results should be interpreted in the light of theory, so should results derived from simulations. If nature itself is seen as a sophisticated numerical simulation where every possible effect has been included, the past successes of analytical models in the study of nature argue that attempts to match numerical simulation results to analytic solutions will often be successful. Due to the theoretical advantages mentioned above for the analytic viewpoint, this success will often mean increased physical insight.

References

Barenblatt, G. I. (1996), *Scaling, Self-Similarity, and Intermediate Asymptotics,* 412 pp., Cambridge Univ. Press, New York.

Bejan, A. (2004), *Convection Heat Transfer,* 728 pp., John Wiley, Hoboken, N. J.

Bolster, D., R. E. Hershberger, and R. J. Donnelly (2011), Dynamic similarity, the dimensionless science, *Phys. Today, 64*(9), 42–47.

Doherty, J. (2002), Addendum to PEST manual for version 6 of PEST, 284 pp., Watermark Numer. Comput., Brisbane, Queensland, Australia.

Rubinstein, L. I. (1967), *The Stefan Problem,* 419 pp., Am. Math. Soc., Providence, R. I.

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MEETINGS

Exploring Hawaiian Volcanism

AGU Chapman Conference: Hawaiian Volcanoes, From Source to Surface; Waikoloa, Hawai'i, 20–24 August 2012

In 1912 the Hawaiian Volcano Observatory (HVO) was established by Massachusetts Institute of Technology professor Thomas A. Jaggar Jr. on the island of Hawaii. Driven by the devastation he observed while investigating the volcanic disasters of 1902 at Montagne Pelée in the Caribbean, Jaggar conducted a worldwide search and decided that Hawai'i provided an excellent natural laboratory for systematic study of earthquake and volcano processes toward better understanding of seismic and volcanic hazards. In the 100 years since HVO's founding, surveillance and investigation of Hawaiian volcanoes have spurred advances in volcano and seismic monitoring techniques, extended scientists' understanding of eruptive activity and processes, and contributed to development of global theories about hot spots and mantle plumes.

The Chapman Conference "Hawaiian Volcanoes, From Source to Surface" was convened on the occasion of HVO's centennial. Conference goals included reviewing current understanding of Hawaiian volcanism developed over the past century, identifying critical problems needing future research, and exploring how Hawai'i informs research elsewhere on the Earth and other planets.

Approximately 180 scientists from 12 countries attended the meeting, including about 40 students. Financial support was provided by the U.S. Geological Survey (USGS), the U.S. National Science Foundation (NSF), and the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). The conference program was structured to trace the route of ascending magma from its source within Earth's mantle to eruption at the surface. Each day consisted of a morning of invited talks summarizing current understanding of key concepts and phenomena, followed in the afternoon by short contributed talks, breakout discussions, and poster presentations. A field trip day offered participants a chance to visit one of the five shield volcanoes that make up the island.

Hawaiian volcanoes are among the best studied in the world, but surprisingly, a number of fundamental questions remain unanswered. It is generally thought that a mantle plume feeds the Hawaiian hot spot. What is the depth and source of melting, and what is the mechanism of melt transport to the surface? Over the last 5 million years, Hawaiian volcanoes have formed two geochemically and geographically distinct chains—the "Loa" and "Kea" trends. What are the origins of these trends, and how far back in time can they be distinguished? The volumes and structures of individual overlapping volcanoes that make up the island of Hawai'i are poorly known. Is Kīlauea a small volcano sitting on the shoulder of Mauna Loa, or does it deeply indent Mauna Loa's flank? A wide range of models have been proposed for the size and shape of magma reservoirs and conduits beneath the surface, but agreement, especially between geophysicists and geochemists, has been elusive. What do subvolcanic magma storage areas and transport pathways look like? Both Kīlauea and Mauna Loa are characterized by explosive deposits in their summit regions. What controls the transition between explosive and effusive volcanism at Hawaiian volcanoes? What geophysical, geochemical, and geological tools will help us to better forecast future volcanic activity?

Consensus emerged that such critical questions would benefit most from interdisciplinary approaches leading to more complete physical and chemical models integrating a variety of observations. The Hawaii Scientific Drilling Project (HDSP) on Mauna Kea, which resulted in more than 3 kilometers of continuous core from the flank of a Kea trend volcano (spanning from about 240,000 to > 650,000 years before present), is a potential example of this approach. On the less expensive end of the spectrum, more rigorous integration of existing and new geodetic, seismic, and geochemical data in Hawai'i is needed to better constrain, for example, the sizes and shapes of magma reservoirs. Ultimately, conference participants felt that an ocean island research initiative, akin to the Ridge Interdisciplinary Global Experiments (RIDGE) and Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS) programs sponsored by NSF, might best coordinate discussion and activity among the numerous but currently independent research groups that focus on Hawai'i and other hot spot volcanoes around the world.

Conference presenters agreed to share their overviews and investigations of aspects of Hawaiian volcanism with the larger community via the 2012 Hawai'i Chapman Conference Web site (http://hilo.hawaii.edu/~kenhon/HawaiiChapman). A technical summary that will highlight major research questions discussed at the conference is forthcoming. Hopefully, this Chapman Conference has stimulated the community that studies Hawaiian volcanism, helped frame critical research targets, outlined future areas of interest, and inspired the next generation of research scientists.

—MICHAEL P. POLAND and PAUL G. OKUBO, Hawaiian Volcano Observatory, U.S. Geological Survey, Hawai'i National Park, Hawai'i; E-mail: mpoland@usgs.gov; and KEN HON, University of Hawai'i at Hilo

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Meetings

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Recommendations for Analysis of Dissolved Osmium in Seawater

Dissolved Osmium Isotope Analysis; Montreal, Canada, 24 June 2012

Osmium (Os) isotopes have emerged as a powerful tool in oceanographic and paleoceanographic research, as this highly redox-sensitive element provides insights into ocean anoxic events, continental weathering processes, extraterrestrial impacts, and anthropogenic contamination. Direct analysis of Os isotopes dissolved in seawater is challenging because of very low (femtomolar) concentrations, a complex matrix, multiple oxidation states, and its likely propensity to bind to multiple ligands. Only a handful of laboratories have attempted such analyses.

