



IRIS

NEWSLETTER

HELL BHZ $\Delta=90^\circ$ $M_w=8.1$



The M_w 8.1 April 1, 2007 earthquake in the Solomon Islands recorded by Transportable Array station HELL near Mitchell Peak, CA

**For more information, see page 17.*

YEAR 2007 • ISSUE 1

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IRIS Supports NSF Projects Contributing to the IPY

The International Polar Year (IPY) is a large scientific program focused on the Arctic and the Antarctic organized through the International Council for Science and the World Meteorological Organization. This IPY is actually the fourth polar year, following those in 1882-3, 1932-3, and 1957-8. In order to have full and equal coverage of both the Arctic and the Antarctic, IPY 2007-8 covers two full annual cycles from March 2007 to March 2009 and will involve over 200 projects. Thousands of scientists from over 60 nations are examining a wide range of physical, biological and social research topics.

To improve our support to the NSF Office of Polar Programs IPY projects in Antarctica, IRIS plans to acquire next-generation broadband seismic sensors, data acquisition systems, environmental enclosures, and power systems specifically designed for year-round operation in remote polar regions. The instrumentation will be purchased with funding from a Major Research Instrumentation award, building on the successful designs of a joint IRIS/UNAVCO instrument development.

The new seismic stations will become a part of the PASSCAL pool specifically designated for polar work assuring that the extreme environmental conditions, limited installation time windows and challenging logistics can be overcome and experiment success can be maximized. These seismic stations will greatly expand global seismic coverage in the most poorly sampled regions of the world, providing higher resolution images of the Earth's interior addressing questions ranging from Antarctic continental evolution, the nature and distribution of inner core anisotropy and the structure of the crust and upper mantle in the polar regions.

The polar science community will be able to obtain fundamentally new datasets to address outstanding questions about the nature of ice sheet dynamics and climate. As in other recent PASSCAL experiments, seismology will also be used to study and monitor glacial motions, which may be vital for understanding ice sheet stability and the nature of other cryospheric systems. ■



Deploying a PASSCAL seismometer on the giant tabular iceberg C16 in the Ross Sea, Antarctica.

Earthquake-resistant buildings and other structures are the first line of defense in reducing losses from earthquakes. To improve building safety, better knowledge is needed of both the ground shaking and the performance of structures subjected to strong earthquake shaking. While seismologists seek to accurately model how seismic waves propagate across the Earth, so that the size and duration of future ground shaking can be more accurately forecast, earthquake engineers similarly work to understand how structures perform when strongly shaken, so that existing structures can be retrofitted and new ones built to limit future damage.

Thorough understanding of how a structure responds to strong ground shaking is limited today by the scarcity of earthquake recordings within structures. Currently, few buildings in the United States have been extensively instrumented to record their performance during earthquakes – the Factor and Millikan buildings described in this issue are examples of advanced efforts to obtain needed detailed data. This scarcity of data means that engineers must infer the characteristics of structural response to earthquakes when they design buildings. Application of laboratory data is problematic because of difficulties simulating realistic building conditions. Consequently, actual earthquake data are needed to improve seismic performance.

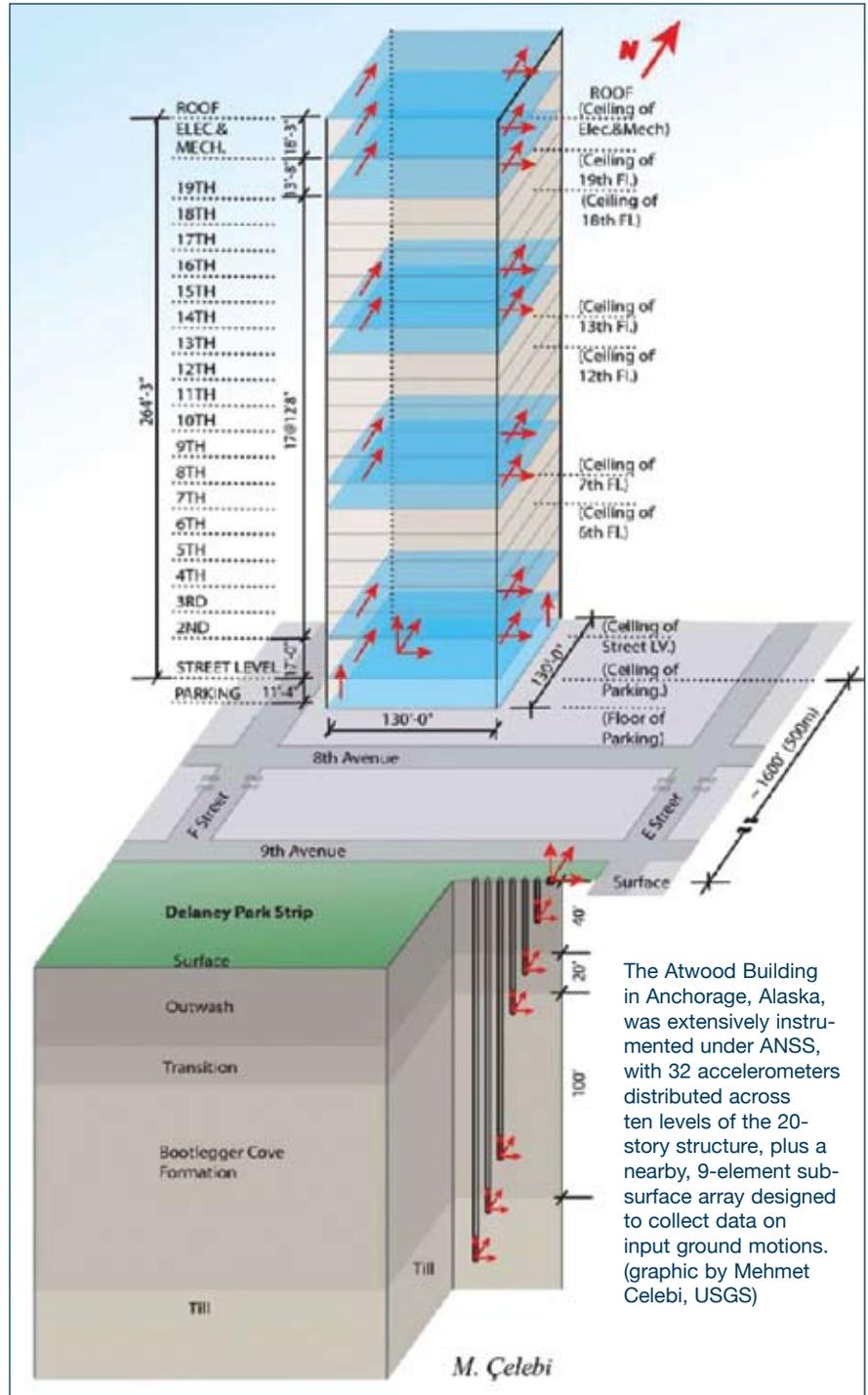
COLLECTING CRITICALLY NEEDED DATA

Ground-motion recordings from networks of sensors in regions of moderate-to-large earthquakes are essential input to predictive models of structural response. Equally essential are extensive recordings from within buildings, bridges, and other structures (pipelines, dams, port facilities), which can be used to evaluate performance, to improve post-earthquake damage assessment, and to improve future structural designs. These data are critical to the evolution of performance-based earthquake engineering, through which structures are designed with predictable and defined seismic performance (see *VISION 2000*, SEAOC, 1995).

Since 2000, the U.S. Geological Survey (USGS) has provided initial funding for a

national program to improve ground and structural recording of earthquake-induced shaking in high-risk urban areas. This effort, known as the *Advanced National Seismic System (ANSS)*, has an eventual goal of placing 9,000 sensors in buildings and other engineered structures around the United States, plus 3,000 ground sensors to obtain accurate measures of shaking across 26 at-

risk urban areas. Together, these structural and ground response monitoring systems will provide earthquake engineers with data to improve structural designs and, hence, performance. Much of the development of this system is being leveraged by contributions from states, educational institutions and the private sector; an example is the sensor deployment at the UCLA →



Factor building. An important parallel effort is the *Network for Earthquake Engineering Simulation* (NEES), an NSF facility supporting advanced research, experimentation and simulation of the ways buildings, bridges, utility systems and geomaterials perform during seismic events.

DOWNSTREAM ECONOMIC BENEFITS

In 2003, the USGS commissioned a study by the National Research Council (NRC) on the economic benefits of improved seismic monitoring. Specifically, the USGS asked the NRC to examine how improved monitoring could reduce future losses and to estimate the benefits that could be realized by the full deployment of ANSS. The committee found that seismic monitoring provides the key to understanding how the built environment responds to significant earthquakes, and specifically that detailed structural response data offer the potential for fine-tuning the design process so that seismic safety requirements are adequately—but not excessively—met. The NRC panel esti-

mated a total building-related annualized loss avoidance of \$142 million per year, nearly three times the projected annual costs of operating the full ANSS.

THE BOTTOM LINE

When ANSS is fully implemented, hundreds of structures will be extensively instrumented. Through this effort, the USGS and its cooperators are poised to greatly expand strong-motion recordings in high-risk urban areas, both on the ground and in buildings, bridges, and other structures. This will provide the earthquake engineering community with the data it needs to improve seismic design practices and thereby reduce future earthquake losses. ■

WEB LINKS TO MORE INFORMATION

www.anss.org • www.nees.org • www.nap.edu/openbook.php?isbn=0309096952 • earthquake.usgs.gov/research/monitoring/anss/docs/ANSS_Guideline_civil.pdf

Incoherent Vibrations Caused by an Earthquake Retrieving the Response of a Building

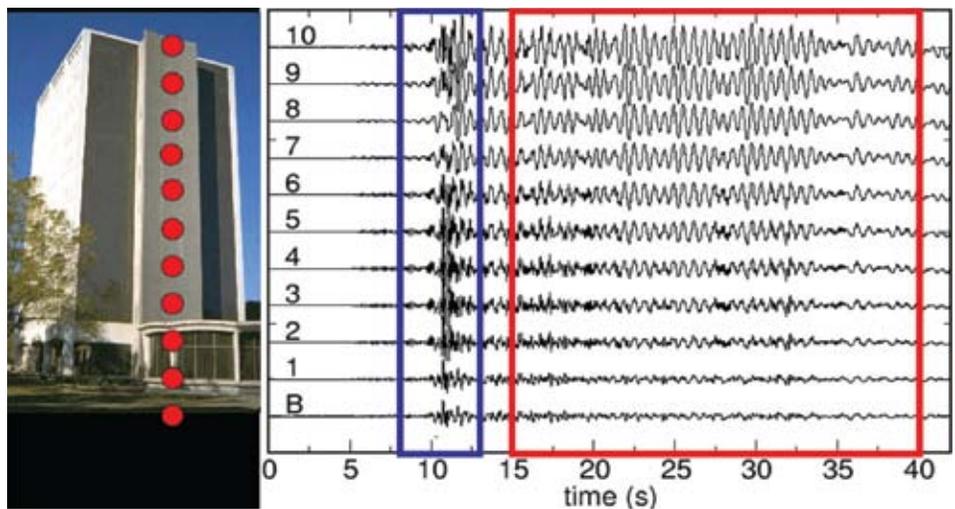
Roel Snieder • Colorado School of Mines

The motion of a building during an earthquake – one of the threats to its structural integrity – depends on not only the shaking by the earthquake, but also on the coupling of the building to the ground and the mechanical properties of the building. Measurements of the motion in the building provide information on the combination of these three ingredients, but structural engineers seek to retrieve the mechanical properties of the building from the recorded motion. A first step in this analysis is to extract the building response from recorded vibrations in the building, which I illustrate using the horizontal motion recorded by accelerometers in the Robert A. Millikan library of the California Institute of Technology.

EXTRACTING THE BUILDING RESPONSE

Recent tutorials give an overview of the rapidly growing field of seismic interferometry, a technique to extract the impulse response of a system from vibrations recorded in that system [Curtis *et al.*, 2006; Larose *et al.*, 2006]. For the Millikan Library, we can retrieve the building response by deconvolving the motion at each level with the motion recorded in the basement [Snieder and Safak, 2006].

The M_L 4.8 Yorba Linda earthquake of Sep 3, 2002, about 50 km southeast of Caltech, caused the Millikan Library



Accelerometers (red circles) are located in the basement and on each of the ten floors of the Millikan Library. The north-south component of acceleration in the west side of the building consists primarily of impulsive shear waves (arriving in the blue box), and surface waves (indicated by the red box).

