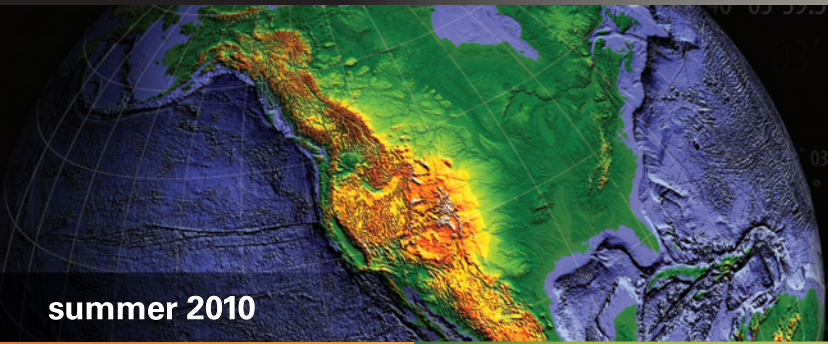

summer 2010

inSights
the EarthScope newsletter

EarthScope News

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

- Register and 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 online application form – deadline August 1 – are at www.earthscope.org/workshops/yellowstone.
- The **EarthScope Speaker Series** presents EarthScope science at college and university seminars. To apply for a speaker visit www.earthscope.org/speakers. The series is committed to reaching diverse audiences and to establishing links to organizations that engage underserved populations.
- 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

continued on page 3

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 fault locking depth (typically 6-18 km), which is less than the typical ~10 km spacing of the present-day PBO network in this region. 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

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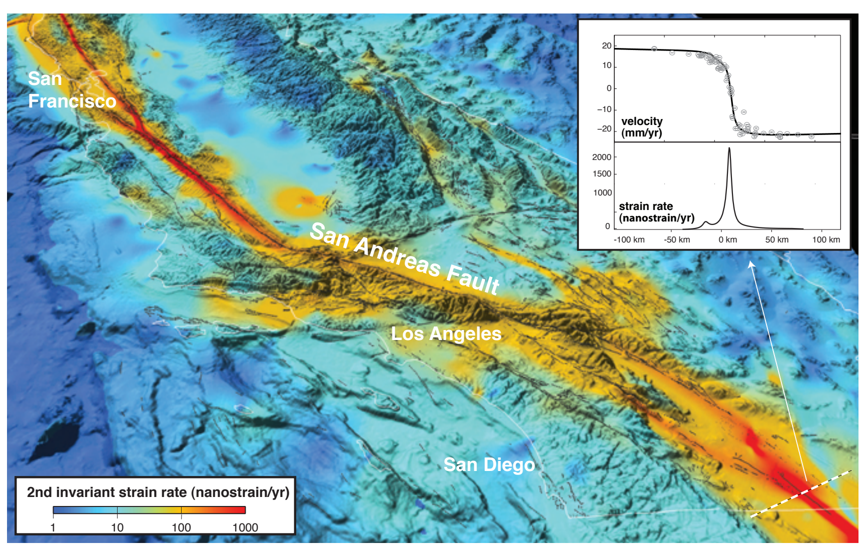


Figure 1: Strain rate of the San Andreas Fault System from a geodetically constrained analytical model. Deep slip occurs on 41 fault segments, where geologic slip rate is applied and locking depth is varied along each fault segment to best fit the GPS data. Inset: (top) Velocity profile (black line), GPS data (gray circles), and (bottom) strain rate across the Imperial fault (white dashed line).

Seismic Investigation of **Edge-Driven Convection** of 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, rift location at the transition from the Colorado Plateau with an average elevation of about 1.8 km to the low relief Great Plains 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. Edge-driven convection may be important for continental rifting in general. A possible answer to the question "why is the Rio Grande rift located here?" is that it is due to the Great Plains, and their thicker lithospheric root, just to the east.