Evidence emerging over the last few years has cast doubt on the accuracy of many of the published seawater data on Os.

This evidence indicates the need for extended heating at high temperature for complete equilibration of tracer and sample Os and includes recently reported contamination from widely used, pre-cleaned high- and low-density polyethylene (HDPE and LDPE) bottles (M. Paul, L. Reisberg, and N. Vigier, "A new method for analysis of osmium isotopes and concentrations in surface and subsurface water samples," *Chem. Geol. 258,* 136–144, 2009, doi:10.1016/j.chemgeo.2008.09.018.; M. Sharma, C. Chen, and T. Blazina, "Osmium contamination of seawater samples stored in polyethylene bottles," *Limnol. Oceanogr. Methods, 10,* 618–630, 2012, doi:10.4319/lom.2012.10.618, and references therein). This contamination is caused by the use of ultrapure nitric acid during cleaning.

These findings resulted from U.S. National Science Foundation-funded GEOTRACES intercalibration efforts in the Pacific and Atlantic oceans.

A half-day meeting on "Dissolved Osmium Isotope Analysis" was held at the Palais de Congrès de Montreal on 24 June 2012 before the annual Goldschmidt Conference. This meeting aimed to review current methods of analysis and to recommend best practices for seawater Os isotope analyses. About 15 scientists participated and made the following observations/recommendations:

- The water sampling and filtration apparatus used on GEOTRACES cruises, though not tested for Os, has not been shown to cause analytical problems for Os.
- Teflon bottles have shown no artifacts associated with storing acidified seawater Os for periods of up to 1 year. Teflon bottles used for storing Seastar® concentrated hydrochloric acid have been used successfully without additional cleaning. No cleaning protocol that ensures the long-term integrity of samples for osmium isotope analyses has been published for HDPE, LDPE, or polypropylene bottles.
- Hydrochloric and hydrobromic acids purified by sub-boiling distillation contain less than 1 femtogram per gram of Os. These acids are recommended for cleaning Teflon bottles.
- Equilibration between seawater and tracer Os can be assured by heating samples at 300°C for at least 10 hours in an oxidizing medium such as hexavalent chromium (Cr^{VI}) or hydrogen peroxide (H_2O_2).
- High yields (~90%) during extraction and purification of Os, coupled with high effective ionization efficiencies (> 5%) and low blanks (< 5 femtograms) are required to achieve the best reported external reproducibilities within two standard deviations of around 1% for isotope ratios ($^{187}Os/^{188}Os$) and about 2% for Os concentration for seawater samples of around 50 grams.
- Details of the cleaning, sampling, storage, and analytical procedures used, particularly on blank corrections, should be given in all publications.

We acknowledge financial support from the U.S. National Science Foundation (OCE-0751616) and the Woods Hole Oceanographic Institution, and thank Katz Suzuki, Sunil Singh, and an anonymous reviewer.

—BERNHARD PEUCKER-EHRENBRINK, Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, Mass.; MUKUL SHARMA, Department of Earth Sciences, Dartmouth College, Hanover, N. H.; and LAURIE REISBERG, Centre de Recherches Petrographiques, Centre National de la Recherche Scientifique (CNRS), Nancy, France.

ABOUT AGU

AGU and American Geosciences Institute Webinar Series to Strengthen Departments

The AGU Education and Public Outreach department in collaboration with the American Geosciences Institute (AGI) are continuing their partnership to support Earth and space science departments through AGU's Heads and Chairs Program. Through this partnership, AGI's Workforce Program and AGU's education staff continue to host monthly, hour-long webinars and online discussions on various topics that hit at the heart of the health and success of Earth and space science departments. We invite department heads and chairs as well as faculty, administrators, and program directors to join in this unique free program.

For those who were not able to attend some (or any) of the webinars we jointly hosted last fall, the audiovisual recordings are accessible at http://www.agiweb.org/workforce/headsandchairs/. Last year's topics included program assessment, exit surveys, student pathways into the geosciences, faculty evaluation, and student recruitment.

The topics for this year's webinars, also listed on the same Web page, are based on input from participants in the 2012 webinars and face-to-face meetings and include recruiting undergraduate students into introductory courses, the role of student organizations and co-curricular activities in building departmental community, and strategies for improving the visibility of Earth and space science programs on campuses. The first 2013 webinar, on legal issues related to field trips, is scheduled for 22 February at 1:00 P.M. eastern standard time and is being organized by David Mogk (Montana State University) and Steven Whitmeyer (James Madison University). Please consider joining us in February and throughout the year in conversations to strengthen your departments and build community amongst academic leaders.

—PRANOTI M. ASHER, Manager, Education and Public Outreach, AGU; E-mail: pasher@agu.org; and CHRISTOPHER M. KEANE, Technology and Communications Director, American Geosciences Institute (AGI)

NEW BOOKS

This column lists recently published books that have been received by Eos.

Advanced Remote Sensing: Terrestrial Information Extraction and Applications, Shun-lin Liang et al., Academic Press, 2012, ISBN 978-0-12-385954-9, $149.95

Environmental Fluid Dynamics: Flow Processes, Scaling, Equations of Motion, and Solutions to Environmental Flows, Jörg Imberger, Academic Press, 2013, ISBN 978-0-12-088571-8, $89.95

Geology Underfoot Along Colorado's Front Range, Lon Abbott and Terri Cook, Mountain Press Publishing, 2012, ISBN 978-0-87842-595-2, $24.

