earthscope

inSights

the EarthScope newsletter

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Inside this issue...

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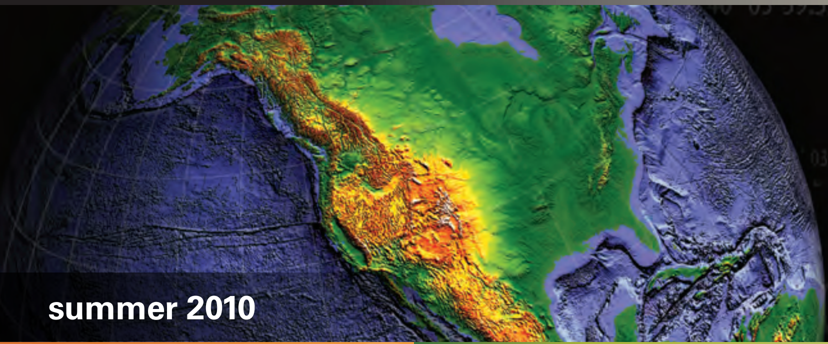
IRIS Celebrates its 25th Anniversary at the 2010 Workshop

More than 230 scientists, including over 50 students and postdocs, gathered June 9-11 at the Snowbird Resort in Utah for the 2010 Workshop and to celebrate the 25th anniversary of IRIS, a success story of extraordinary collaboration within the seismological community. Plenary sessions covered a wide range of topics. Prompted by the recent earthquakes in Haiti and Chile, "The Science and Policy of Deadly Earthquakes" session highlighted societal aspects of reducing loss and lessons learned from catastrophic disasters. Scientific sessions showed results from current research on mantle dynamics and tremor and transient slip events. These fields have benefited from EarthScope USArray instrumentation, which has provided opportunities to develop new data-driven analysis techniques. Stimulating presentations from the realm of exploration seismology introduced new concepts on how to best exploit large datasets and arrays. The poster sessions included EarthScope research from the Transportable Array, Flexible Array experiments, and the magnetotelluric (MT) array. Special Interest Groups (SIGs) and facility breakouts provided updates on current activities and discussions on exciting future directions. Several breakout sessions focused on Education and Outreach. During the dinner on June 9, workshop participants celebrated the first 25 years of IRIS while looking forward to building on its foundation of facilitation, collaboration, and education. (www.iris.edu/hq/iris_workshop2010). ■

Danielle Sumy (LDEO) shows seismicity in the Sea of Cortez from the amphibious SCOOBA experiment. Photos: Rick Callender.



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EarthScope San Andreas interpretive workshop participants (www.earthscope.org/eno/parks) show how the PBO-GPS station at CSU San Bernardino is moving relative to North America. Photo: Shelley Olds.

- Register & apply for travel support by July 15 for the EarthScope Institute on the **Spectrum of Fault Slip Behaviors**, October 11-14 in Portland, OR (www.earthscope.org/workshops/fault_slip10).
- Attend the **EarthScope workshop for interpretive professionals** in the Yellowstone-Snake River Plain-Teton region, September 9-12 in Jackson, WY. Information and an application form (deadline August 1) are at www.earthscope.org/workshops/yellowstone.
- Proposals for the next **EarthScope National Office** are due October 1.
- The **EarthScope Speaker Series** presents EarthScope science at college and university seminars. To apply for a speaker visit www.earthscope.org/speakers.
- EarthScope was selected as one of 15 NSF exhibits for the inaugural **USA Science and Engineering Festival** on Washington, DC's National Mall October 23-24 (www.usasciencefestival.org). More than 500 organizations will present hands-on activities to inspire the next generation of scientists.
- The **EarthScope Automated Receiver Survey** (EARS) is now implemented at the IRIS DMC (http://ears.iris.washington.edu). Developed by the University of

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Integrating GPS & InSAR to **Resolve Stressing Rates** Along the San Andreas System

The absence of a major earthquake over the past three centuries along the southern San Andreas fault, a region home to over 10 million people and the site of large earthquakes in the past, provides ample motivation for studying the loading conditions of an active plate boundary. A comparison of strain rate maps of the western United States, produced by 15 research groups using primarily the same GPS measurements, reveals that modeled rates can differ by a factor of 5-8, with largest differences along the most active faults.