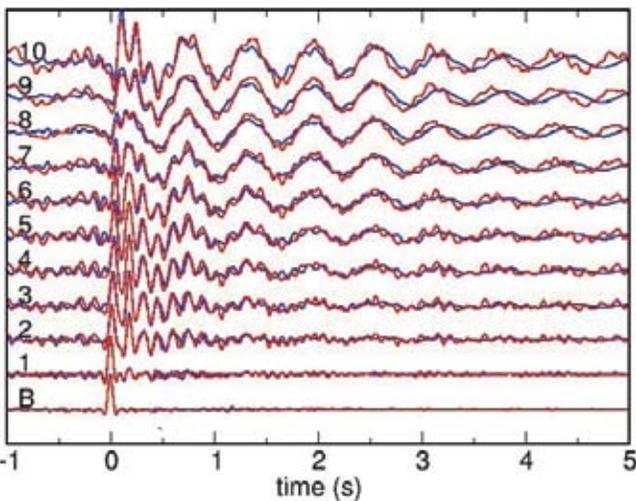
to sway and, as expected, the motion increases with height. After deconvolution with the basement records, we see a superposition of upgoing and downgoing traveling waves for early times ($t < 1$ s), and of a resonance of the building for later times ($t > 1$ s). That is, the building behaves similarly to a plucked guitar string; for early times the motion is best described by traveling waves, while for later times the motion is better characterized by a normal mode. Seismic interferometry has turned the incoherent motion of the building into the building response.

One might expect that the S-waves would give the traveling waves in the building response, and that the surface waves would give the resonance of the building. Instead, perhaps surprisingly, seismic interferometry applied to either the S-waves or to the surface waves each give both the traveling waves and the resonance. The building response is encoded in the spectral properties of the wave motion, and part of the building recorded motion is sufficient to extract the building response. This is reminiscent of holography in optics, where an image of an →

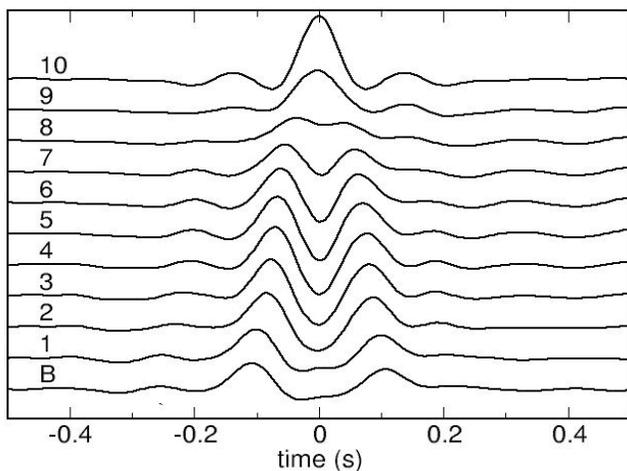
object is reconstructed by the interference of the waves emitted by a hologram and a reference light beam. The hologram is a piece of developed film. When one cuts a hologram in two, the holographic image is still intact, just as the building response can be retrieved from part of the recorded motion in the building.

WHAT IF THE BUILDING HAD A DIFFERENT GROUND COUPLING?

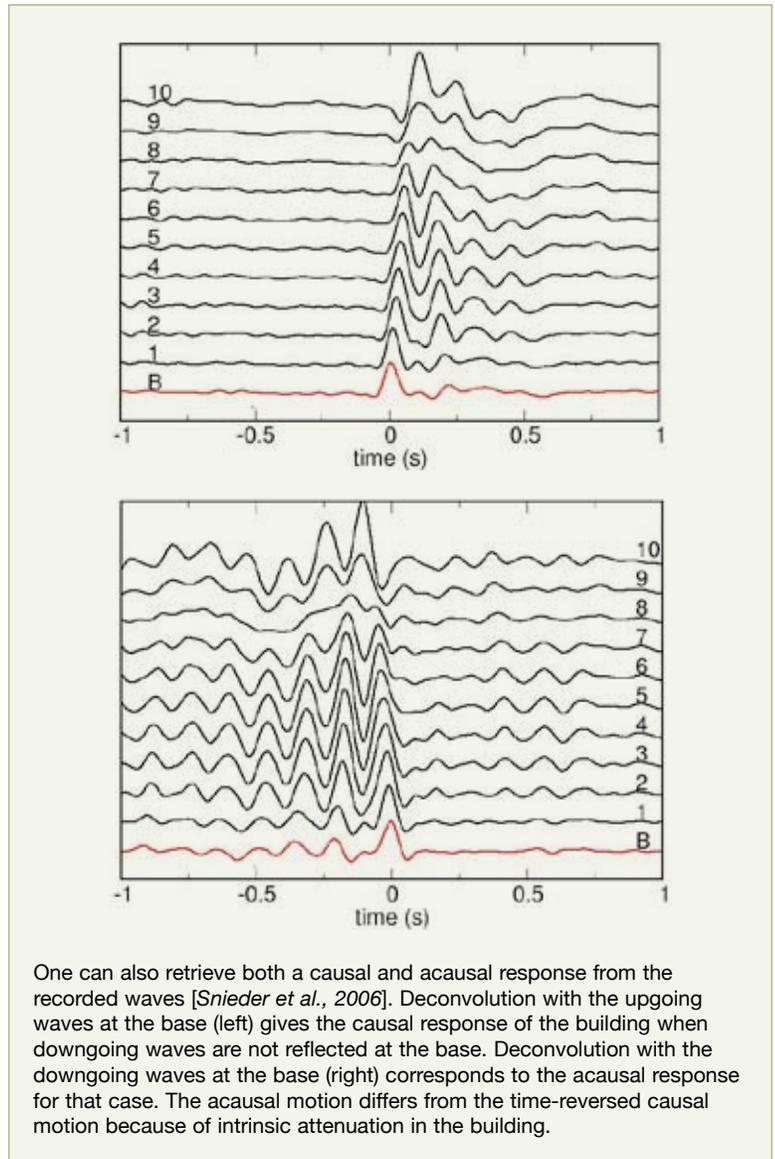
Rather than deconvolving the motion at every floor with the motion recorded in the basement, one can instead deconvolve the motion with the waves recorded at the top floor. Now the response consists of one upgoing wave for negative time, and one downgoing wave for positive time. Note that the downgoing wave is not reflected when it strikes the base of the building around 0.15 s! Of course the real building has a nonzero reflection coefficient at its base because of the large impedance contrast between the building and the subsurface. But in this wave state the downward propagating wave is not reflected upwards, meaning that this is the response that the building would have on a subsurface with an impedance equal to the impedance of the building.



Waveforms after deconvolution with the record from the basement. The blue waveforms are obtained by deconvolution of the S-waves in the blue box of the first figure, while the red waveforms are from the surface waves in the red box.



Waveforms after deconvolution with the record from the top floor.



One can also retrieve both a causal and acausal response from the recorded waves [Snieder *et al.*, 2006]. Deconvolution with the upgoing waves at the base (left) gives the causal response of the building when downgoing waves are not reflected at the base. Deconvolution with the downgoing waves at the base (right) corresponds to the acausal response for that case. The acausal motion differs from the time-reversed causal motion because of intrinsic attenuation in the building.

These examples show that in seismic interferometry one can indeed retrieve the response of the system for a variety of different boundary conditions. We can separate the response of the building from the coupling of the building to the subsurface by processing of the recorded data, and it is not necessary to use a numerical model of the building. The principle of changing the boundary conditions in seismic interferometry also finds application in seismic exploration where, in a collaborative project with Shell Research, we use the pressure and displacement recorded at an ocean-bottom network to remove the waves reflected from the water surface (multiples) from seismic data. ■

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The UCLA Factor Building Seismic Array Monitoring Structural State of Health

Monica Kohler • University of California, Los Angeles; Thomas Heaton • California Institute of Technology

The development of robust designs in seismometer hardware and software is making it more feasible to densely instrument civil structures on a permanent basis in order to study their states of health. The 17-story UCLA Factor building contains one of those cutting-edge structural arrays, recording building vibrations continuously at high sample rates. It is one of only a handful of buildings in the U.S. permanently instrumented on every floor, providing us with information about how a common class of urban structures, mid-rise moment-frame steel buildings, will respond to strong ground shaking and how the response changes as the building is damaged. For example, structural stiffness undoubtedly decreased when welded beam-column connections extensively fractured in numerous moment-frame steel buildings during the 1994 Northridge earthquake. Unfortunately, there are no seismic records from buildings with this type of damage. However, we anticipate that changes should be observable through analysis of vibration data for a well-instrumented building.

In state-of-health monitoring of engineered structures, determining how structural properties change with excitation amplitude, time, and other geophysical and environmental conditions constitutes a major research challenge, especially as the changes relate to rapid damage assessment. Methodologies to design earthquake-resistant buildings are ever-evolving with new understanding of how earthquake shaking impacts a building. While we wait for the infrequent, large amplitude shaking events to record nonlinearities, we are using the valuable, small-to-intermediate amplitude data to characterize the linear behavior of the building-soil system. To complement the data gathering, we have constructed a



three-dimensional model of the Factor building based on structural engineering

Finite-element model of the Factor building showing the major structural features. The model is based on object-based elements such as columns, moment-frame beams, slabs, walls, and beam-column intersections whose properties were obtained from structural engineering drawings (printed with permission from BSSA).

drawings for dynamic analysis of building response to observed and scenario excitation. In a sense, working with the Factor building array is analogous to collecting global seismological data that are evenly distributed over Earth's entire surface and having access to an accurate 3D starting model of Earth structure at relatively small length scales.

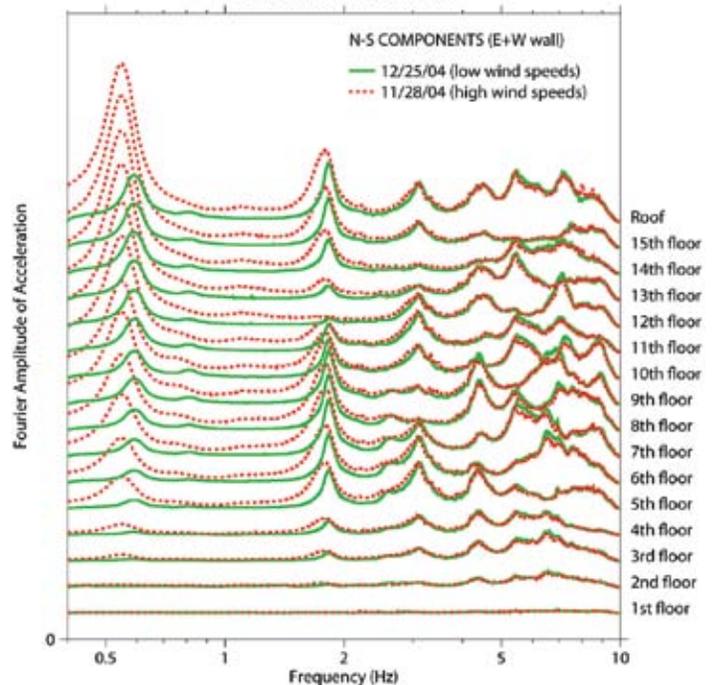
THE FACTOR BUILDING ARRAY

The Factor building is a prototype USGS Advanced National Seismic System instrumented structure for use in structural health monitoring and engineering research applications. The building array comprises 72 channels distributed four per floor and the roof. The horizontal sensors are oriented north-south and east-west along the mid-sections of most floors. GPS receivers for timing are located on the roof. Six channels from nearby down-hole and surface borehole seismometers, and four free-field stations are contributing data to characterize input ground motions and the dynamic interactions between the building and the underlying soils. Two borehole seismometers (one at the surface and one at 100 m depth) are located 25 m east of the Factor building in the UCLA Botanical Gardens. Each consists of a three-component accelerometer connected to a 24-bit digitizer located in a garden shed a few meters from the borehole. The borehole and free-field data are being piped directly into a real-time system controlled by the monitoring software. Two

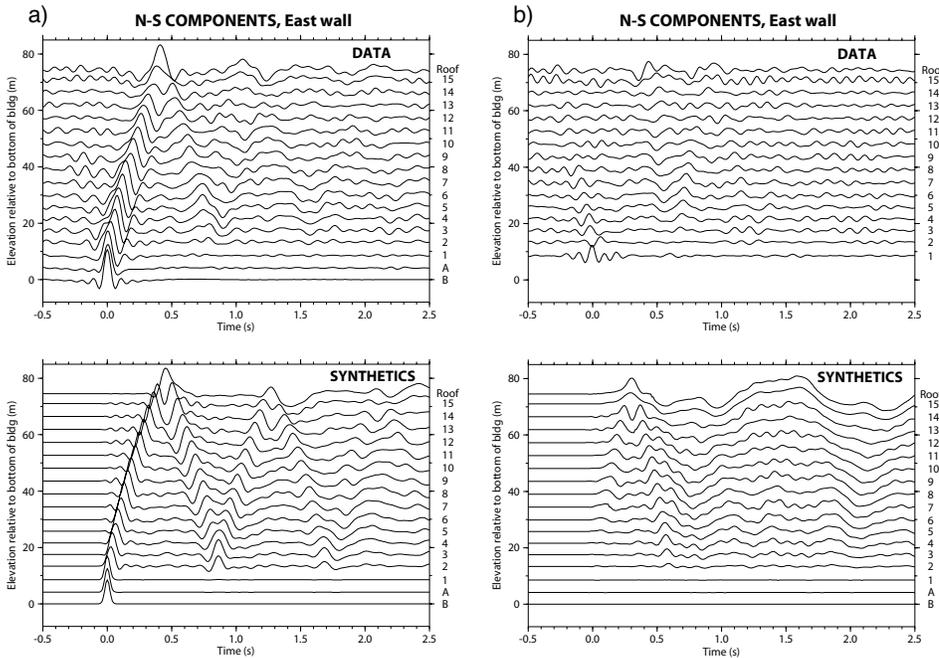
GPS antennas were installed on the roof to test the continuous recording of building displacement and inter-story drift.