How to Succeed as a Scientist: From Postdoc to Professor, Barbara J. Gabrys and Jane A. Langdale, Cambridge University Press, 2012, ISBN 978-0-521-18683-4, $36.99

An Introduction to Dynamic Meteorology, Fifth Edition, James R. Holton and Gregory J. Hakim, Academic Press, 2013, ISBN 978-0-12-384866-6, $94.95

Landslides: Types, Mechanisms and Modeling, John J. Clague and Douglas Stead (Eds.), Cambridge University Press, 2012, ISBN 978-1-107-00206-7, $150.

Practical Chemical Thermodynamics for Geoscientists, Bruce Fegley Jr., Academic Press, 2013, ISBN 978-0-12-251100-4, $124.95

Understanding the Earth System: Global Change Science for Application, Sarah E. Cornell et al. (Eds.), Cambridge University Press, 2012, ISBN 978-1-107-00936-3, $80.

What's on the Web?

Read the latest offerings from the AGU Blogosphere:

The Landslide Blog: "A call for landslide photos for the USGS library archive" (http://goo.gl/A062R)

Dan's Wild Wild Science Journal: "Greenland ice core may rewrite some climate books" (http://goo.gl/oqJPs)

Georneys: "The last train to nowhere in pictures" (http://goo.gl/0eLj8)

Mountain Beltway: "Do you believe in M.A.G.I.C.?" (Mid-Atlantic Geo-Image Collection) (http://goo.gl/7Tkf4)

Dan Satterfield

In Dan's Wild Wild Science Journal, blogger Dan Satterfield recalls his time observing the collection of the North Greenland Eemian (NEEM) ice core. The project's research station, above, housed a kitchen, dining room, offices, and a shower.

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POSITIONS AVAILABLE

Atmospheric Sciences

DIRECTOR, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR).

The Director of NCAR is the national center's executive and scientific leader. The director is responsible for the scientific direction, productivity, innovation capacity, and overall success of NCAR research, facilities, and programs, including the formulation and execution of plans, budgets, and priorities, as well as directing all phases of the operation of the national center. A major responsibility of the director of NCAR is to build and maintain strategic partnerships with the National Science Foundation (NSF) and the 104 university members of UCAR.

The successful candidate will have demonstrated the ability to lead and inspire on a broad intellectual front and will possess a significant record of scientific or technical achievement in the atmospheric or related sciences. He or she will have demonstrated successful planning, management, execution, and administration of complex research and facility activities and will possess a breadth of interest, vision, and judgment. The candidate will be adept at advocating for NCAR's science and facilities to various constituencies and will have experience in applying research to pressing societal needs. She or he will have shown a strong commitment to increasing diversity in the atmospheric and related sciences community and to supporting educational engagement initiatives.

The National Center for Atmospheric Research (NCAR) is a Federally Funded Research and Development Center (FFRDC) sponsored by the National Science Foundation (NSF) and operated by the 104-university nonprofit consortium, the University Corporation for Atmospheric Research (UCAR). Headquartered in Boulder, Colorado, NCAR has approximately 900 staff members and annual expenditures of about $131 million.

Salary will be based on experience and qualifications, and is subject to the approval of the National Science Foundation. UCAR is an equal opportunity/affirmative action employer, and offers a competitive employee benefit package.

View detailed job description and application instructions at https://www2.ucar.edu/ncar-director-search. Initial consideration will be given to applications received prior to 27 March 2013. We value diversity. AA/EOE

Faculty Position in Marine Biogeochemistry.

Stony Brook University's School of Marine and Atmospheric Sciences (SoMAS) invites applications for a tenure track faculty position in Marine Biogeochemistry, to begin as early as Fall 2013. The position will be filled at the Assistant Professor level. Review of applications will begin March 1, 2013, but applications will be considered until the position is filled. Candidates are expected to interact with and augment existing activities in biogeochemistry at SoMAS. The successful candidate is expected to carry out an independent research program, attract external grant support for independent and collaborative projects, support and foster the development of graduate students, contribute to teaching activities at both the graduate and undergraduate levels, and participate in School and University service. Application instructions and procedures, as well as further information about this position, can be found at www.somas.stonybrook.edu/about/empopps.html (Ref #F-7743-13-01). Stony Brook University/SUNY is an affirmative action, equal opportunity educator and employer.

POST-DOCTORAL POSITION IN AIR QUALITY MODELING.

The Office of Commercialization and Regional Development, Utah State University, Vernal, Utah has an immediate opening for a post-doctoral position in air quality modeling. The ideal candidate will be a recent Ph.D. with experience in atmospheric simulations (WRF) and photochemical dispersion modeling (CAMx and/or CMAQ) in a parallel-processing, Linux environment. The appointment will be for two years, with the possibility of an additional year depending on the availability of funding. The salary will be competitive. Please send resume before 03/15/2013, including publication list and the names of three references, to Marc Mansfield, Ph.D., marc.mansfield@usu.edu.

Postdoctoral Positions in Indian Monsoon Prediction.

The Center for Ocean-Land-Atmosphere Studies is looking for up to three self-motivated postdoctoral research scientists in the area of Indian monsoon prediction and predictability. The incumbents will join a multi-national project in collaboration with the National Monsoon Mission of the Government of India. The selected candidates will investigate ocean-land-atmosphere coupling and initialization strategies to improve CFSv2 and monsoon prediction. Particular attention will be paid to three aspects of the problem: land-atmosphere feedbacks, multiple analysis ocean initialization, and ocean-atmosphere feedbacks. The successful candidates are also expected to take leadership roles in preparation of manuscripts for publication and conference participation. Applicants must have a Ph.D. in atmospheric sciences or a related field, with experience in climate variability or climate modeling and prediction. The appointment will be for one year, with potential for renewal for the second and third years, given satisfactory performance. For consideration, interested and qualified applicants should submit a cover letter including a statement of research interests, a curriculum vita, and contact information of two professional references to the NMM PostDoc Search Committee (Dr. James Kinter, chairperson; ikinter@gmu.edu). Applications received before 28 February 2013 will receive highest priority.