New estimates of seismic hazard will rely on high resolution measurements of crustal deformation and a secure understanding of strain rate derived from such measurements. The growing archive of EarthScope's Plate Boundary Observatory (PBO) GPS data is uniquely positioned to provide a large-scale perspective on plate boundary strain; however, it cannot accurately resolve the highest strain rates near the most active faults. Integrating GPS and InSAR velocities may be key to improving strain rate accuracy and resolution - information that is critical for assessing seismic hazards.

Strain rate, which is typically greatest within 10-50 km of an active fault, is calculated by taking the spatial derivative of measured crustal velocities (Figure 1). Full resolution of velocity gradients requires a spatial sampling at about 1/4 of the typical 6-18 km fault locking depth, which is less than the typical ~10 km spacing of the present-day PBO network along the San Andreas system. A physical model or an interpolation method must, therefore, be used to compute continuous velocities before obtaining a strain rate map.

Simple dislocation models predict that strain rate is proportional to slip rate divided by the locking depth, so even when using similar slip rates, strain rates can differ by a factor of 2-3 because of different fault depth assumptions.

A collaborative effort involving 15 research groups is currently comparing large-scale plate boundary strain rate maps to establish best practices for strain rate estimation (see online version for participants and results). Two main conclusions can be drawn from comparing the community maps: 1) Nearly identical GPS datasets result in very different maps, and 2) It is difficult to determine which maps capture the true strain rate best. Maps derived from isotropic interpolation suggest lower rates (e.g., 50-500 nanostrain/year, Imperial fault) than maps generated from dislocation models and methods that localize strain onto faults (e.g., 1000-2700 nanostrain/year, Imperial fault). The large variations are mainly due to different methods used to construct a high resolution

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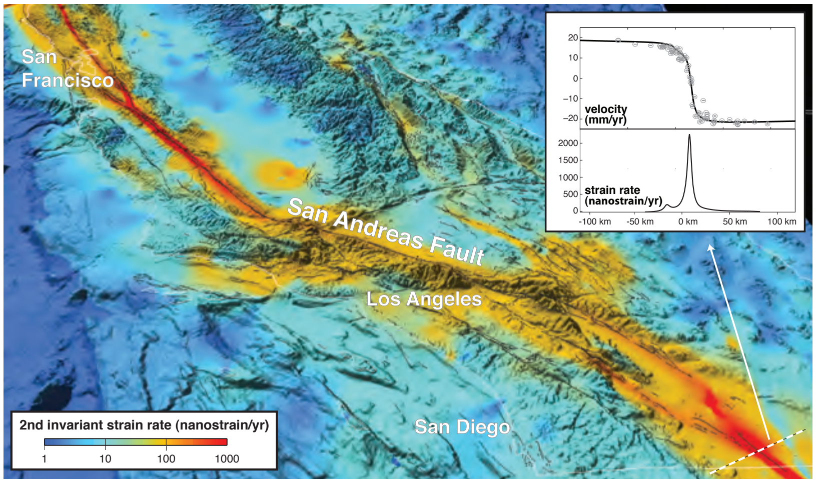

Figure 1: Strain rate of the San Andreas Fault System from a geodetically constrained analytical model. Deep slip occurs on 41 fault segments where geologic slip rate is applied and locking depth is varied along each fault segment to best fit the GPS data. Dashed white line shows location of inset. Inset: cross-section across the Imperial fault. Top: velocity profile (black line) and GPS data (gray circles). Bottom: strain rate across the Imperial fault.

Edge-Driven Convection Beneath the Rio Grande Rift

The Rio Grande Rift is a series of north-south trending faulted basins extending for more than 1000 km from Colorado to Chihuahua, Mexico and the Big Bend region of Texas. The rift is a Cenozoic feature with a mid-Oligocene (~30 Ma) early rifting stage, possibly related to foundering of the flat-subducting Farallon plate, and a recent late Miocene (~10 Ma) phase, which continues today.

There is no clear cause for the resurgence in magmatism and extension. However, the rift location at the edge of the Great Plains, with its stable, thick lithosphere suggests that edge-driven convection along the eastern border of the Southern Rockies may play an important role in the current tectonics of the Rio Grande Rift. In particular, edge-driven convection may erode the lithosphere beneath the Rift and Great Plains, cause lower crustal flow, and produce magmatism long after initiation of the rift.