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

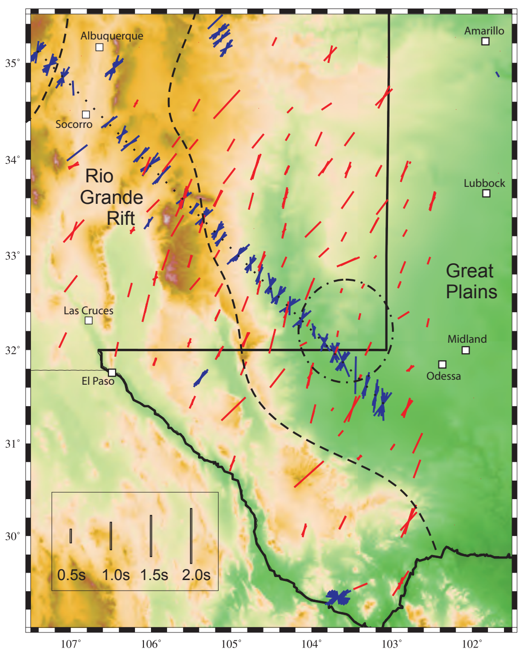


Figure 1: SKS splitting parameters for SIEDCAR (red) and TA (yellow) stations deployed 2008-2010 in the study area. Previous splitting measurements (La Ristra linear array and others) are shown in blue. Dash-dot circle indicates area where the SKS delay-times decrease; this area coincides with the "downwelling" 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 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 whether the necessary conditions for small-scale convection exist over a broad area. The conditions include thickened crust beneath the Great Plains and fast velocity anomalies in the mantle's top 500 km that might indicate thermal and/or density anomalies. If they do, a second goal is to obtain quantitative estimates of size, geometry, and contrasts of these anomalies 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

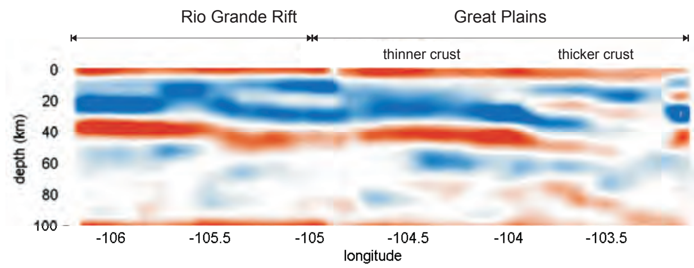


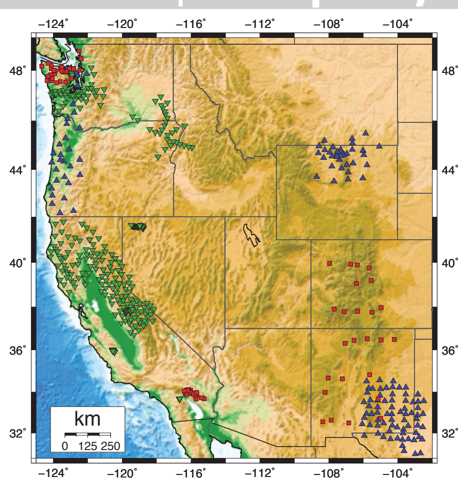
Figure 2: Receiver function image of crust and uppermost mantle beneath the eastern flank of the Rio Grande Rift from SIEDCAR and TA data for the NW-SE-oriented La Ristra transect (dotted line in Figure 1). Thickened crust beneath the Great Plains extends both to the north and the south but the transition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

clearly separated from the Great Plains craton and that it extends southward to at least the Big Bend region of Texas. The SKS splitting measurements show a marked decrease in delay times above the fast "downwelling" anomaly in the mantle and generally larger delays on the rift flank proper. Receiver function images suggest a thickening of the crust to the east, which might produce the temperature gradient needed to initiate small-scale convection. Geodynamic modeling constrained by SIEDCAR will help determine whether this is happening at the boundary between the Great Plains and the Rio Grande Rift.

Scientists have long noted that rifting tends to occur along lines of pre-existing weakness including orogenic belts and deformational structures. Edge-driven convection may be one reason why. ■

By Jay Pulliam[a], Stephen P. Grand[b], Yu Xia[b], Carrie Rockett[a], and Tia Barrington[a], [a]Baylor University, [b]University of Texas at Austin.