Two Faculty Positions in Atmospheric Sciences at Texas A&M University-Corpus Christi.

The Department of Physical and Environmental Science (http://www.pens.tamucc.edu) at Texas A&M University-Corpus Christi invites applications for two tenure-track faculty positions in Atmospheric Sciences to begin in Fall 2013 or Spring 2014. The applicant for the first position (job#0054) should be in the field of synoptic, mesoscale and tropical meteorology. Applicant for the second position (job#0054) should be in a broad field

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of atmospheric sciences including atmospheric dynamics, climate dynamics and other relevant research areas. Candidates must identify the position for which they wish to be considered in the cover letter.

Successful applicants will be expected to establish an externally funded research program supporting graduate students in the Environmental Science MS and Coastal and Marine System Science PhD programs and a proposed new MS program in High Impact Meteorology and Incident Response. Both faculty members are also expected to contribute to a new BS program in Atmospheric Sciences. Teaching expectations are normally 3 courses per year with an allowance of reduced teaching in the first year to allow laboratory development. Courses will be in support of the undergraduate and graduate programs mentioned above. Requirements include a Ph.D. at the time of appointment in Atmospheric Sciences or a closely related field. Post-doctoral experience is preferred. Both positions will be filled at the tenure-track Assistant Professor level.

Texas A&M University-Corpus Christi is a Hispanic-serving institution located on the Gulf of Mexico, with a modern campus overlooking Corpus Christi Bay. With more than 10,500 students, the university offers a wide array of academic programs with 18% of the students enrolled in graduate programs. Applications are particularly encouraged from individuals whose research interests can take advantage of the university's facilities, numerous research vessels and dive operations, and potential collaborations with our faculty in the environmental, engineering, computing, geological, biological and marine sciences.

Apply online at https://islanderjobs.tamucc.edu. Applications must include 1) a cover letter, 2) a curriculum vitae, 3) copies of undergraduate and graduate transcripts (unofficial is acceptable for application), 4) a statement of teaching philosophy, 5) a description of research interests, and 6) a list of at least three references. Questions regarding this position may be addressed to the Chair of the Search Committee, Dr. Darek Bogucki (Darek.Bogucki@tamucc.edu) or the Co-chair: Dr. Dorina Murgulet (Dorina.Murgulet@tamucc.edu).

The positions will remain open until filled but preference will be given to applicants submitting all requested documentation by February 15, 2013. Texas A&M University-Corpus Christi is an Equal Opportunity/Affirmative Action Employer committed to excellence.

Geochemistry

Open-rank Professor Positions in Geochemistry (Paleoclimatology, Biogeochemistry and Carbon Sequestration), Institute of Surficial Geochemistry, Nanjing University, China.

The Institute of Surficial Geochemistry (ISG) at Nanjing University is seeking qualified candidates worldwide to fill multiple (3 to 5) professor positions in the area of Geochemistry (e.g., low-temperature geochemistry, environmental geochemistry, paleoclimatology, biogeochemistry). The successful candidates are expected to develop research programs in their specialties supported by internal and external funding and to collaborate with other ISG researchers with expertise in the Asian aeolian dust system, hydrological cycle and hydrological environment evolution, organic geochemistry, and carbon cycle and carbon sequestration. The new hires will have chances to teach courses and advise talented undergraduate and graduate students. ISG will provide strong support for new hires to conduct cutting-edge geochemistry studies; The salary of these open rank positions (assistant, associate, and full professorship) range from 200,000 to 400,000 RMB (~ $32,000 to $64,000) depending on qualifications and experience, with considerable startup funds and benefits (e.g., housing bonus). Applicants should send a letter of interest, curriculum vitae with a complete list of publications, summary of academic achievements (within 500 words), future research interests (1-2 pages), as well as 2-3 reference letters to Dr. Yang Chen (phone: 8625-83686042 and email: chenyang@nju.edu.cn). Review of applications began Jan. 2013, and will continue until all positions are filled.

Hydrology

Two-year Post-doc Position in Hydrology Offered at the University of Notre Dame.

The Environmental Change Initiative (ECI) [http://environmentalchange.nd.edu/] at the University of Notre Dame (ND) in collaboration with the Dept. of Civil and Environmental Engineering and Earth Sciences (CEEES) is seeking applicants for a two-year post-doc position to conduct large-scale hydrologic modelingstudies over the Great Lakes region. The research will create long-term observed meteorological records and future projections of climate from regional and global scale climate models, coupled to large-scale hydrologic models. These tools will be used to explore the impacts of observed climate variability, climate change, and land use/management on human systems and ecosystems in the Great Lakes region, supporting interdisciplinary research within the ECI and CEEES at ND. A successful candidate will have a PhD in hydrology, hydroclimatology, ecohydrology, or a related field in the physical sciences. Well-developed computer programming skills in the UNIX environment (e.g. experience with C or Fortran, scripting languages, and use of LINUX clusters for parallel computing), experience dealing with large data sets, and excellent written and oral communication skills are important qualifications for the position. Experience with statistical or dynamical downscaling of climate model simulations and with implementation and calibration of physically-based, distributed hydrologic simulation models is also desired, as is experience in the analysis and modeling of water resources systems. Applicants with experience working in an interdisciplinary research environment are also particularly encouraged to apply.

ND is an equal opportunity employer and offers a competitive salary and comprehensive benefits package. In addition to primary research activities, the position will involve the supervision of graduate students, preparation of grant proposals, teaching, stakeholder education /outreach opportunities, and extensive interdisciplinary collaboration with researchers in a number of fields outside of hydrology. Several publications are expected to result from the research.

Applicants should submit a statement of interest (~2 pages), a brief summary of qualifications and recent research activities (less than 5 pages), a list of three professional references (name, affiliation, and contact information), and a CV. Please send these application materials via e-mail as a single pdf file to Dr. Alan F. Hamlet, CEEES, University of Notre Dame (http://engineering.nd.edu/profiles/ahamlet/) to alan.hamlet.1@nd.edu. Applications received by March 15, 2013 will receive full consideration, but applications will be accepted until the position is filled.