In 2008, a group of university scientists and high school teachers deployed 71 broadband seismographs interspersed between the EarthScope Transportable Array (TA) stations, essentially doubling the station density in southeastern New Mexico and west Texas (Figure 1).

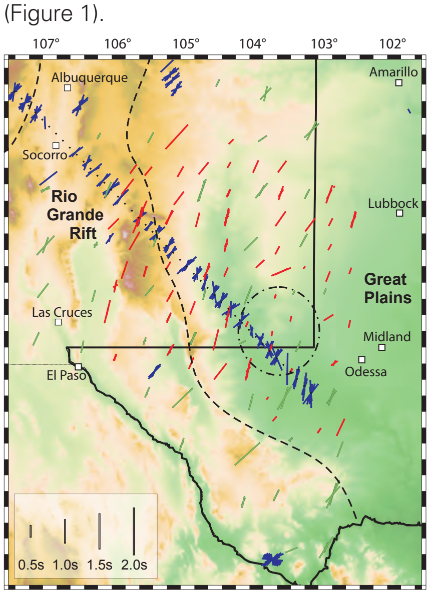

Figure 1: SKS splitting parameters for SIEDCAR (red) and TA (green) stations deployed 2008-2010 in the study area. Previous splitting measurements (La Ristra linear array and others) are shown in blue. Dash-dot circle indicates area where the SKS delay-times decrease; this area coincides with the "downwelling" fast anomaly in the mantle. The NW-SE-oriented La Ristra line is indicated by a dotted line.

The dense network increases resolution of tomographic and receiver function images and shear wave splitting measurements, and allows construction of a detailed 3-D investigation of the eastern edge of the Rio Grande Rift structure. The primary goal of SIEDCAR (**S**eismic **I**nvestigation of **E**dge **D**riven **C**onvection **A**ssociated with the Rio Grande **R**ift) is to determine if the necessary conditions for small-scale convection exist over a broad area. The conditions include thickened lithosphere beneath the Great Plains and fast velocities in the mantle's top 500 km that might indicate thermal and/or density anomalies. If these anomalies are detected, a second goal is to obtain quantitative estimates of their size, geometry, and contrasts for use in geodynamic modeling.

Initial results of SKS splitting measurements to constrain patterns of mantle anisotropy (Figure 1), receiver functions to show crustal thickness (Figure 2), and body-wave and surface-wave tomography to determine P and S wave velocities show patterns consistent with edge-driven convection. Tomographic images indicate that the fast upper mantle anomaly beneath the eastern flank of the Rio Grande Rift, which was identified by the earlier, linear, La Ristra array, is clearly separated from the Great Plains craton and that it extends southward to at least the Big Bend region of Texas. SKS splitting measurements show a marked decrease in splitting times above the fast "downwelling" anomaly in the mantle and generally larger splits on the rift flank proper. Receiver function images suggest a thickening of the crust to the east, which might indicate lower crustal flow induced by the edge convection or even delamination of lithosphere. Geodynamic modeling constrained by SIEDCAR will help determine whether this is happening at the boundary between the Great Plains and the Rio Grande Rift.

Edge-driven convection may explain why, after a long period of quiescence, the Rio Grande Rift became active again. The SIEDCAR project seeks to understand how this process continues to modify the sub-continental lithosphere long after the formation of the rift. ■