In the building's attic, nine 24-bit digitizers record the continuous data in two data streams: one at 100 sps for long term archiving and one at 500 sps on a RAID array from which local and regional earthquakes are being extracted. The data are recorded both on-site and in the seismology laboratory at UCLA. A dedicated fiber optic Internet connection within the Factor building enables continuous data flow from Factor into other laboratories. The building and borehole data can be viewed from the Factor array web site <http://factor.gps.caltech.edu/>.

Fortunately, the IRIS DMC has made archival and subsequent retrieval of the data for general engineering research convenient. The 100 sps data are being archived at the IRIS DMC in miniSEED format and are immediately available for request. The DMC also has the metadata for use in generating the miniSEED files, and for conversion to other data formats. →



Ambient vibration spectral data from the Factor building for two 24-hour periods: one windy day (November 28, 2004) showing a decrease in the north-south horizontal modal frequencies, and one calm day (December 24, 2004). Each curve consists of stacked spectra from one-hour time series. Maximum average wind speeds recorded nearby on the UCLA campus on November 28, 2004 were 25 mph, and gusts were nearly 40 mph.



The north-south translational (left) and torsional (right) response functions for a north-south impulse at the base of the building. These responses were computed from 100-s time series that contained the initial shear wave for earthquakes. The records were bandpass filtered for frequencies between 2.0 and 10.0 Hz to isolate the shear waves whose propagation effects dominated building response. Records for upper floors were each deconvolved by the subbasement record which served as the approximate source input impulse function. Twenty individual impulse response functions were then stacked and compared with simulations using 2% modal damping with a Gaussian curve input in the north-south direction (printed with permission from BSSA).

The DMC has data starting in mid-2005. Eventually the earlier waveform data will be transferred to the DMC.

STRUCTURAL HEALTH MONITORING

With the availability of high-quality building waveform data, structural health monitoring research is making more frequent use of wave propagation methods, in addition to the more traditional modal methods. The combination of frequency change information coupled with that provided by wave propagation properties could constitute the elements of tools for real-time damage detection in instrumented buildings. Towards that end, we are using both time and spectral domain representations of real and simulated building response to understand the relationship between damage patterns and motions recorded in the building.

A tremendous advantage of building waveform data is the ability to observe translational, rocking, and torsional (twisting) motions which can be significant for this type of structure. Torsional motions (including approximate torsions calculated from pairs of recordings) are rarely recorded in buildings; thus their importance in redesigning building codes is often underestimated [Chopra, 2001]. We

have used a technique similar to Green's functions to characterize waves that propagate through the Factor building. Impulse response functions of a building theoretically represent only the building property effects on the wave propagation between receivers. In the case of the Factor building, we obtain an approximate impulse source by deconvolving the subbasement waveform from the upper floors.

We computed the impulse response functions for small and intermediate-size earthquakes recorded by the Factor array, and stacked the resulting waveforms [Kohler et al., 2007]. The stacked results are compared to synthetic waveforms computed for our finite-element model of the building, calibrated with the recorded earthquake data. Both the impulse response functions from the data and the dynamic analysis synthetics show the impulsive shear waves traveling up and down the building. They also show a reflection of the initial upgoing wave from the bottom of the 10th floor for the east-west component of the motion. The building has cantilevered, overhanging sections between the 10th floor and roof on the east and west faces that are supported by diagonal steel braces. They stiffen the upper floors of the building against inter-story shearing in the east-west direction. In effect,

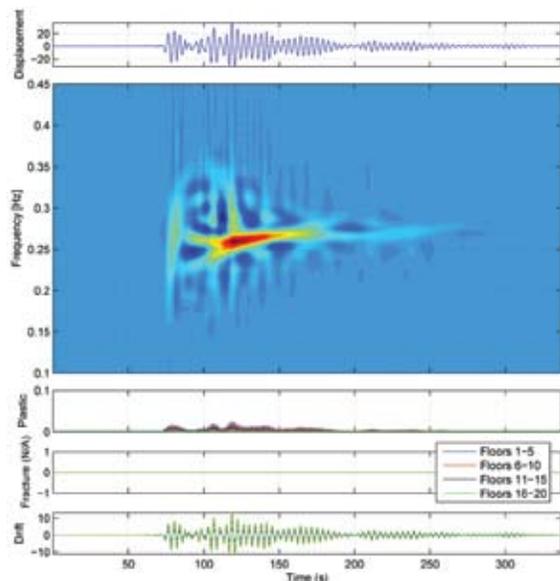
the shear-wave velocity (approximately 150 m/s for a vertically propagating SH wave) increases at the 10th floor.

Both data and synthetics show asymmetry in the excitation of vertically-propagating torsional waves. These torsional waves are due primarily to inter-story shearing in which floors rotate about a vertical axis; this rotation can be obtained by differencing identical components of motions recorded at opposite ends of any floor. When the ground motion is an east-west impulse, the torsions begin immediately at the first floor and then propagate up the building. However, when the ground motion is a north-south impulse, torsional waves do not begin appearing until the north-south shear waves reach the upper floors. The asymmetry in the excitation of torsional motions is probably due to the fact that the building foundation is embedded in the soils of a south-sloping hillside, which means that the ground-level story effectively has a shear wall only on the north face. It may be possible in the future to identify additional torsional motions due to specific types of damage such as cracked welds in one region of a structure. The resulting changes in stiffness may give rise to changes in torsional modes.

We are also investigating new ways to more accurately pinpoint the time at which deviations from linearity occurred as a signature of significant structural damage. Measurable nonlinear effects are occurring for small-to-intermediate earthquake and wind excitation that cause changes in the stiffness of the Factor building-soil system [Kohler et al., 2005]. Modal frequency data show a decrease in frequencies during the shaking events, returning to previous ambient vibration levels soon after the cessation of the shaking.

We have begun to develop a new tool that provides a better compromise between frequency and time resolution than that produced by familiar spectrogram and wavelet techniques [Bradford et al., 2006]. The new tool, based on the Wigner-Ville distribution from quantum mechanics, is a nonlinear transformation that provides a view of the time-frequency decomposition that is more suitable for instantaneously analyzing the changing frequency content in a signal. While the Wigner-Ville distribution provides extremely high resolution, it comes at the expense of interference terms which can be reduced by appropriate filtering. →

In order to assess the usefulness of this new tool, we have applied it to a finite-element model of a 20-story steel frame building that includes material and geometric nonlinearities, plastic steel rheology, and weld fractures. We simulate the inertial motions of every location in the building while also keeping track of the structural characteristics of the building (*e.g.*, plastic rotations, weld fractures). Simulations of the model building subjected to simulated, full-scale and scaled-down motions of the 2003 M_w 8.2 Tokachi-Oki earthquake result in linear and nonlinear behavior whose differences are immediately obvious. The near-linear response for the scaled-down input is



Simulated, time-dependent frequency response (reduced interference Wigner-Ville distribution) of a 20-story steel frame building using scaled-down (left) and full-scale (right) motions of the 2003 $M_w=8.2$ Tokachi-Oki earthquake. The near-linear response (left) is dominated by the fundamental mode of the building, while the nonlinear response (right) shows a marked decrease in building frequency and the generation of an additional modal frequency due to the damaged elements.

dominated by the fundamental mode of the building. However, the nonlinear response for the full-scale input shows a steep decrease in the building frequency during plastic deformation. The nonlinear building develops additional peaks in the waveforms that show up as the two frequencies identified by the new frequency-time algorithm. The long-term goal is to run algorithms based on techniques such as this on embedded structural arrays in order to make near real-time assessments of structural integrity.

FUTURE SOFTWARE AND HARDWARE DEVELOPMENTS USING THE DATA

We are now using our building model to develop a quantitative method of identifying modal and wavefield characteristics from a “damaged building” (*e.g.*, simulated combinations of broken welds, damaged columns, asymmetrically weakened structural elements) to determine what is realistically observable for dam-

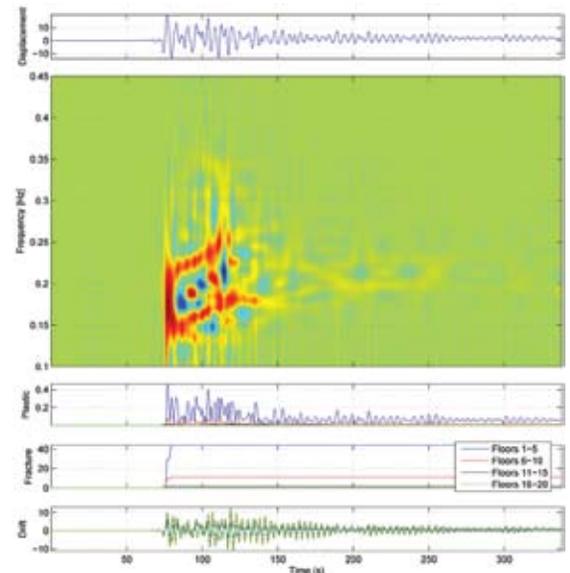
age detection tools. This is where the big challenge lies because it is not clear yet how to address the non-uniqueness of this problem or how to combine the results of numerical modeling in an all-encompassing tool for damage detection. However, because the ability now exists to calibrate the finite-element model with observed earthquake data, damage simulation results can be produced with increased modeling and statistical rigor.

Truly useful structural health monitoring networks need to be designed with processors that can support the execution of algorithms based on damage detection research such as that described here.

However, the process of installing wired networks in structures in heavily populated urban settings such as Los Angeles can take years because of difficulties in obtaining appropriate funding to cover the costs (typically hundreds of thousands of dollars per structure), seeking owner permission, and installing the sensing and communication hardware. Logistical limitations increasingly point to the need for a relatively inexpensive, low-power, easy-to-install network that can complement existing wired networks. This is particularly critical for deployments that are to take place in multiple structures on varying length scales for monitoring and damage assessment.

If we are to reach the goal of quickly deploying dense structural monitoring networks after a large earthquake has occurred, we need to consider innovative hardware and software designs. For example, a network that consists of two levels of complexity would make network reconfiguration based on suspected damage

locations easier [Gnawali *et al.*, 2006]. The higher-level nodes could include a processor on which the algorithms would run continuously, reporting back to a central unit. Lower, more primitive nodes would simply consist of the sensor and digitizer, but these would be in constant communication with at least one higher-level node. The results of the networking software could be used to redeploy nodes during aftershock sequences in areas where significant damage is suspected. The Factor array is being used in side-by-side tests of structural monitoring wireless network hardware and software that have the potential of accomplishing many of these long-term goals. ■



ACKNOWLEDGMENTS

Support for this network is being provided by the USGS Earthquake Hazards Program as a component of the Advanced National Seismic System, and the NSF Center for Embedded Networked Sensing at UCLA.

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AS-1 Operators Workshop

Providing a Foundation for Seismograph Use

Michael Hubenthal, Lora Bleacher • IRIS Consortium

In January, twenty-one classroom teachers from across the United States gathered in the geoscience computer labs of California State University, Northridge to improve their geophysics content knowledge and learn the principles of seismometry. This two-day AS-1 Seismograph Operators Workshop, hosted by Gerry Simila and the Department of Geological Sciences, was offered as part of the IRIS Seismographs In Schools Program; an effort that promotes the installation and effective use of school-based seismographs and seismic data for instruction [Braile et al., 2003].



Teachers discuss the basic principles of seismometry during an activity at the 2006 AS-1 Operators workshop held at Boston College.

“Operators” workshops, staffed by volunteers from the IRIS community as well as IRIS personnel, provide teachers with the basics of setting up and using the seismograph, an overview of software to record the data, instruction in how to manipulate and analyze seismic data, and methods of sharing data locally and across the country. These events are held once or twice annually for teachers that have an AS-1 seismograph, regardless of whether they received it through the IRIS seismograph distribution program or purchased it with their own funding.

The initial AS-1 Operators Workshop in 2004 was a one-day event designed to support teachers as they installed, maintained, and used the seismograph and recorded seismic data in their classrooms.