Ocean Sciences

Texas A&M University at Galveston Marine Sciences Department POSITION ANNOUNCEMENT ASSISTANT PROFESSOR IN MARINE GEOSCIENCES.

Texas A&M University at Galveston invites applications for a nine-month, tenure-track faculty position at the Assistant Professor level with expertise in marine geology, or related field, beginning fall 2013. Desired areas of specialization include: coastal and continental margins geological/sedimentary processes, including sediment transport (instrumentation as well as modeling), high-resolution marine geophysics, paleoclimate, and marine geological hazards. Candidates with demonstrated excellence in field-oriented research are encouraged to apply, but also welcome applications from candidates comfortable employing modeling, experimental and/or laboratory approaches. The successful candidate will be based in the Department of Marine Sciences in Galveston, and will be capable of obtaining an appointment as a graduate faculty member in a graduate department in College Station related to his/her research focus (e.g. Oceanography, Geology and Geophysics, Geography).

The successful candidate must have evidence of or potential for strong teaching and research performance. We are specifically looking for a person that can contribute to - and benefit from - an interdisciplinary environment and interact with colleagues in our natural sciences and resource management programs. Teaching responsibilities will support our undergraduate and graduate programs and may include: physical geology, sedimentology and stratigraphy, coastal processes, marine geology, and courses in their specialty.

The Department is interested in candidates with a strong record of, or potential for externally funded research, scholarship, and peer-reviewed publication. Applicants must have completed their doctorate in geology, marine science, oceanography or a related discipline by September 1, 2013. Salary is commensurate with qualifications and experience.

The Department has recently moved into the new Ocean and Coastal Science Building, a ~100,000 sqf LEED certified facility that facilitates close interactions across all fields of science on campus. The multidisciplinary offerings of the

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Department also include geological, chemical, physical, and biological oceanography; environmental law, remote sensing and geospatial analyses, coastal planning as well as resource management and environmental policy. Recently, the Board of Regents of Texas A&M University approved the creation of the new Institute of Sustainable Coastal Communities as a collaboration between Texas A&M University at Galveston and Texas A&M's College of Architecture. The successful candidate will have an opportunity to contribute to the development of research and academic programs of this multidisciplinary Institute.

To apply, send a curriculum vitae, statement of current research and teaching interests, a list of three references, as well as a completed and signed official TAMUG application form (http://www.tamug.edu/hrd/Employment.htm) to: Chair, Coastal/Marine Geology Search Committee, Human Resources Department, Texas A&M University at Galveston, P.O. Box 1675, 200 Seawolf Parkway, Galveston, TX 77553-1675.

Review of applications will begin immediately and will continue until the pos filled. Employment is contingent upon successful completion of a background check and verification of eligibility to work in the US. Texas A&M University at Galveston is an affirmative action and equal opportunity employer committed to diversity. For more information on the position contact Dr. Tim Dellapenna, Chair of the search committee, by email at dellapet@tamug.edu.

Solid Earth Geophysics

Tenure-track Position in Hydrogeophysics.

The University of Wyoming invites applications for a tenure-track position in hydrogeophysics at the assistant professor level. This is a joint position (#4866) between the Department of Geology and Geophysics and the Department of Civil and Architectural Engineering. We seek a hydrogeophysicist with expertise in the development and use of near-surface geophysical techniques for hydrological problems and interested in integrative research. Of particular interest are emerging applications in electrical and electromagnetic geophysics such as complex resistivity and magnetic resonance sounding.

This position is part of a growing emphasis on watershed science exemplified by the new Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG; uwyo.edu/wycehg). This interdisciplinary, NSF-funded center houses new facilities dedicated to near-surface geophysics and surface/subsurface hydrology. The successful hire will have an earned PhD in geophysics, civil engineering, or a closely related field at the time of appointment, will have the potential to develop an internationally recognized, externally funded research program, will integrate his/her research with the goals of WyCEHG and will provide academic support to the Ph.D. Program in Hydrology (WRESE; uwyo.edu/wrese).

The University's policy has been, and will continue to be, one of nondiscrimination, offering equal opportunity to all employees and applicants for employment on the basis of their demonstrated ability and competence without regard to such matters as race, sex, gender, color, religion, national origin, disability, age, veteran status, sexual orientation, genetic information, political belief, or other status protected by state and federal statutes or University Regulations.

The University of Wyoming is committed to providing a safe and productive learning and living community. To achieve that goal, we conduct background investigations for all final candidates being considered for employment. Background checks may include, but are not limited to, criminal history, national sex offender search, employment and motor vehicle history. Offers of employment are contingent upon the completion of the background check.

Application Materials Required:

Applications must be submitted as a single PDF file to: Dr. W. Steven Holbrook, Search Committee Chair, steveh@uwyo.edu. Applications must contain a cover letter, a statement of research interests, a statement of teaching interests, a curriculum vita, and contact information for at least three references. Review of applications will begin on February 28, 2013, and will continue until the position is filled.

Space Physics

The Center for Space Physics at Boston University invites applications for a postdoctoral researcher position supervised by Professor Paul Withers. The research will involve the analysis of accelerometer and other measurements made by Curiosity during its descent to the surface of Mars, leading to an accurate reconstruction of the atmospheric conditions encountered by Curiosity and subsequent scientific interpretation of these results. Candidates should possess a PhD degree in a relevant field. Experience conducting research on planetary atmospheres and/or experience working with spacecraft observations are desirable. The salary offered will be competitive and commensurate with experience. Funding is available for two years with the possibility of extension. The appointment is expected to begin as soon as possible after 1 April 2013. Please contact Paul Withers (withers@bu.edu) for further information.

Applications should be sent by email to Paul Withers (withers@bu.edu).