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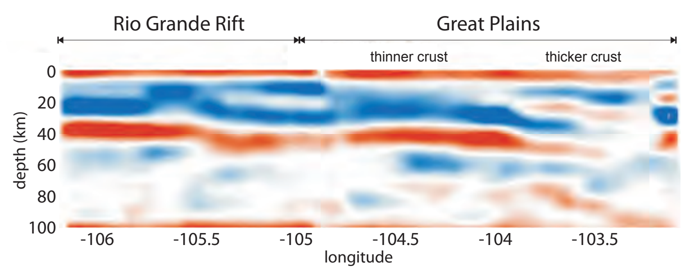
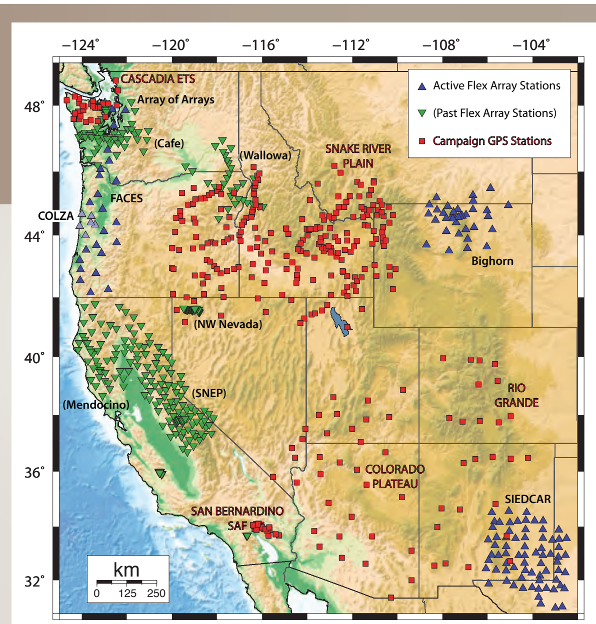


Figure 2: Receiver function image of crust and uppermost mantle beneath the eastern flank of the Rio Grande Rift from SIEDCAR and TA data for the NW-SE oriented La Ristra transect (dotted line in Figure 1). Thickened crust beneath the Great Plains extends both to the north and to the south, but, south of this cross-section, the transition from thick to thin crust moves to the southwest.

EarthScope **Temporary Deployments**

Temporary deployments of seismic and geodetic instruments allow for focused observation and study of key geophysical targets. EarthScope maintains ~100 Campaign GPS systems and ~2100 broadband and short-period FlexArray seismic sensors available for PI-driven, focused studies. This map shows present and past seismic and GPS deployments. The article on this page highlights initial results from SIEDCAR, one of the current studies. The Sierra Nevada EarthScope Project (SNEP) was featured in the spring/summer 2008 onSite, while the Rio Grande and the Snake River Plain GPS experiments were highlighted in the winter 2009 onSite. For more information on field experiments visit www.earthscope.org/science/field_programs.



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South Carolina as an EarthScope data product, EARS calculates bulk crustal properties at USArray sites using receiver functions. Visit www.iris.edu/dms/products/ears for more information on EARS and www.earthscope.org/science/data_products for other EarthScope data products.

- UNAVCO provided a terrestrial laser scanner (TLS, ground based LiDAR) to scan surface ruptures after the April 4, 2010 M 7.2 northern Baja California earthquake. Four **EarthScope campaign GPS receivers** were used to provide geodetic control for the TLS surveys. For more information visit www.unavco.org/research_science/science_highlights/2010/M7.2-Baja.html.
- The revised and expanded **EarthScope Education and Outreach** web pages include links to handouts, animations, teachable moments, presentations and much more from EarthScope and its partners. The materials, aimed at students, teachers, faculty, news media, and the public, can be accessed at www.earthscope.org/eno.
- The **Bighorns Flexible Array** experiment recently deployed more than 150 short period instruments in the Bighorn Mountains of Wyoming. The experiment uses newly developed "quick deploy" boxes where stations are shipped in deployment-ready enclosures. They worked so well that the field teams completed station installations one week ahead of schedule.

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Integrating GPS & InSAR to **Resolve Stressing Rates** Along the SAF System

(1 km) map from sparse (~10 km) GPS data. Second order differences can be attributed to assumed fault locations and rheological assumptions.

How can the geodetic community improve accuracy and resolution of strain rate maps? First, when GPS resolution is inadequate, proper localization of strain seems to require that models include major fault locations. Second, a solution is to densify the GPS network such that station spacing is smaller than the spatial variations in crustal strain. This approach has been tested in areas such as the Imperial fault, where strain is adequately resolved. Indeed, installation of a few dense GPS arrays across poorly-resolved, high-strain-rate faults is feasible and should be pursued. Recently we deployed a second dense GPS array across the Imperial fault to resolve the high strain rate in the highly-populated Mexicali area of Baja California (Figure 2).