EarthScope **Temporary Deployments**



Temporary deployments of seismic and/or geodetic instruments allow for focused observation and study of key geophysical targets. EarthScope maintains ~100 Campaign GPS systems and ~2100 FlexArray seismic sensors available for PI-driven focused studies. This map shows present and past seismic and GPS deployments. The main article on this page highlights initial results from SIEDCAR, one of the current, exciting studies. For more information visit www.earthscope.org/science/field_programs.

EarthScope News

continued from front

(http://ears.iris.washington.edu/). Developed by the University of 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 numerous 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.

continued from front

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

(e.g., 1000-2700 nanostrain/year, Imperial fault). The large variations are mainly due to different methods used to construct a high resolution (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 like 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).

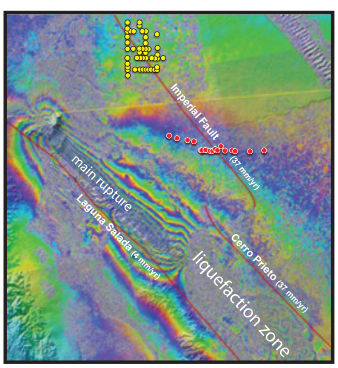


Figure 2: Interferogram of the April 2010 earthquake in Baja California, Mexico, from ALOS PALSAR. One color cycle (fringe) is 11.6 cm of line of sight (LOS) deformation. Locations of dense GPS monuments across the Imperial fault are also shown. The Imperial array (yellow) was first surveyed in 1993. Reoccupations in 1999, 2000 and 2008 have provided unprecedented accuracy and resolution. In January 2009, 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 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 by the time since the last major rupture. Strain rate mapping is, therefore, only one component needed to forecast earthquakes; paleoseismic estimates of the timing and slip of recent (~2000 years) major

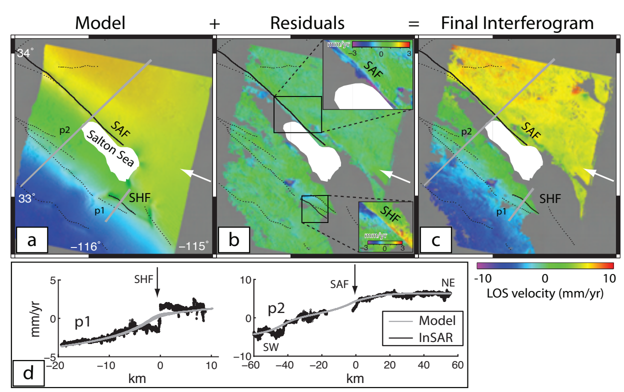


Figure 3: Remove-stack-restore interferograms for the Salton Sea area. (a) Physical model constrained by GPS data. (b) Stacked residual interferograms after applying the filtering method. (c) Final interferogram, as the sum of (a) and (b). Grey solid lines show profile locations in (d). White arrow indicates 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.

ruptures are equally important. It is interesting to note that the last 4 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 Major-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.
boundary. ■

By Bridget Smith-Konter[a], David T. Sandwell[b], and Meng Wei[b], [a]University of Texas at El Paso, [b]Scripps Institution of Oceanography.

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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 on June 9-11 at the Snowbird Resort, UT to celebrate the 25th anniversary of IRIS, a success story of extraordinary collaboration within the seismological community. The plenary sessions covered a wide range of topics. Triggered 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. Academic seismologists probably felt more at home during sessions on mantle dynamics and tremor and transient slip events. These fields depend on EarthScope USArray instrumentation which leads to 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 session showcased EarthScope research from the Transportable Array, FlexArray experiments, and the magnetotelluric (MT) array. Special Interest Groups and Facility breakouts provided updates on current focused activities and challenges. Several breakout sessions focused on Education and Outreach. The USArray breakout was packed. On Thursday evening we celebrated the first 25 years of IRIS and looked forward to continued facailitation, collaboration, and education. (Website with abstracts?). ■

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