The application should be submitted in PDF format and contain a curriculum vitae, statement of research interests, and contact information for three referees. Review of applications will begin on 28 February 2013. Women and underrepresented minorities are particularly encouraged to apply. Boston University is an equal opportunity/affirmative action employer.

Interdisciplinary/Other

GDL Foundation Fellowships in Structure and Diagenesis.

The GDL Foundation supports study and research of chemical and mechanical interactions, structural diagenesis, in sedimentary basins. Practical applications are of particular interest.

We are currently seeking applications from M.S. and Ph.D. candidates, post-doctoral researchers, and scientists for fellowships, up to $10,000, based on specific proposals for research and participation in meetings and conferences to share results.

Submit applications (available at: www.gdlfoundation.org) by April 5, 2013

Project Coordinator.

American Geophysical Union (AGU) invites outstanding candidates to apply for the Thriving Earth Exchange (TEX) Project Coordinator position. The position provides an exceptional opportunity to help develop an innovative program, focused on the sustainability of our planet. This appointment is for one year, with a possible renewal for a second year.

The Project Coordinator is responsible for coordinating activities of the Thriving Earth Exchange project through all project phases, including planning, development, implementation, and documentation development, and managing the daily work activities. The successful candidate serves the project efficiently and effectively by executing the project's goals and objectives both internally and externally. S/he represents the interests of the project, both inside and outside of the organization. S/he serves as the day-to-day staff liaison for this project. This position reports to the Director, Science and works closely with the Director, Product Development, TEX Task Force chair, CEO and AGU President, among others.

Applicants must have a Bachelor's degree and one to three years of relevant experience, or an equivalent combination of education and experience. Strong detail-orientation, organizational skills and analytical skills. Excellent written and oral communication skills, research and project/process management skills. Excellent customer service skills and diplomacy. Proficiency with Microsoft Office (i.e. Word, PowerPoint and Excel). Ability to multi-task and work independently to achieve expected results. Ability to collaborate well with others, including respect for others and their perspectives, the sharing of relevant data/information, the sharing of thoughts and active listening, and contribution of skills and expertise so the team succeeds. Ability to learn and innovate, including maintaining flexibility and adaptability, conducting research to continually advance knowledge and generate insights, and

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INSTITUTE FOR GEOPHYSICS
JACKSON SCHOOL OF GEOSCIENCES

SHELL CHAIR IN GEOPHYSICS

The Institute for Geophysics at The University of Texas at Austin, an organized research unit in the Jackson School of Geosciences, is seeking applicants for the Shell Chair in Geophysics. Appointment will be at Senior Research Scientist level within the Institute and applicants with significant research experience in industry and academia are encouraged to apply.

The successful applicant will be expected to establish an externally funded research program that addresses today's most relevant problems in applied geophysics. Among the areas of research interests are: reflection seismology with an emphasis on 3D imaging and/or time lapse (4D) observations; inversion of geophysical data; and, geomechanics and geodynamics.

A joint appointment with the Department of Geological Sciences, the teaching and degree granting unit of the Jackson School, may be possible depending on the applicant's professional experience, interests, and the teaching needs of the department.

An application should include a cover letter, statement of research interests, CV, list of publications, and names of at least three references. The application should be submitted via http://utdirect.utexas.edu/pnjobs/index.WBX. Applications should use posting number 13-01-08-01-0701. More information on hires can be found at http://www.ig.utexas.edu/jobs/research.htm.

VICTORIA UNIVERSITY OF WELLINGTON

Victoria University delivers internationally-acclaimed results in teaching and research, as well as programmes of national significance and international quality.

As one of Wellington's largest and most established employers, we're committed to providing our staff with opportunities for rewards, recognition and development, all within a dynamic and inclusive culture where innovation and diversity are highly valued.

RESEARCH FELLOW (3 YEAR FIXED TERM POSITION)

School of Geography, Environment and Earth Sciences
Victoria University of Wellington, New Zealand

This is an opportunity for an early career scientist working in one or more of the following fields; palaeoecology, paleoclimatology, sedimentology or geochronology.

It is expected that the successful applicant will develop new research projects in collaboration with the host employer, contribute to ongoing research activities in Quaternary environmental change at VUW including assisting Masters and PhD projects, and contribute to undergraduate and postgraduate teaching programmes in physical geography at VUW.

Requirements are:

- PhD in any field related to Quaternary Science
- Experience in numerical analysis of palaeoecological, bilological or sedimentological data
- Proficiency in programming in 'R'
- Excellent oral and written communication skills in English.

Informal inquiries may be made to Rewi Newnham at rewi.newnham@vuw.ac.nz

How to Apply

Interested candidates should send an application letter including curriculum vitae, statement of research interest including specific ideas for projects, copies of degree transcripts, and names and contact information of at least two referees via: http://vacancies.vuw.ac.nz/

Further Information

Read about Rewi's research interests at:
http://www.victoria.ac.nz/sgees/about/staff/rewi-newnham

Read about Quaternary research at VUW at:
http://www.victoria.ac.nz/sgees/research/research-groups/quatenary

Our laboratory provision at VUW includes a range of facilities that support research activities in Quaternary environmental change including:

- Palaeoecology laboratories for sample preparation and microscopy (pollen, foraminifera, phytoliths, diatoms, plant macrofossils)
- Sedimentology
- A range of lake sediment and peat coring equipment with access to GPR
- An Electron Probe Microanalysis Facility, providing qualitative and quantitative information about the chemical composition of a sample, at a spatial resolution of less than 1 µm that is also capable of taking high resolution images at a sub micron scale. http://www.victoria.ac.nz/sgees/research/facilities/microanalysis-facility
- A state of the art ICPMS facility allowing measurement of a wide range of trace elements and determination of isotopic ratios, in materials such as minerals, rocks, ice, foraminifera and biological samples.
  http://www.victoria.ac.nz/sgees/research/facilities/geochemistry-lab
- A Luminescence Dating Facility
  http://www.victoria.ac.nz/sgees/research/facilities/luminescence-dating-facility
- Plus various Specialised Microscopes including digital imaging, various spectrometers and Sedigraph and multi-wavelength particle size analyser.