Since that time, the format of the workshop has evolved to accommodate a more pedagogically sound “hands-on, minds-on” instructional format, which emphasizes both geophysics content knowledge as well as an understanding of the seismograph and associated recording and analysis software. Specific sessions focus on setting-up, calibrating and trouble-shooting the seismograph, the development and use of station catalogues, recognizing patterns in seismograms, epicenter location, and various magnitude calculations. To date, approximately 90 teachers have participated in these workshops.

Evaluations of these workshops have shown that all participants find them to be a valuable use of their time, and that 96% of participants feel they can easily apply the information/skills learned in the workshop to their teaching with limited modification. More importantly, these evaluations have shown that the workshops are capable, even two years following the workshop, of significantly increasing a teacher’s confidence in their ability to set-up and maintain the instrument, to analyze seismic data, and to use the resulting data for instruction with students. Such increases in teacher confidence and subject matter understanding are critical to the successful implementation of the Seismographs in Schools program since research suggests that confidence and content understanding may be linked to reform-oriented science instruction (e.g. the use of instructional activities that involve learners in higher-order thinking skills, inquiry-oriented lessons, and develop relevance between students’ lives and the content [Allinder, 1994; Haney et al., 2002; Khourey-Bowers and Simonis, 2004]). In direct response to these findings, as of January 2007, all teachers receiving a seismograph through the IRIS Seismographs in Schools program are now required to attend an “Operators” workshop before receiving and installing their seismograph. We anticipate this new strategy will further enhance the implementation at all sites and will be continuing to monitor its success.

At the core of the Seismographs in Schools effort is an educational seismograph, the AS-1 vertical seismometer,

and the seismic recording and analysis software designed for use with the AS-1, Amaseis [Jones et al., 2003]. Although simple in design, which is useful for allowing students to grasp the principles of seismometry, the AS-1 is capable of recording both minor local events and large earthquakes around the world in an effective manner [Levy and Taber, 2005]. The robust functionality of the instrument allows teachers to take advantage of the excitement of the “teachable moment” that occurs when the seismograph begins recording an earthquake right in front of students’ eyes [Kafka, 2006; 2003]. Annually the Seismographs in Schools program distributes 15 to 30 of these instruments to schools that apply to the yearly or bi-yearly solicitation. Since the program inception in 2000 over 140 seismographs have been placed in schools around the country. Growing in popularity, the fall 2006 solicitation received more applications than ever before. The 2007 round of selections will begin in March. Applications will be available online at www.iris.edu/edu/AS1.htm and are due by April 30.



A participant at the January 2007 Operators Workshop interprets their seismic data as part of an earthquake location exercise.

The time and energy volunteered by the IRIS membership in the form of online technical support, development of classroom exercises, interaction with teachers at workshops, and other →

resources have greatly enhanced the Seismographs In Schools program making it more effective for both teachers and students. If you are interested in contributing your expertise or other resources to the Seismographs in Schools program or would like more information, please contact Lindsay Wood (lindsay@iris.edu). ■

ACKNOWLEDGMENTS

The volunteers from the IRIS community working at the January, 2007, AS-1 workshop were Larry Braile (Purdue University), John Lahr (US Geological Survey) and Gerry Simila (California State University, Northridge).

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Command Line Toolkit Using SOD While Learning (Almost) Nothing New

Tom Owens • University of South Carolina

The latest release of SOD, Standing Order for Data (<http://www.seis.sc.edu/SOD>), contains an exciting new set of simple to use tools to retrieve commonly needed seismic information and waveforms. SOD has always been an extremely powerful tool for accessing seismic archives worldwide, but that power came at a price. Simply stated, you have to learn something new to use SOD directly! Now, with the introduction of the CLT, Command Line Toolkit, the power of SOD is available for common tasks with little effort. The four CLT tools are `find_events`, `find_stations`, `find_responses`, and `find_seismograms`. Each does what you might expect, bringing back events, stations, responses and seismograms based on simple arguments to the CLT tools.

Behind each of the CLT tools is SOD, behind SOD is the DHI (Data Handling Interface). The CLT utilities merely use custom SOD recipes and fill in values based on the command line arguments and passes them to SOD for execution. One beneficial side effect of this is that the CLT can be used to generate SOD recipes for further customization (and to help those who *do* want to learn something new!). Making small changes to a working recipe is much easier than starting from scratch, and so these tools lower the learning curve needed to make use of the full power of SOD.

To illustrate the use of these new tools, we will use them, along with Generic Mapping Tools, GMT (<http://gmt.soest.hawaii.edu>), to generate the map shown at right. First, we apply a standard GMT command to generate a map with grey land and a border.

```
pscoast -R-130/-120/40/50 -JM6 -B2 -G220 -Di -P -K > map.ps
```

Next, we want to find events within -130° to -120° longitude and 40° to 50° latitude so far during 2007. The output of `find_events` lists these events in a format that can be piped directly into the `psxy` command of GMT.

```
find_events -b 2007 -R-130/-120/40/50 | \
psxy -R-130/-120/40/50 -JM6 -G0 -Sc.1 -O -K >> map.ps
```

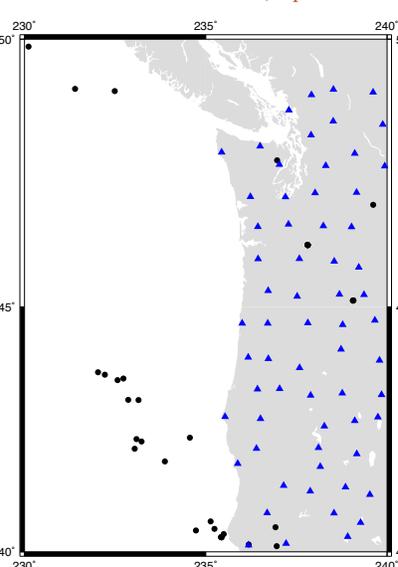
Next, we will find all of the new USArray stations within this region by using the network code TA. Again the output of `find_stations` can be piped directly into the GMT `psxy` command. This completes the map.

```
find_stations -R-130/-120/40/50 -n TA | \
psxy -R-130/-120/40/50 -JM6 -St.1 -G0/0/255 -O >> map.ps
```

Lastly, we will retrieve the seismograms for events over magnitude 5 on the map for each station. To do this we make use of the CLT's ability to output a SOD recipe via the `-r` option. We use the same `find_events` (with a `-m 5` added restrict the magnitude) and `find_stations` commands that we used in the map generation, piping the output recipe to the next tool in line. In this case, `find_events` and `find_stations` don't actually do any work, but simply forward their recipe on to the next tool. All actual data retrieval is done by the last tool, `find_seismograms`.

```
find_events -b 2007 -m 5 -R-130/-120/40/50 -r | \
find_stations -R-130/-120/40/50 -n TA -r | \
find_seismograms -c BHZ -B -2P -E 5S
```

In this case, we request BHZ channels for 2 minutes before the P-wave until 5 minutes after the S-wave. All travel-times are calculated with the TauP Toolkit (<http://www.seis.sc.edu/TauP>).



Map generated with a three-line shell script using CLT and GMT.

this command, a directory called seismograms will be in the current directory. Inside will be one subdirectory per event, and in those will be SAC files with the seismograms. The above command delivered 127 seismograms to our laptop in under 7 minutes.

We think that the SOD's new Command Line Toolkit is the greatest thing since, well, since SOD itself, and hope it will be as useful to the community as it has been to us. Please give the CLT a try. ■

The TUCAN Broadband Seismometer Experiment

Probing Mantle Melting in the Nicaragua-Costa Rica Subduction Zone

Geoffrey A. Abers • Boston University; Karen M. Fischer • Brown University; Marino Protti • Universidad Nacional, Costa Rica; Wilfried Strauch • Instituto Nicaragüense de Estudios Territoriales, Nicaragua

VOLCANIC ARCS

Despite decades of research, the origin of arc magmas remains somewhat of a mystery. Cold material is advected into the earth's interior at subduction zones, yet melting occurs. The trigger for that melting probably relates to the flux of fluids originating from metamorphic devolatilization within the descending plate,

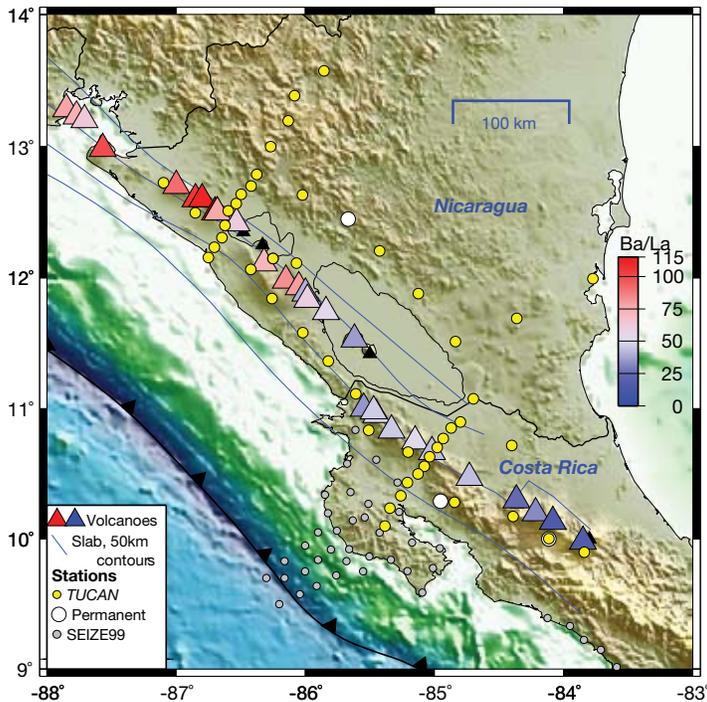
or perhaps the advection of hot material upward by corner flow within the wedge. A variety of slab-derived fluids appear in arc magmas, indicating great variation between and within arcs in both the extent of melting and the contribution from slab-derived fluids. This processing of materials input at the trench to form arc magmas has been termed the Subduction Factory,

and is the basis of one of the NSF MARGINS Initiatives. Central America is a critical place for testing theories of arc melting, because nearly the global range is observed in geochemical proxies for slab-derived fluids. In central Nicaragua, the global maximums are achieved in ^{10}Be , a short-lived isotopic tracer of the shallowest subducted sediments, and a variety of other elements enriched in subducted sediments and altered oceanic crust such as Ba. Within 300 km along strike to the southeast, in central Costa Rica, nearly all of these tracers

are absent from primitive arc lavas, and geochemical indicators of the maximum extent of melting also appear to be lower [e.g. Carr et al., 2003]. Recent direct measurements of water contents within arc basalts show a systematic decrease from Nicaragua to Costa Rica [Wade et al., 2006]. Thus the Subduction Factory operates very differently over a short distance in a single arc. For that reason, Central America was chosen as a MARGINS Focus Site, leading to a great deal of work there in the past decade. Seismology could hold the key to understanding the causes for these variations in melting process, and hence the origins of arc volcanism. Geochemistry describes the inputs and outputs of the Subduction Factory, but seismic imaging lets us look inside. The potential for discovery comes from the varying sensitivity of commonly observed seismic parameters (V_p , V_p/V_s , Q_s , anisotropy, etc.) to temperature, melt, and composition, as well as the ability of seismic waves to image the interfaces that define the geometry of subduction.

THE TUCAN EXPERIMENT

To that end, we designed and carried out a broadband field experiment across Nicaragua and Costa Rica, TUCAN (Tomography and other things Under Costa Rica And Nicaragua). We deployed 48 PASSCAL broadband seismographs starting in July 2004, with the main phase ending in March 2006 and final instrument recovery in November 2006. The experiment →



Circles show broadband seismographs with TUCAN stations in yellow. Blue lines show depth to slab at 50 km intervals. Triangles show volcanoes, color-coded by the element ratio Ba/La in lavas. This ratio is often used to represent the contribution of slab-derived fluids to arc lavas (Carr et al. 2003), and varies over its global range from a high in central Nicaragua to near-MORB background in Costa Rica.

Volcanoes Momotombo and Momotombito, Nicaragua.





Catherine Rychert, Victor Gonzalez and Ellen Syracuse installing station FINA in the Costa Rican fore-arc, July, 2004.

features two dense arc-crossing lines optimized for teleseismic P-coda imaging across two sections that best show the contrast in arc geochemistry, and following older refraction surveys; additional stations provided sparse along-arc coverage.

The deployment is almost equally divided between two countries, Costa Rica and Nicaragua, which speak a common language but have many differences in culture, politics, and customs laws. In Costa Rica, our partners are Marino Protti and Victor Gonzalez from OVSICORI (Observatorio Vulcanológico y Sismológico de Costa Rica), a research institute affiliated with Universidad Nacional. The facilities at OVSICORI, in Heredia, served as a base for the deployment in July, 2004 and subsequent servicing by Protti and Gonzalez. Sites were mostly located on private lands, typically in a farm or ranch. In Nicaragua, we collaborate with Wilfried Strauch and the Geophysics group at INETER (Instituto Nicaragüense de Estudios Territoriales), the agency that monitors earthquakes nationally. The August, 2004 deployment built on the lessons in Costa Rica, and proceeded efficiently despite greater difficulty with customs and transport. Between the two countries, we were able to import, test, deploy and recover initial data from all 48 instruments within about 5 weeks of fieldwork.