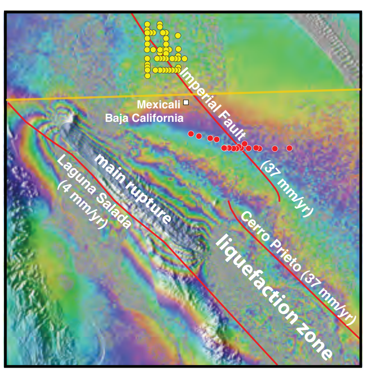

Figure 2: Interferogram of the April 2010 earthquake in Baja California, Mexico, from ALOS PALSAR (Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar). One color cycle is 11.6 cm of line of sight deformation. Locations of dense GPS monuments across the Imperial fault are also shown. The Imperial array (yellow) was first surveyed in 1993. Reoccupations in 1999, 2000 and 2008 have provided unprecedented accuracy and resolution. In January 2010, 17 new monuments (red) were installed across the fault in Mexicali.

A third approach is to utilize InSAR's spatial coverage and to stack long time interval interferograms to augment GPS derived estimates. We are developing a remove-stack-restore procedure to optimally combine GPS and InSAR, which considers signal, measurement noise, sampling rate, and environmental noise characteristics of each system (Figure 3). This method involves constructing a wide-area, 3-D dislocation model from the GPS data; after low-pass filtering at 40 km, the model is removed from each interferogram. Because the residual interseismic signal and noise have different scale dependencies, filtering an interferogram can increase the signal-to-noise ratio by as much as 20%. Multiple interferograms are stacked to reduce atmospheric error. Finally, the complete deformation field is constructed by adding the low-pass filtered model back to the stack of interferograms. Application to a large stack of ERS (European Remote Sensing) interferograms in Southern California demonstrates better than 2 mm/yr accuracy over the wide range of length scales (200 m to 500 km). Extending the method to Northern California, where InSAR coherence is poor at C-band, will require using the longer wavelength L-band data from ALOS.

The likelihood of a major earthquake depends on the accumulated stress, which is roughly equal to strain rate multiplied by the crustal shear modulus and the time since the last major rupture. Strain rate mapping is, therefore, only one component needed to forecast earthquakes; paleoseismic

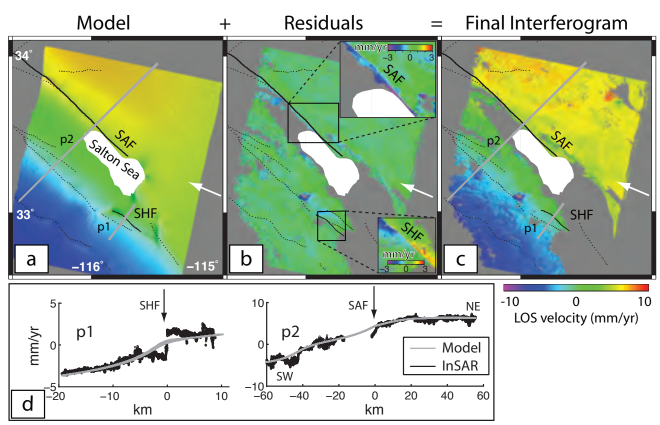

Figure 3: Remove-stack-restore interferograms for the Salton Sea area. (a) Physical model constrained by GPS data. (b) Stacked residual interferograms after applying the filtering method. (c) Final interferogram; sum of (a) and (b). Gray solid lines in (a) and (c) correspond to profile locations in (d). White arrow indicates satellite look direction. (d) Profile across Superstition Hills fault (SHF) and the main faults of the southern San Andreas fault (SAF) system. Arrow identifies short wavelength signal absent in GPS data.

estimates of the timing and slip of recent (~2000 years) major ruptures are equally important. It is interesting to note that the last four major earthquakes in Southern California have not occurred on faults with the highest slip rate (Landers, 1992; Northridge, 1994; Hector Mine, 1999; and the recent Sierra El Mayor-Cucapah earthquake [Figure 2]). In addition to resolving high strain rates on the primary faults, it is thus very important to measure the lower rates on subsidiary faults that rupture far less often but have recently produced the most damaging events. GPS and InSAR, when optimally integrated, will be the primary geodetic tools for resolving crustal strain rate in the most critical regions of our active plate boundary. ■

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