A more complete list of research equipment and facilities available at the School of Geography, Environment and Earth Sciences can be found at:
http://www.victoria.ac.nz/sgees/research/equipment

In addition, through our research collaborations in the Wellington region including in particular GNS Science and NIWA we have access on a collaborative basis to an extensive range of laboratory equipment and facilities in the Earth Sciences.

Applications close 25 February 2013

Victoria University of Wellington is an EEO employer and actively seeks to meet its obligations under the Treaty of Waitangi.

For more information and to apply online visit **http://vacancies.vuw.ac.nz**

Reference A022-13.

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA UNIVERSITY OF WELLINGTON

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experimenting and improving products and programs. Ability to develop and follow processes and procedures and to encourage and seek out customer feedback for product and program improvement. Maintain personal accountability for performance and help establish team norms for personal accountability.

Renewable Energy and Earth System Science Assistant Professor Position.

The Department of Geological and Environmental Sciences at California State University, Chico invites applications for a tenure-track position to start August 2013. Candidates must possess a Ph.D. in Energy Resources or related area such as Climate Change or Sustainability Sciences. Candidates nearing completion of the doctorate may be considered; however, the doctorate must be complete prior to the end of the first semester in December 2013. Preferred specialization in Renewable Energy Resources, Earth System Science, Climate Change Mitigation and Adaptation, or Carbon Sequestration. The full position announcement is available at http://csucareers.calstate.edu/Detail.aspx?pid=34250.

Reservoir Modeler - Houston.

ExxonMobil Upstream Research Company has an immediate opening for a Reservoir Modeler at its Upstream Research Laboratory located in Houston, Texas.

The successful candidate should have a solid background in geology coupled with a strong interest in digitally characterizing reservoir scale features using existing and innovative techniques. This position primarily supports our broad and diverse reservoir modeling research portfolio, while at same time being flexible enough that the individual's skillset could be applied to a broad range of geologic modeling challenges.

The candidate filling this position will be expected to immediately contribute to on-going projects as well as formulate and direct future endeavors. Collaboration is required with corporation geoscientists and engineers with a broad range of disciplines, including seismic interpretation, stratigraphy, formation evaluation, reservoir engineering and software developers.

Candidates should have the following qualifications:

-A Ph.D. or M.Sc. in Geologic Modeling or related field.

-A B.Sc. in Geology or related field.

-Ability to use standard coding languages (e.g. MATLAB, C++ etc) applied to geologic modeling algorithm creation/manipulation.

-Understanding of fundamentals of industry standard geologic modeling algorithms and workflows (Geostatistical Modeling, Object Based Modeling, Multi-point Statistics Modeling).

-Demonstrated willingness to take risks in research while maintaining objectivity.

-Creative, adept at team work, and able to drive projects to completion.

-Strong communication, organization, and interpersonal skills.

-Industry or post-graduate experience in reservoir modeling would be a plus.

Please submit your application and resume to our website: www.exxonmobil.comex. Please apply to Job No. 16713.

ExxonMobil is an Equal Opportunity Employer

Student Opportunities

The Department of Atmospheric Sciences at the University of Alaska Fairbanks still accepts applications for graduate assistantships for fall 2013. We seek highly qualified PhD/MS applicants interested in aeronomy, remote sensing, air quality or climate modeling, air-sea interaction, and ABL physics. They should have strong backgrounds in math, physics, meteorology or related. For information visit http://ffden-2.phys.uaf.edu/atm/ or contact bdday@alaska.edu. Apply electronically at http://www.uaf.edu/admissions/.

GFZ

Helmholtz-Zentrum Potsdam

Helmholtz-Zentrum Potsdam
Deutsches GeoForschungsZentrum

The Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum (GFZ) is the national Research Centre for Geosciences in Germany and a member of the Helmholtz Association of German Research Centres. Department 5 "Earth Surface Processes", Section 5.4 "Hydrology", invites applications for a

PhD position (m/f)

Vacancy No. 07/5/13 G

with the focus on hydro-gravimetry.
Changes of the water cycle from local to global scales are subject of research in Section 5.4. In the field of hydro-gravimetry, ground- and satellite-based gravimetric techniques are applied to assess variations in continental water storage. The application of (super-conducting) gravimeters as an innovative hydrological tool is developed in ongoing and future research activities in close co-operation with Department 1 (Geodesy and Remote Sensing).

Tasks:

- Contribution to the installation and maintenance of hydrological monitoring networks and gravimeters
- Analysis of water storage variations based on gravimetric and complementary data and hydro-geophysical modelling
- Contribution to the development of (super-conducting) gravimeters as hydrological monitoring devices
- Presentation and publication of scientific results

Qualifications:

- Master/Diploma in hydrology, geodesy, geophysics, environmental sciences or similar
- Experimental background and experience with catchment hydrology, unsaturated zone hydrology and/or gravimetric techniques
- Willingness to work in the field
- Programming skills (e.g. R or Matlab)
- Motivation to work in a multi-disciplinary team
- Good command of English language, German is an asset
- Driver's license

Availability: As soon as possible
Duration: 2+1 years
Salary: 75 % EG 13 TVöD-O
Contact: Dr. A. Güntner (guentner@gfz-potsdam.de)
Application deadline: Evaluation will begin two weeks after the announcement of the position and will continue until the position is filled.

Equal opportunity is part of our personnel policy. The GFZ Potsdam encourages applications from qualified female candidates. There is a kindergarten service available. Handicapped applicants will be given preference in the case of equal qualifications.