With the hard work and 4-8 week visits by the INETER and OVSICORI groups, the TUCAN stations enjoyed exceptional reliability. After 12 months we estimated 96% successful data recovery, somewhat higher than the GSN. Reliability dropped after the second wet season, in September-

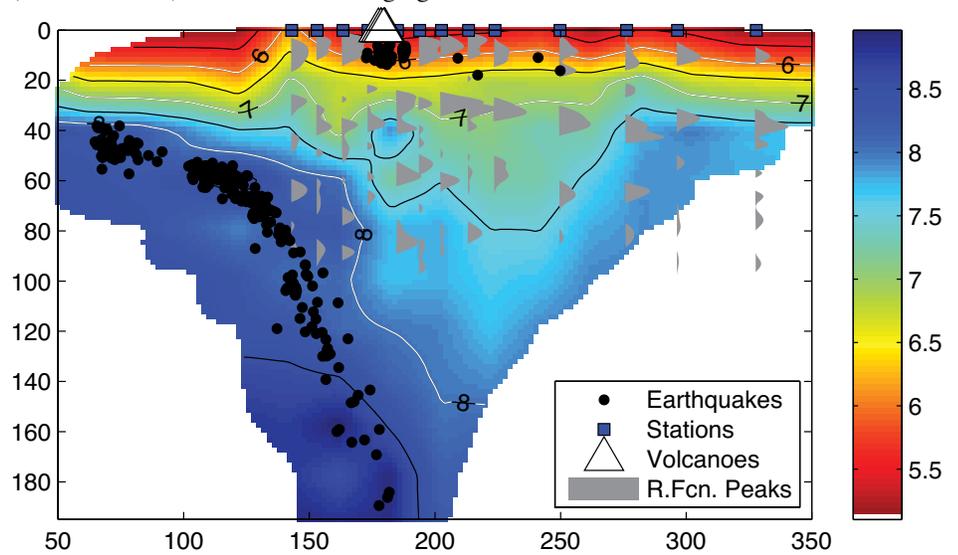
October 2005, but we were able to recover well over 90% of all possible data, lost only one sensor to flooding, and encountered virtually no problems with theft or vandalism. All data were processed at Boston University, and delivered via PASSCAL to the IRIS DMC.

INITIAL IMAGING

In the first round of analysis, these data are being run

through the gamut of seismological tools, including joint inversions of P and S travel times for velocities and hypocenters (E. Syracuse, BU), inversion for attenuation structure (C. Rychert, Brown), receiver-function imaging of interfaces (L. Auger, BU), 3D inversion of shear-wave splitting for anisotropy (D. Abt, Brown), search for anomalous low-frequency events (J. Brewer, BU), surface-wave imaging

of km below the Moho behind the volcanic front, unusually low. In receiver functions, the Nicaragua Moho itself is sharp behind the volcanic front and in the backarc but becomes faint or complicated beneath the arc and forearc. The along-strike line and Costa Rica transect both show a similarly complicated conversion structure, with low back-arc mantle velocities. Sub-solidus temperature variations cannot produce the low velocities seen behind the arc, indicating likely contributions from melt, although the presence of residua from magmatic differentiation cannot be ruled out. The forearc wedge, or region trenchward of the volcanoes and above the Wadati-Benioff zone, shows relatively elevated velocities and sharply higher Q. Similar patterns are seen in many subduction zones [e.g. Stachnik et al., 2004], and indicate that the forearc is quite cold, probably isolated from the main mantle flow. The pattern of velocity anomalies beneath Costa Rica is more complicated, but velocities are generally higher than in the Nicaragua mantle wedge. Similarly, the mantle wedge beneath Costa Rica exhibits significantly less shear attenuation. These results are



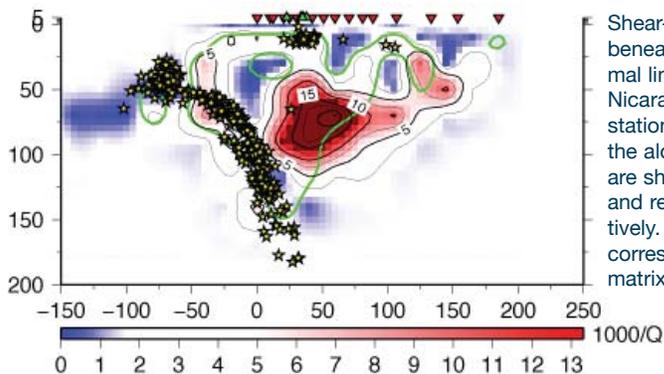
P-wave velocities and receiver functions beneath the arc-normal line of stations in Nicaragua.

(M. Salas, Brown), and a pair of studies of aftershock sequences for large earthquakes (S. French, Brown; G. Reyes, BU; L. Warren, University of Arizona). We present a flavor of these results here.

The most obvious pattern seen in both velocity and attenuation imaging is the first-order distinction between fast, cold slab and a hot, low-V, low-Q wedge. The pattern is clearest in Nicaragua, where velocities near 7.5 km/s are seen for 10's

consistent with cooler temperatures or less hydrated mantle beneath Costa Rica, thus correlating with the geochemical data that suggest less water and lower extents of melting. A rigorous comparison of V_p , V_p/V_s , and Q may allow some assessment of where in the system melt is forming.

Within the downgoing plate, the seismic zone itself is only a few km wide, < 10 km wide where hypocentral uncertainties are lowest. Even though the starting model →

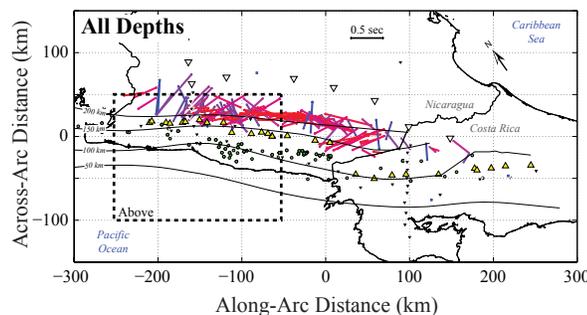
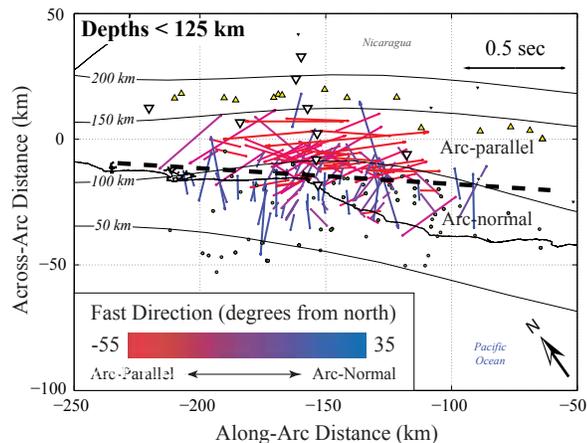


Shear-wave attenuation beneath the arc-normal line of stations in Nicaragua. Events and stations within 50 km in the along-arc direction are shown by yellow stars and red triangles, respectively. Green contours correspond to a resolution matrix diagonal of 0.4.

for the inversions include fast slabs, lower velocities are recovered in the region of the slab just below the Wadati-Benioff zone seismicity. While the thickness of this lower-velocity zone within the slab is poorly constrained, these observations are consistent with hydration of the subducted crust and underlying mantle forming low-velocity minerals such as serpentine that carry water to the deep Earth.

Resolving the geometry of flow in subduction zones is essential to understanding mantle wedge thermal structure and melting processes. Shear-wave splitting measurements from local events recorded by the TUCAN array are dense and fairly complex, but subsets of the data reveal arc-normal fast directions in the fore-arc, where waves sample the shallow wedge corner, while arc-parallel fast directions dominate large regions beneath the arc and back-arc. Using an iterative, damped, least-squares inversion to solve for crystallographic orientation and fabric strength, we find a 3D model of anisotropy in which olivine a-axes vary in the mantle wedge beneath the arc and back-arc. Significant volumes of roughly arc-parallel anisotropy exist throughout the model, and in the shal-

low mantle wedge corner, a-axis alignment tends to be more arc-normal. Splitting in SKS and other teleseismic core phases shows a more uniform pattern of arc-parallel fast directions and much larger splitting times, indicating significant arc-parallel anisotropy is present both deeper in the mantle wedge and/or beneath the subducting plate. The presence of anisotropy with an arc-parallel fast direction in the mantle wedge beneath the arc and back-arc cannot be explained by simple 2D arc-normal corner flow, even allowing for the presence of B-type olivine LPO in the shallow wedge corner [e.g. Kneller et al., 2004]. The anisotropy could be explained by 3D flow with a significant arc-parallel component in the mantle wedge. Thorough modeling is still required to evaluate the plausibility of such flow and its implications for melting processes, but potential drivers include flow around the slab edge beneath southeast



- Splitting Vector
- Permanent Station
- Slab Surface Contour
- Arc Volcano
- Station (plotted splits)
- Hypocenter (plotted splits)
- Other TUCAN Station

Shear-wave splitting for events from depths <125 km to Nicaraguan fore-arc stations (top) and for events from all depths to Nicaraguan back-arc stations (bottom); all 791 splits (not shown) are denser and more complex. Splitting vectors are color-coded to emphasize their orientation and their length reflects splitting time. Measurements are plotted at path mid-points.

Costa Rica, steepening of the slab to the northwest beneath Nicaragua, and slightly oblique subduction of the Cocos Plate. ■

ACKNOWLEDGMENTS

The TUCAN experiment team includes Ellen Syracuse and Laura S. Auger of Boston University, Catherine A. Rychert, David L. Abt and Mariela Salas-de la Cruz, of Brown University, J. Marino Protti and Victor Gonzalez of Universidad Nacional, Costa Rica, and Wilfried Strauch of Instituto Nicaragüense de Estudios Territoriales, Nicaragua. Many thanks to the staff of the PASSCAL Instrument Center, in particular Tim Parker for his excellent help in the field. Pedro Perez and Allan Morales of INETER were essential to array deployment and maintenance in Nicaragua and Alexis Walker (Brown) and Gustavo Reyes (BU) provided valuable field assistance. The TUCAN experiment was funded by the NSF MARGINS Program through OCE-0203650 and OCE-0203067.

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Footquakes

Garrett G. Euler, Doug A. Wiens • Washington University in St. Louis; Katy M. Lofton • University of Missouri, St. Louis



AP/WIDE WORLD PHOTOS

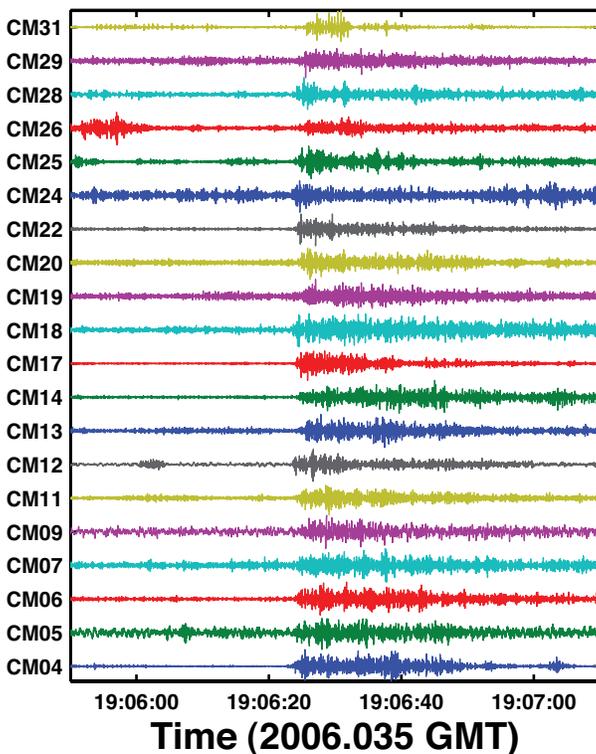
We were puzzled over a number of strange seismic signals recorded by the broadband seismometer array deployed at the start of 2006 as part of our Cameroon Seismic Experiment. The strange tremors were characterized by high frequencies (>1Hz) and a simultaneous onset throughout the country (zero ray parameter). No physical disturbance in the earth should be able to propagate across the country so rapidly, so why did these signals appear

to do just that? With a little help from a non-seismologist's intuition, we reasoned out this mystery once we realized all the enigmatic phases were perfectly aligned in time with goals scored by the Cameroon National Football team in the 2006 African Cup of Nations. The "quakes" actually were the lively celebrations of entire villages and cities of Cameroonians watching television broadcasts of the games.