Please direct your application in writing quoting the reference number at: **Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum, Personal- und Sozialwesen, Telegrafenberg, 14473 Potsdam**

E-Mail please apply exclusively to: bewerbungen@gfz-potsdam.de

POSTDOCTORAL, RESEARCH AND VISITING RESEARCH SCIENTISTS
ATMOSPHERIC AND OCEANIC SCIENCES
PRINCETON UNIVERSITY/GFDL

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University solicits applications to its Postdoctoral, Research and Visiting Research Scientist Program.

The AOS Program and GFDL offer a stimulating environment with significant computational and intellectual resources in which to conduct collaborative or independent research. We primarily seek applications from recent Ph.D.'s for postdoctoral positions but will accept applications from more experienced researchers. Applications from independent researchers and more senior scientists who may need partial support for sabbatical or short visits may also be considered in exceptional circumstances. Postdoctoral appointments are initially for one year with the possibility of renewal for a second year based on satisfactory performance and continued funding. A competitive salary is offered commensurate with experience and qualifications.

We seek applications in all areas of the climate sciences. This includes research in basic processes in atmospheric and oceanic dynamics; climate dynamics; variability and prediction; atmospheric physics and chemistry; cloud dynamics and convection; boundary layer processes; land-sea-ice dynamics; continental hydrology and land processes; physical oceanography; ocean-atmosphere interaction; climate diagnostics and analysis. Applicants must hold a PhD in a relevant discipline.

Further information about the Program may be obtained from: http://www.princeton.edu/aos/. Applicants are encouraged to contact GFDL and Princeton University scientists prior to application.

Complete applications, including a CV, copies of recent publications, names and contact information for at least 3 references in order to solicit letters of recommendation, and a titled (about three page) research proposal should be submitted by April 1, 2013 for full consideration. Applicants should apply online to http://jobs.princeton.edu, Requisition # 1300077. Princeton University is an equal opportunity employer and complies with applicable EEO and affirmative action regulations.

RESEARCH SPOTLIGHT

Highlighting exciting new research from AGU journals

High pore pressure in seafloor related to slow slip earthquakes

Lying within the seafloor off the southern coast of southwestern Japan, the Nankai Trough is the surface expression of the subduction of the Philippine tectonic plate beneath the Eurasian plate. In the past, this fault has been responsible for producing large, tsunami-generating earthquakes—the most recent one, a magnitude 8.2 event in 1944. Similar events are expected in the future. One geologic feature that may predispose the region to such earthquakes is the presence of a low velocity zone previously identified that stretches shoreward from the Nankai Trough. The low velocity zone, a subsurface region through which primary seismic waves propagate with reduced velocity, may be related to increased seafloor uplift during an earthquake, a property that would tend to generate tsunamis.

Through deformation experiments conducted on core samples, *Kitajima and Saffer* determined the relationship between the rock's effective stress, the pore pressure, and the propagation velocity of primary seismic waves. From this experimentally determined relationship, the authors then used the results of previous seismic surveys to estimate the pore pressure and effective stress in the sediments hosting the plate boundary and other major faults in the Nankai Trough region.

The authors found that within the low velocity zone the pores were overpressured, resulting in stress levels far below expected levels and in a reduction of the mechanical strength of the faults and the surrounding rocks. Further, the authors found that the regions that had the highest pore pressures and the lowest effective stress aligned with the areas known to produce slow slip and very low frequency earthquakes, the first time such properties have been quantitatively co-located. (*Geophysical Research Letters*, doi: 10.1029/2012GL053793, 2012) —CS

More greenhouse gases needed to explain warm Archean Earth

During the Archean eon, from 3.8 to 2.5 billion years ago, life on Earth was thriving for the first time, growing in a world with much less land and a faster planetary rotation than today. At the same time, the energy flowing to the early Earth from the Sun was just three quarters of what it is now. Despite the drastically lower levels of solar irradiance, previous research has suggested that the Archean Earth was not a planet encased in ice but instead remained a watery world. To explain this seeming inconsistency, a dilemma known as the "faint young Sun paradox," researchers have suggested that the planetary greenhouse effect must have been much more potent than today. Previous research suggested that atmospheric carbon dioxide levels would need to have had a partial pressure of approximately 0.06 bar, equivalent to an atmospheric concentration 200 times that of the pre-Industrial modern era.

Using a coupled ocean-atmosphere model that includes representations of meridional ocean circulation and the effect of the ice albedo feedback cycle, systems neglected in previous research, *Kienert et al.* found that the partial pressure of carbon dioxide needed to keep the Archean Earth from freezing over would have been closer to 0.4 bar, nearly 7 times that of previous estimates, and 1400 times pre-Industrial levels. The authors note that the elevated critical carbon dioxide levels for the late Archean are inconsistent with existing geochemical records. They suggest that even the currently favored carbon dioxide–methane greenhouse effect could be insufficient to solve the faint young Sun paradox for the late Archean. (*Geophysical Research Letters*, doi:10.1029/2012GL054381, 2012) —CS

Georg Feulner

An illustration of a possible Archean landscape, depicting a watery world with a much fainter Sun.

Similarities between rivers and submarine channels

Scientists have long known that the width and depth of rivers follows a power law relationship with discharge. They have also noticed that submarine channels appear to be similar to terrestrial rivers, but there have not been many systematic comparisons of the relationships between submarine channel morphology and discharge. *Konsoer et al.* compared the width, depth, and slope of 177 submarine channels to those of 231 river cross sections. They found that submarine channels are up to an order of magnitude wider and deeper than the largest terrestrial rivers, but they exhibit a similar power law relationship between width and depth. For submarine channels that were similar in size to rivers, the authors found that submarine channels tend to be 1 to 2 orders of magnitude steeper than rivers. The authors also inferred values for sediment concentration in the turbidity currents in the channels and combined this with estimated mean flow velocities to look for a relationship between discharge and morphology in the channels. They found that like rivers, the width and depth of the submarine channels follow a power law scaling with discharge. (*Journal of Geophysical Research-Earth Surface*, doi:10.1029/2012JF002422, 2013) —EB

—Ernie Balcerak, Staff Writer, and Colin Schultz, Writer