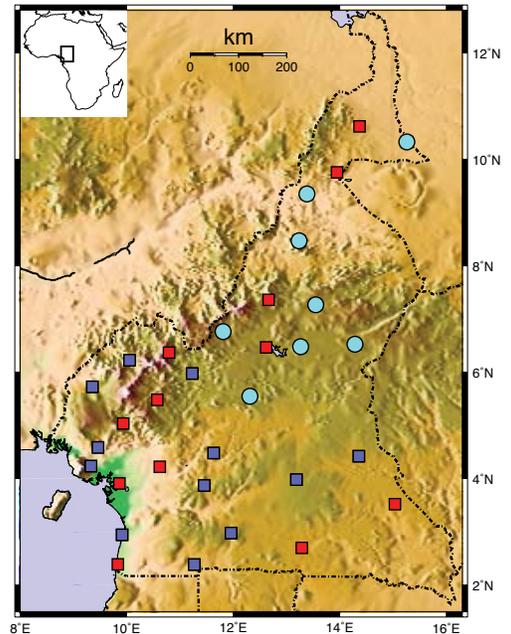
The Cameroon Lions scored eight goals in their four matches of the tournament, all of which had an associated "footquake". Closer inspection also revealed

that the strength of the footquakes varied between each goal. Goals occurring early in the games corresponded to tremors with a weak signal-to-noise ratio, while goals that came later in a match – when the tension was near the boiling point – caused substantially larger tremors. One of the strongest came as a result of a Cameroon overtime goal that sent the match into a double overtime shootout with the World Cup-qualifying Ivory Coast team on February 4th, 2006.

The signal was recorded by two-thirds of the stations in the array, with some of the stations as far as 1200km away from one another, and was recognizable on all three components of each station. Furthermore, differences observed in the amplitudes between the stations and an apparent trend that stations located in the northern provinces of Cameroon exhibit a shorter coda for the footquake compared to those in the south may be indications of variations in local attenuation structure, participating population size and even the strong cultural differences between these two regions. Seismic stations that did not record the dramatic tremor were generally far from large population centers or were in remote locations with no television reception.



Vertical component recordings of the February 4th, 2006 "footquake" from an overtime goal.



Broadband seismometer locations in Cameroon. Stations that recorded the February 4th, 2006 "footquake" with a long coda are indicated by blue squares, those with a short coda by light blue circles, and those that show no signal by red squares.

The footquakes were not just limited to Cameroon goals though; several more also correlated with other events in the games: near misses, penalty shots, the double overtime shootout, and opponent team goals can be picked out as well. A dull seismic roar echoed through Cameroon for hours after each game as everyone celebrated and crowded the streets on their way home. Such strange tremors, while regarded as high frequency cultural noise by us seismologists, are the testimony of Cameroon's intense passion for football.

CAMEROON SEISMIC EXPERIMENT

The Cameroon Seismic Experiment is a two-year PASSCAL deployment by Washington University and Pennsylvania State University with the objectives of imaging the crustal and mantle structure of the Cameroon Volcanic Line and aid in delineating its origin and evolution. The array consisted of eight initial broadband stations deployed in January of 2005 and expanded to 32 stations in January of 2006. Stations were removed in January 2007 and data are now being analyzed using body and surface wave tomography and receiver function methods. ■

Long-term Instrument Loans

Leveraging Resources for Research, Hazard Mitigation, and Capacity Building

Ray Willemann • IRIS Consortium

At its 2006 Workshop, IRIS announced plans to loan refurbished RefTek-72A data loggers for use in permanent geophysical observatories. IRIS's goals for the loans are to

- Help densify global coverage of stations offering free and open data access by complementing other efforts to expand or establish permanent broadband seismic networks.
- Advance partnerships and encourage IRIS Affiliates to adopt standards and policies that support free and open data exchange.
- Advance Earth sciences in regions that would benefit from the introduction of digital broadband instrumentation.
- Foster capacity building by making loans to institutions with a technical capability to operate instruments independently and an intention to educate students.

IRIS modeled the loan initiative, in part, by AfricaArray (<http://africaarray.psu.edu>), an initiative to promote coupled training and research programs for building and maintaining a scientific workforce for Africa's natural resource sector. Pennsylvania State University and the University of Witwatersrand conceived of AfricaArray and were able to use IRIS's offer of refurbished instruments and data management services to leverage funding from a wide range of sources that include the US National Science Foundation, the South African National Research Foundation, and private industry.

The IRIS Board of Directors has approved instrument loans for three projects thus far. Ambitious plans envision regional monitoring that is integrated into the worldwide community through exchanges of data and expertise that complement the transfer of instruments.

UNIVERSITY OF DHAKA, BANGLADESH

Bangladesh is situated on the northern end of the India-Burma subduction-convergence boundary and has a history of large damaging earthquakes, including the 1897 Assam (NE India) earthquake to the north and the 1762 Arakan earthquake to the south. The next further to the south was the 2004 Sumatra-Andaman earth-



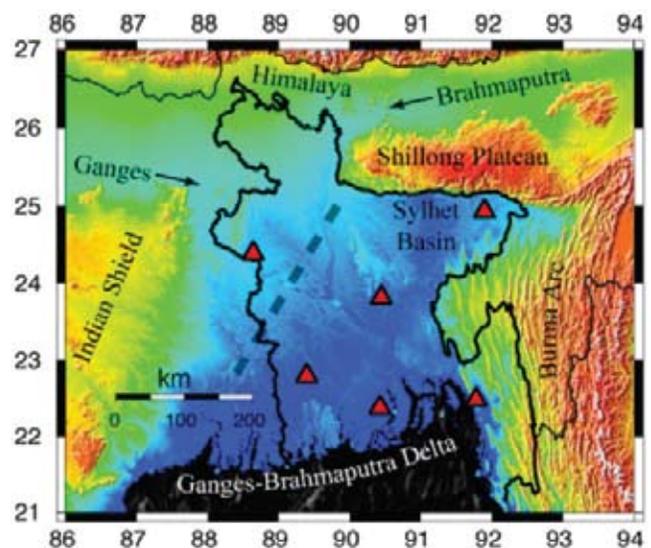
Curzon Hall on the Science Campus of Dhaka University is the site of a vault with a permanent seismic station installed by Humuan Akhter with help from Nano Seeber and Michael Steckler of LDEO.

quake, which greatly increased awareness of seismic hazard in Bangladesh. But this hazard is poorly known in part because the rupture history of the Tripura segment of the subduction zone through Bangladesh is unknown and in part because local instrumental earthquake recordings have been lacking.

Humuyan Akhtar of Dhaka University, Bangladesh, has worked almost continuously over the past several years with Nano Seeber, Michael Steckler and other geoscientists at Lamont-Doherty Earth Observatory (LDEO) as they carried out a series of NSF-funded research projects that included the development of a university-based network of continuous GPS stations. A newly funded LDEO project will establish a temporary network of six PASSCAL-instrumented seismic stations in the Burma Arc foldbelt and support two Bangladeshi graduate students, focusing on joint

analysis of the geodetic and seismological data. The NSF award provides funds for maintenance of the seismic network and travel funds to support extended visits by Humuyan and the students to US institutions for training and collaboration.

Leveraging the time that LDEO investigators will spend in Bangladesh carrying out this project and the skills that Humuyan and his students will acquire, Dhaka →



A series of NSF-funded LDEO research projects have facilitated progressive development of geophysical monitoring infrastructure in Bangladesh.

University instigated plans for a network of permanent seismic stations. With help from the University Grants Commission – Bangladesh’s analog to NSF – Dhaka joined universities at Sylhet, Chittagong, Rajshahi, Khulna and Puatakhali in a consortium to operate seismic stations on or near each campus. Each university is installing a vault at its own expense, LDEO is providing sensors, and the data will be recorded on IRIS RefTek-72As.

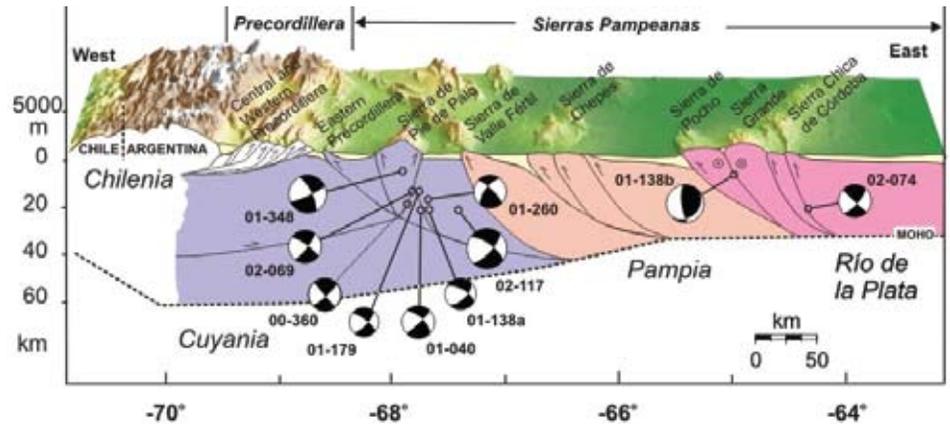
LDEO plans additional research in Bangladesh for the foreseeable future and development agencies – such as the Asian Development Bank – will be asked to contribute funding for interim operations and further development in instrumentation and personnel. Coordinating their plans with LDEO and the Meteorological Department, the new Bangladesh university consortium hopes in a few years to install five stations widely spaced over the Ganges-Brahmaputra delta and the Burma Arc foldbelt east of the delta.

INPRES-UNSJ, ARGENTINA

The Precordillera and Sierras Pampeanas of west central Argentina saw five large, damaging earthquakes during the 20th century including, in 1944, extensive destruction and over 10,000 deaths – the greatest loss of life from a natural disaster in the Argentinean history. Instituto Nacional de Prevención Sísmica (INPRES) operates a national earthquake monitoring network and has accrued an earthquake catalog that spans several decades. INPRES developed a national hazard assessment based on their catalog and participates in regional and international projects. Because funding is limited, however, the INPRES network is predominantly short period.



The M_w 7.0 earthquake of 1944 on an eastward dipping thrust fault in the Argentine Precordillera caused extensive destruction in San Juan [modified from Diario de Cuyo, Argentina, 2004].

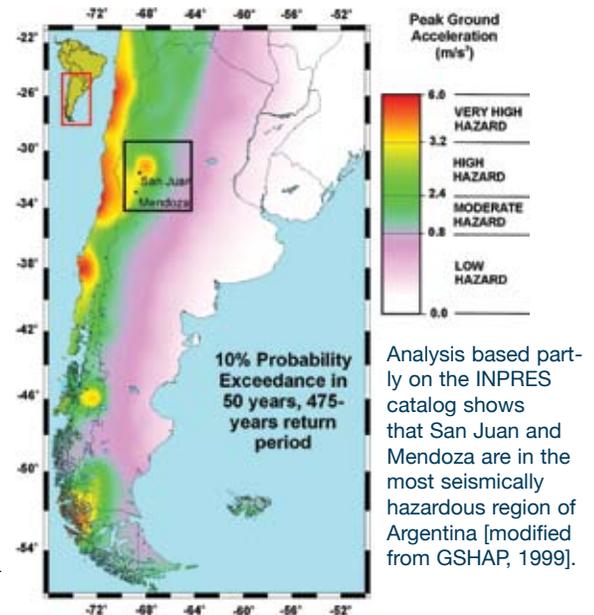


Geologically mapped thrusts in north-central Argentina dip both east and west; moment tensor inversions demonstrate that large crustal earthquakes occur on both sets of faults [modified from Alvarado et al., 2005].

Patricia Alvarado joined the faculty of Universidad Nacional de San Juan (UNSJ), Argentina, last year after completing her Ph.D. studying with Susan Beck. Working at the University of Arizona with data from the PASSCAL experiment CHARGE, she learned to use broadband data for computing higher order earthquake and earth structure parameters. Patricia returned home intending to collect more broadband data in Argentina, expanding on the information available for earthquake hazard assessment.

Patricia and Alejandro Giuliano of INPRES jointly developed a successful proposal to borrow RefTek data loggers from IRIS and mate them with sensors owned by INPRES, including seven Guralp 40T broadband seismometers. Ten permanent stations will form a core regional broadband/intermediate period network and the investigators

are exploring possibilities for telemetry, both to make operations more efficient and to facilitate a real-time monitoring. Data acquired from improved station coverage around San Juan will facilitate computation of regional moment tensor solutions and help characterize active



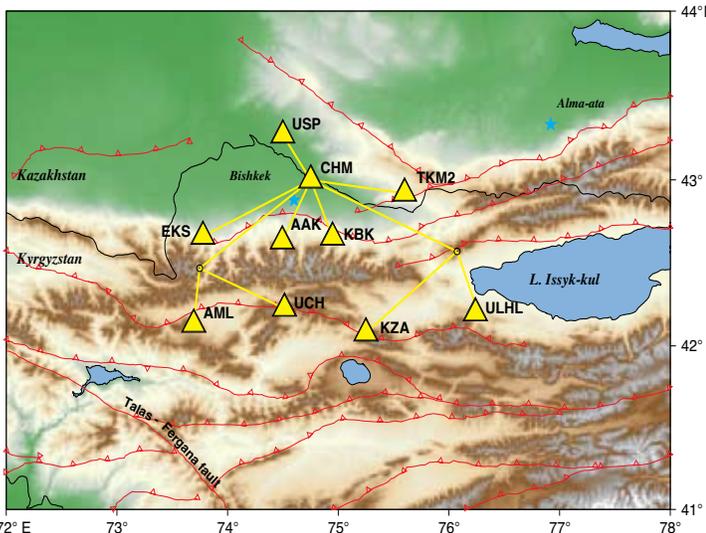
Analysis based partly on the INPRES catalog shows that San Juan and Mendoza are in the most seismically hazardous region of Argentina [modified from GSHAP, 1999].

faults, including suspected blind thrusts. Integrating information about faults with improved crust and upper mantle models, a comprehensive research and educational program is expected to improve assessment of the seismic hazard near San Juan, a province of about 600,000 inhabitants.

The new deployment will be coordinated with an upcoming 40-station University of Arizona experiment to study the flat slab region of Argentina, which is planned to use next-generation PASSCAL instruments for two years and has already been approved for funding NSF. Working together, INPRES, UNSJ and Arizona students will gain experience configuring and installing the instruments, downloading and managing the data, and performing a range of different analyses. The ten stations that continue operating after the experiment are expected to help INPRES and UNSJ develop further research and hazard mitigation projects.

KNET, KYRGYZSTAN

Research Station of the Russian Academy of Sciences (RAS) has maintained the Kyrgyz Seismic Network (KNET) since it was constructed in northern Tien Shan in 1991. KNET consists of



The Kyrgyzstan Seismic Network consists of ten stations around Bishkek that have operated reliably since 1991.

ten 3-component broadband stations, three repeater sites and two data collection centers – at the Research Station of RAS and the Kyrgyz Institute of Seismology. KNET was upgraded in ten years ago with new communications equipment and firmware for the data loggers. Since then, engineers at Research Station of RAS have been



The east repeater site in the Tien Shan relays data from stations TBD1 and TBD2 to Bishkek.

solely responsible for the operations and maintenance of KNET. Consultants from the University of California, San Diego (UCSD) have advised on repairs, while UCSD and IRIS have provided spare equipment that could not be secured locally.

KNET has been delivering continuous data in near real-time to the DMC with a

rate in excess of 96% for the past several years, and works closely with DMC staff to identify and rectify data and communications outages. But the KNET data loggers are aging, and though their productivity is still high, maintenance issues are increasing.

Parts for the data loggers are no longer available from RefTek and KNET was at risk of losing capacity indefinitely in the event of a severe failure.

Working with UCSD, Research Station of RAS developed a plan to adapt the refurbished IRIS RefTek-72As for use in KNET. IRIS data loggers were shipped to UCSD, which is modifying the firmware for compatibility with

KNET systems and shipping them onward to Bishkek. Research Station of RAS has adequate spare parts of other station components even in the event of catastrophic failure, and these instrument loans are expected to ensure continued, high up-time operation of KNET for years to come.

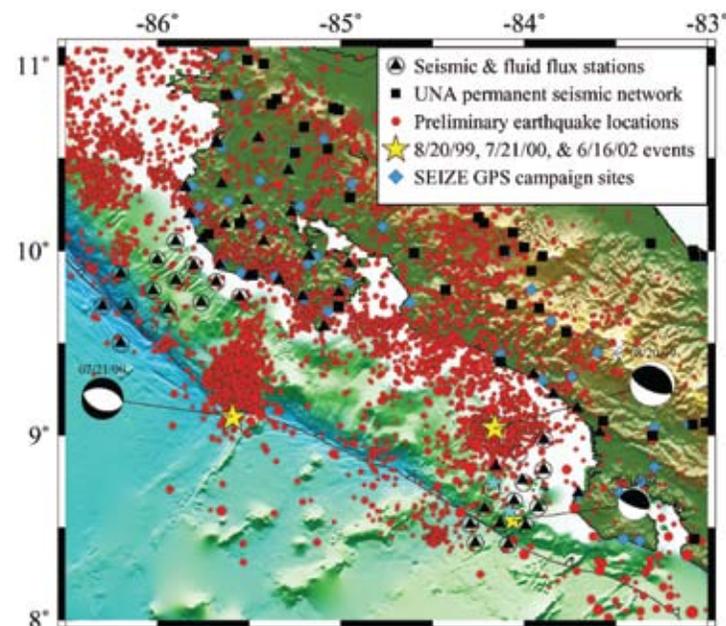
UNIVERSIDAD NACIONAL, COSTA RICA

The Nicoya Peninsula, Costa Rica, is a volcanic construct that extends out from the general trend of the Central America Pacific coast towards the Middle America trench. The PASSCAL experiments CRSEIZ and TUCAN took advantage of this rare on-land coverage of the shallow part of the seismogenic portion of a subduction zone to improve understanding of the structure and background seis-

micity of Nicoya and elsewhere in Costa Rica and Nicaragua. But the seismicity is of more than academic interest, partly because this segment of the subduction zone has ruptured in large earthquakes once every 50 years or so for the past two centuries, but not since 1950.

Within Nicoya, the PASSCAL experiments temporarily filled gaps in a seismographic and geodetic network operated by Observatorio Vulcanológico y Sismológico de Costa Rica (OVSICORI) of the Universidad Nacional. In the course of the experiments, over 30 broadband vaults were built on the peninsula and in northern Costa Rica. OVSICORI continues to maintain the observatory network in the Nicoya peninsula as part of the university's Operative Academic Plan, assuring operations for the foreseeable future. After the PASSCAL experiments ended, however, the Observatory lacked resources to install alternative instruments in enough of the vaults to continue producing a complete earthquake catalog for the region.

With the loan of RefTek data loggers from IRIS, OVSICORI was able to secure promises for sensors. Susan Schwartz will loan five STS-2s from her pool at the University of California, Santa Cruz, Gerry Simila will loan three seismometers from California State University, Northridge, and UNA will purchase five short period instruments. Located strate-



Configuration of the Costa Rica Seismogenic Zone Experiment and epicenters of approximately 4,000 earthquakes. Harvard CMT solutions are shown for the August 20, 1999, Mw=6.9 Quepos underthrusting earthquake and the July 21, 2000, Mw=6.4 outer-rise normal earthquake.



Victor Gonzalez of OVSICORI servicing a PASSCAL seismic station with a RefTek data logger. The station was deployed as part of a cooperative, multi-disciplinary project with the University of California, Santa Cruz, to monitor Arenal Volcano, Costa Rica.

gically along current service routes, the new stations will fill gaps in the existing network yet require marginal incremental effort for maintenance and operations. OVSICORI plans to service the sta-

tions every two to three months and send raw reldump files immediately to the University of California at Santa Cruz. At Santa Cruz, Susan Schwartz will produce SEED volumes and send them to the DMC.

BENEFITS TO US SEISMOLOGISTS

The USArray component of EarthScope seems likely to ensure availability of an abundance of data from stations in North America at unprecedented resolution over the next ten years. But studies Earth structure and earthquake source processes based on North American data alone would provide a limited and probably biased picture. During the coming decade, while NSF funding for seismological infrastructure will almost inevitably be concentrated within North America more than ever before, further improvements in access to data from the rest of the world will require innovation and leveraging of non-NSF resources.

A happy coincidence of need for data among US researchers and need for instrumentation to improve earthquake hazard mitigation around the world can provide mutual advantages. Each recipient of an IRIS long-term instrument loan commits itself to seamless data access, which is most easily accomplished by delivering continuous data to the DMC. Just as importantly, seismologists with experience using broadband instrumentation and high resolution digital recording and a compelling interest in data quality are contributing their expertise to the projects. ■

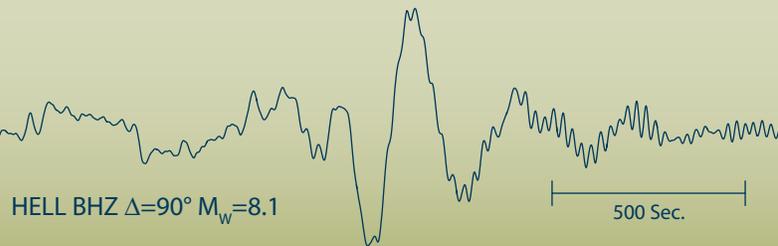
ACKNOWLEDGMENTS

Data loggers that are no longer used in PASSCAL experiments are reconditioned at low cost by Refraction Technology, Inc. so that they can provide data meeting original equipment specifications to participants in IRIS's long-term loan initiative.

This Issue's Bannergram

Animating the Seismic Wavefield

Charles J. Ammon • Pennsylvania State University

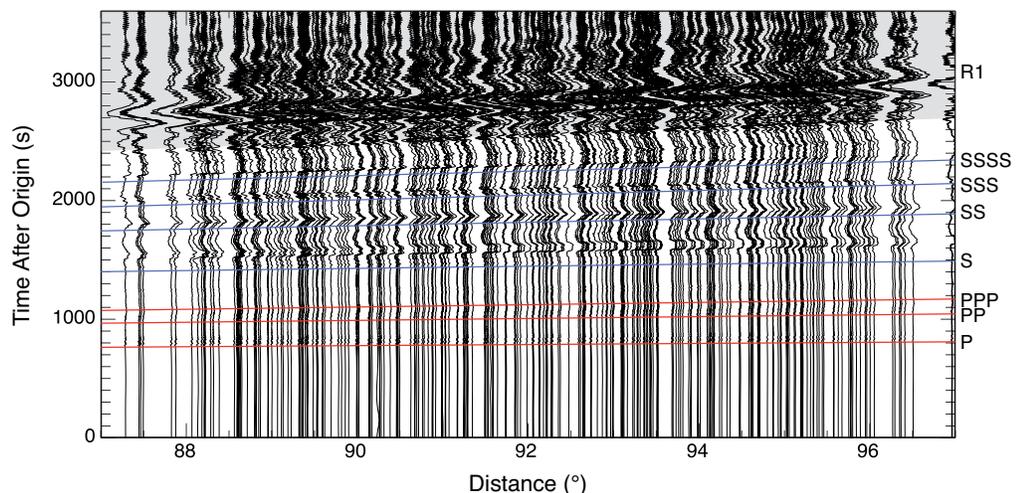


Seismologists have studied the seismic wavefield for many years using mostly sparse networks of individual seismic stations and/or relatively small aperture, narrow-band seismic arrays. USArray, the seismic component of the NSF-supported EarthScope facility has changed all that. Of particular interest for this note is USArray's Transportable Array (TA), which provides opportunities to explore the seismic wavefield with new visualizations that can help students on all levels understand aspects of seismic wave propagation and that can help researchers deepen their intuitive understanding of seismic-wave interactions.

The TA's uniform installation procedures and stable instrument responses produce high-fidelity recordings of the seismic wavefield over an area with dimensions of about 1500 x 1000 km. The consistent, high quality of the observations

are illustrated using a traditional record section in the figure below. The section contains vertical-component displacement

seismograms from the great 01 April, 2007 Solomon Islands earthquake (Mw 8.1). The short-arc arrivals in the teleseismic



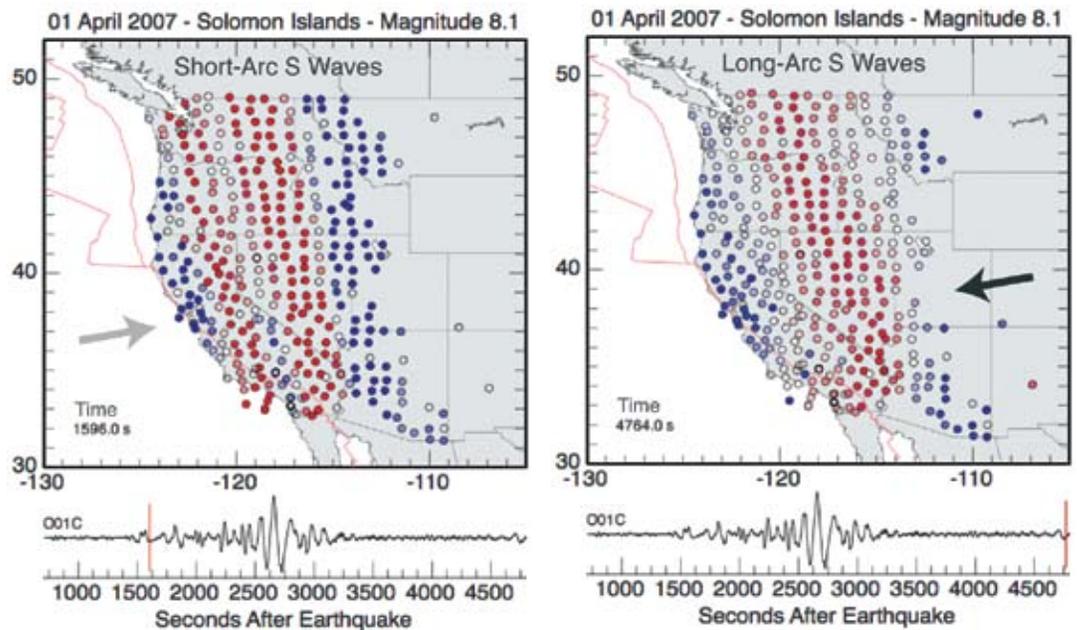
A traditional seismic record section showing the consistency of observations across the large-aperture TA. Theoretical iasp91 arrival times are indicated (the event had a rupture duration of roughly a minute).

wavefield are well represented, and the large source (which had a duration of about one minute) emphasizes the low-frequency content of the signals.

In addition to well-known research advantages of the TA, the uniformity and stability of the TA allows one to create animations that clearly illuminate both expected and unexpected aspects of seismic wave interactions with geologic structures beneath the western North America. Two frames from an animation of the great Solomon Islands earthquake are shown at right.

In both panels, each symbol represents one station and the arrow shows the predicted direction of wave travel if the Earth was radially symmetric. Time, shown to the lower left, is referenced to the event origin. The frame to the left shows a snapshot of ground motion during the propagation of short-arc S arrivals across the western United States; the frame on the right shows the propagation of long-arc S arrivals almost an hour later. Symbol color reflects the amplitude of ground velocity at this particular snapshot in time (red is positive, blue is negative). To create the animation, raw velocity seismograms were corrected for a gain factor and band-pass filtered to include signals with periods between 250s and 50s (the large size of the event also emphasized longer periods). Both panels show plane waves sweeping across the western United States. Displacement seismograms of the long-arc S arrivals shown in the right panel are shown at right.

Such animations are extremely effective in educational presentations. At the introductory non-science level, all students can quickly appreciate some basic ideas related to earthquake location, such as the direction to the earthquake. In more quantitative classes, students can use the anima-



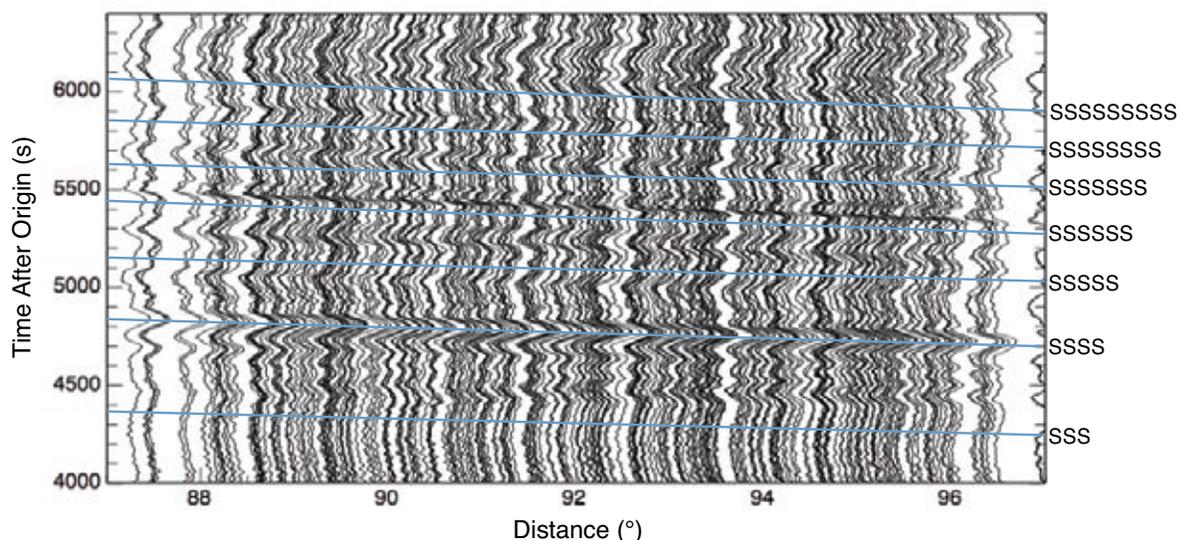
Snapshots of ground deformation across the western US following the 01 April 2004 earthquake. Each circle represents one TA station.

tions side-by-side with more traditional seismogram plots and record sections to study fundamental concepts such as phase velocity, wavelength, scattering, etc. Using familiar computer tools such as QuickTime, students can explore the propagating waves using sliders, estimate horizontal wavelengths, and phase velocities. Although I've only looked at (and used) a few wavefields from large earthquakes, the animations provide a fascinating view of wave interactions and include a number of surprises, including examples of amplitude focusing, and the effects of heterogeneity on the deterministic components of the wavefield. Perhaps most intriguing is

the propagation of spatially coherent scattered waves seen in the Solomon Islands signals that propagate at a high angle to the expected directions of wave arrival.

The Solomon Islands earthquake animation discussed above can be accessed at: <http://eqseis.geosc.psu.edu/~cammon/QA/Islands01Apr07.html>.

Coming soon – more animations from the IRIS DMC, which has begun development on tools to construct the routine construction of animations from events that occur while the TA migrates eastward across the conterminous states, and then on to Alaska. Stay tuned.



Long-arc S-wave train with iasp91 predicted arrival times indicated. Station density allows individual phases to be traced for 10° and accurate phase-velocity measurements – although source rupture complexity complicates the specific identification of the arrivals.

Staff News

Matthew Canfield
Data Control Technician



I have lived in Seattle since 1991 and worked in IT since 1993 mostly as a Software Test Engineer. Since February I have been working with Anh Ngo, MaryAnn, Thani and Chad Trabant in the Operations Group for the US-Array.

In my free time I read, cycle, work on my motorcycles, watch movies, and play with my cat.

Anthony Gonzales
USArray Lead Construction Engineer



I will report to Bob Busby, and although much of my time will be "in the field", my home is in Socorro. My most recent work experience was with the NM Institute of Mining & Technology (EMRTC). I also served in the U.S. Army for seven years as a Quality Control Inspector.

Gillian Sharer
USArray Data Control Analyst



I joined the IRIS team in October 2006 as a USArray Data Control Analyst. I am working to ensure quality control of the USArray data.

I moved to Seattle from Florida where I worked for ENSCO, Inc. supporting nuclear treaty monitoring. I have an M.S. degree in Geophysics from the University of Washington, Seattle and a B.A. degree in Earth and Planetary Science from Washington University in St. Louis.

In my spare time I play Irish traditional music on a simple system flute and take road trips.

Gale J. Eschete
Office Manager

I joined Iris in June 2007 as the new Office Manger for the Seattle DMC. I've lived in Seattle since 2001 and am originally from South Louisiana.

Previously, I worked for a group of Oceanographic Consultants here in the Seattle area as their Corporate Administrator.

In my spare time I explore the Pacific Northwest, play with my cats, read, cook and attempt to garden.

A Transition at TACO

George Patton left a giant void at the Transportable Array Coordinating Office (TACO) when he died unexpectedly in April this year. TACO is the nerve center of Transportable Array station reconnaissance, permitting, construction and installation, supporting the TA manager by coordinating site selection activities, scheduling station field activities and station service visits, and addressing station engineering issues.

George, a PhD engineer, joined TACO in November 2005 as the Senior Field Engineer after retiring from Sandia National Laboratory and serving as Dean of Education at the ITT Technical Institute. Drawing on his wealth of experience and keen ability to work with others, George kept his finger on the TACO pulse, ensured that installation and service teams received the supplies required, and removed obstacles from their path. This-jack-of-all-trades and charismatic leader was a driving force behind TA development and implementation of processes that allow for routine installation of 18 new stations a month and reliable operation of more than 400 stations.

In July, Steve Welch stepped into the gap left by George's untimely death. A New Mexico Tech graduate in engineering, Steve has managed ordnance test programs at EMRTC in Socorro, construction projects at White Sands Missile Range, and been an Operations Manager for Aerojet Corporation. We welcome Steve to TACO – he has big shoes to fill.

IRIS Workshop June 4–6, 2008

Next year the IRIS Workshop will return to Skamania Lodge, in Stevenson, WA. Workshop program chairpeople Suzan van der Lee (Northwestern University) and John Vidale (University of Washington) are planning a program of several oral sessions featuring plenary discussion of broad-interest developments, Special Interest Group (SIG) meetings to discuss topics of particular interest in more depth, and poster sessions that offer an opportunity one-on-one interaction.

As in the past, it will be possible to accommodate a limited number of pre- and post-Workshop symposia and tutorials. Write to IRIS Meetings Coordinator Lindsay Woods (lindsay@iris.edu) if you might want to suggest a SIG meeting or an all-day activity before or after the Workshop.



IRIS Newsletter

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Please address your letters or inquiries to:

IRIS NEWSLETTER
1200 NEW YORK AVENUE, NW, SUITE 800
WASHINGTON, DC 20005
PHONE: 202-682-2220 • FAX: 202-682-2444 • WWW.IRIS.EDU

The Incorporated Research Institutions for Seismology (IRIS) is a university consortium of more than 100 research institutions dedicated to facilitating investigation of seismic sources and Earth properties, promoting exchange of geophysical data and knowledge, and fostering cooperation. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and monitoring underground nuclear explosions. IRIS core programs are operated through a Cooperative Agreement with the National Science Foundation under the Division of Earth Science's Instrumentation and Facilities Program. IRIS also manages the USArray component of the EarthScope project. Funding is provided by the National Science Foundation, the Department of Energy, other federal agencies, universities, and private foundations. All IRIS programs are carried out in close coordination with the U.S. Geological Survey and many international partners.

The IRIS Newsletter welcomes contributed articles. Please contact one of the editors.

Editor-in-Chief: David Simpson (simpson@iris.edu)	Executive Editor: Raymond Willemann (ray@iris.edu)	Production Editor: Jason Mallett (jason@iris.edu)
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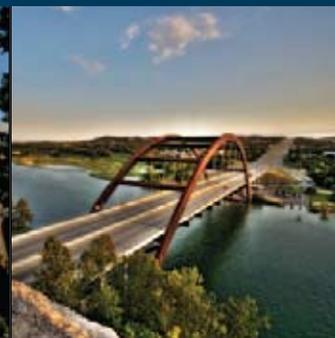
E&O
Washington, DC
September 24–25, 2007

PASSCAL
Socorro, NM
October 4–5, 2007

DMS
St. Louis, MO
October 11–12, 2007

GSN
Albuquerque, NM
October 18–19, 2007

Board of Directors
Austin, TX
November 7–8, 2007



IRIS Standing Committees

Each of the IRIS Core Programs – GSN, PASSCAL, DMS, E&O – sets priorities and develops plans with guidance from a Standing Committee that represents the views of the IRIS community. Voting members of the Standing Committees, who are listed at <http://www.iris.edu/about/committees.htm>, are appointed to three-year terms by the IRIS Board of Directors. In addition, the Committees may include participants from partner organizations that work with IRIS in operating its facilities. Many Committee members appointed by the IRIS Board are open to suggestions from the broader community about the Core Program activities.

Each Committee meets twice a year. At their spring meetings the Committees prepare detailed proposals for budgets for the upcoming financial year (July to June), which are reviewed and approved by the IRIS Board of Directors. In their fall meetings the Committees review the status of plans for the ongoing year, advise the Program Manager, and suggest policy updates for consideration by the Board.

Is there an aspect of GSN station operation that needs more attention? Is there service that would be particularly helpful in executing PASSCAL experiments? Is there a seismographic network whose data ought to be collected by the DMS? Do you have a suggestion about E&O activities? If so, then consider contacting a member of the relevant Standing Committee to talk it over, perhaps before the fall meetings this year.

SEPTEMBER 23-28, 2007

Society of Exploration Geophysicists Annual Meeting
San Antonio, Texas

<http://meeting.seg.org/>

OCTOBER 9-11, 2007

CIG/SPICE/IRIS Workshop in Computational
Seismology
Jackson, New Hampshire

www.geodynamics.org/

OCTOBER 18-19, 2007

Second International Workshop on Opto-electronic
Sensor-based Monitoring in Geo-engineering
Nanjing University, China

www.acei.cn/osmg/2007/

OCTOBER 21-26, 2007

Managing Waveform Data and Related Metadata for
Seismic Networks
Kuala Lumpur, Malaysia

www.iris.edu/workshops/2007/metadata/

OCTOBER 28-31, 2007

Geological Society of America Annual Meeting
Denver, Colorado

www.geosociety.org/meetings/2007/

DECEMBER 10-14, 2007

AGU Annual Fall Meeting
San Francisco, California

www.agu.org/meetings/fm07/



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