2005 Joint Workshop

June 9 - 11, 2005

Dolce
Skamania Lodge
at Stevenson,
Washington

Thursday, June 9th

7:00am – 8:00am	CONTINENTAL BREAKFAST	Conference Center Lobby
8:00am – 8:15am	**Welcome**	**Cascade Ballroom**
	Organizing Committee: Greg Beroza (Stanford), Herb Dragert (Geological Survey of Canada), Mark Tamisiea (Harvard-Smithsonian Center for Astrophysics), Anne Trehu (Oregon State)	
	Will Prescott, President, UNAVCO	
	David Simpson, President, IRIS	
	Herman Zimmerman, NSF/EAR	
8:15am – 10:15am	**Science Session I: Sumatra Earthquake – Organizers: Roger Bilham, Jeffrey Park**	**Cascade Ballroom**
	Slip Tease in the Andaman Islands – 5000 mph Rupture Followed by Leisurely Slip in the Sumatra/Andaman M_w9.3 Earthquake of 26, December 2004 **Roger Bilham** (Univ of Colorado)	
	Indian Ocean Tsunami: The Australian Perspective **Phil Cummins** (Geoscience Australia)	
	Giant Sumatran Earthquakes: Past, Present and Future **Kerry Sieh** (Caltech)	
	The Sumatra Earthquakes and Tsunamis: Perspectives After a 40-year Gap in Mega-Events **Emile Okal** (Northwestern Univ)	
	BREAK	
10:45am – 12:15pm	**Special Interest Group Session**	
	Sumatra Earthquake Issues – **Roger Bilham** (Univ of Colorado) and **Jeff Park** (Yale)	Cascade Ballroom
	Poster Session	Adams & Hood
12:15pm	LUNCH	Stevenson Ballroom
1:30pm – 3:30pm	**Science Session II: Polar Geoscience – Organizers: Erik Ivins, Andy Nyblade**	**Cascade Ballroom**
	Exploring Antarctica with Broadband Seismology **Douglas Wiens** (Washington Univ)	
	Monitoring Crustal Motion in Antarctica with GPS: Current Status and Future Goals **Carol Raymond** (JPL)	
	Interdisciplinary Studies of a Persistently Active Volcano in Antarctica **Richard Aster** (New Mexico Tech)	
	Joint GPS and Seismic Inversion for Tidally-Modulated Displacement of Ice Stream B, West Antarctica **Sridhar Anandkrishnan** (Penn State)	
	BREAK	
4:00pm – 5:30pm	**Special Interest Group Sessions**	
	Polar Sciences Issues and IPY – **Terry Wilson** (Ohio State)	Cascade Ballroom
	Stable North America Reference Frame (SNARF) – **Tom Herring** (MIT) and **Jim Davis** (Harvard-Smithsonian Center for Astrophysics)	Baker
	Seismic Analysis Code (SAC) – **Arthur Snoke** (Virginia Tech) and **Peter Goldstein** (LLNL)	Ranier
	Cascadia Tremor and Slip – **Herb Dragert** (Geological Survey of Canada)	Jefferson
6:00pm	DINNER	Stevenson Ballroom
7:00pm – 8:30pm	**IRIS Proposal Presentation**	**Cascade Ballroom**
8:00pm – 9:30pm	**UNAVCO Members Meeting**	**Baker**

Friday, June 10th

7:00am – 8:00am	CONTINENTAL BREAKFAST	Conference Center Lobby
8:00am – 10:00am	**Science Session III: Explosive Volcanism – Organizers: Steve McNutt, Steve Malone**	**Cascade Ballroom**
	Lessons Learned About Explosive Volcanism and Seismicity from the 2004-2005 Eruption of Mount St. Helens **Seth Moran** (CVO)	
	Volcano Seismology: A Tool to Monitor and Understand Explosive Volcanism **Steve McNutt** (AVO)	
	The CALIPSO Project and the Ongoing Eruption of Soufrière Hills Volcano, Montserrat: What We Knew Before We Started, What We Have Learned Since, and What We Can Expect in the Future **Glen Mattioli** (Univ of Arkansas)	
	Is There a Disconnect Between Geodetic Models of Explosive Volcanism and Reality? **Michael Lisowski** (CVO)	
	BREAK	
10:30am – 12:00pm	**Special Interest Group Sessions**	
	Explosive Volcanism Issues – **Steve McNutt** (AVO) and **Steve Malone** (Univ. of Washington)	Cascade Ballroom
	Field Experiments: State of the Art Seismic and GPS Instrumentation and Opportunities for Collaborative Experiments – **Chuck Meertens** (UNAVCO) and **Jim Fowler** (IRIS)	Jefferson
	PBO Nucleus – **Freddie Blume** (UNAVCO)	Ranier
	Poster Session	Adams & Hood
12:00pm	LUNCH	Conference Center Lobby
	Pick-Up Boxed Lunches	
12:30pm	Field Trip to Mt. Hood	Main Entrance
	Leaders: **Mike Lisowski, Evelyn Roeloffs, Willie Scott** (USGS)	
	Free Time	
7:00pm	DINNER	Stevenson Ballroom
	Dinner Speaker **Stuart Wier**, *"Navigation and Mapping on the Lewis & Clark Expedition"*	

Saturday, June 11th

7:00am – 8:00am	CONTINENTAL BREAKFAST	Conference Center Lobby
8:15am – 10:15am	**Science Session IV: New Generation Imaging – Organizers: Roland Burgmann, Alan Levander**	**Cascades Ballroom**
	Geodetic Imaging of Lithosphere Rheology **Roland Burgmann** (Univ of California, Berkeley)	
	Imaging Spatial and Temporal Patterns of Deformation at Parkfield, CA Using Geodetic Data **Jessica Murray** (USGS)	
	Surface Wave Tomography from Ambient Seismic Noise **Mike Ritzwoller** (Univ of Colorado)	
	Source Imaging Using Teleseismic P Waves **Peter Shearer** (Univ of California, San Diego)	
	BREAK	
10:45am – 12:15pm	**Special Interest Group Sessions**	
	Next Generation Imaging Issues – **Lianxing Wen** (SUNY) and **Alan Levander** (Rice Univ)	Cascade Ballroom
	Cascadia: Megathrust to Subduction Factory – **Geoff Abers** (Boston Univ) and **Anne Trehu** (Oregon State)	Jefferson
	EarthScope: USArray – **Shane Ingate** (IRIS)	Ranier
12:15pm	LUNCH	Stevenson Ballroom
1:30pm – 3:00pm	**Special Interest Group Sessions**	
	EarthScope: PBO – **Mike Jackson** (UNAVCO)	Cascade Ballroom
	Need Help with Broader Impacts? How to Fund and Host an Intern. – **Susan Eriksson** (UNAVCO) and **John Taber** (IRIS)	Baker
	Nuclear Explosion Monitoring – **Brian Stump** (SMU) and **Rick Schult** (AFRL)	Ranier
	BREAK	
3:30pm – 5:00pm	**Special Interest Group Sessions**	
	Global Earth Observatory System of Systems (GEOSS) – **Paul Earle** (USGS) and **Rhett Butler** (IRIS)	Cascade Ballroom
	Digital Photography: Applications in Science and Outreach – **David Phillips** (UNAVCO)	Baker
	Data Facilities: Access to UNAVCO and IRIS Data – **Fran Boler** (UNAVCO) and **Tim Ahern** (IRIS)	Ranier
6:30pm	BBQ	Yurt Area

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SKAMANIA LODGE®
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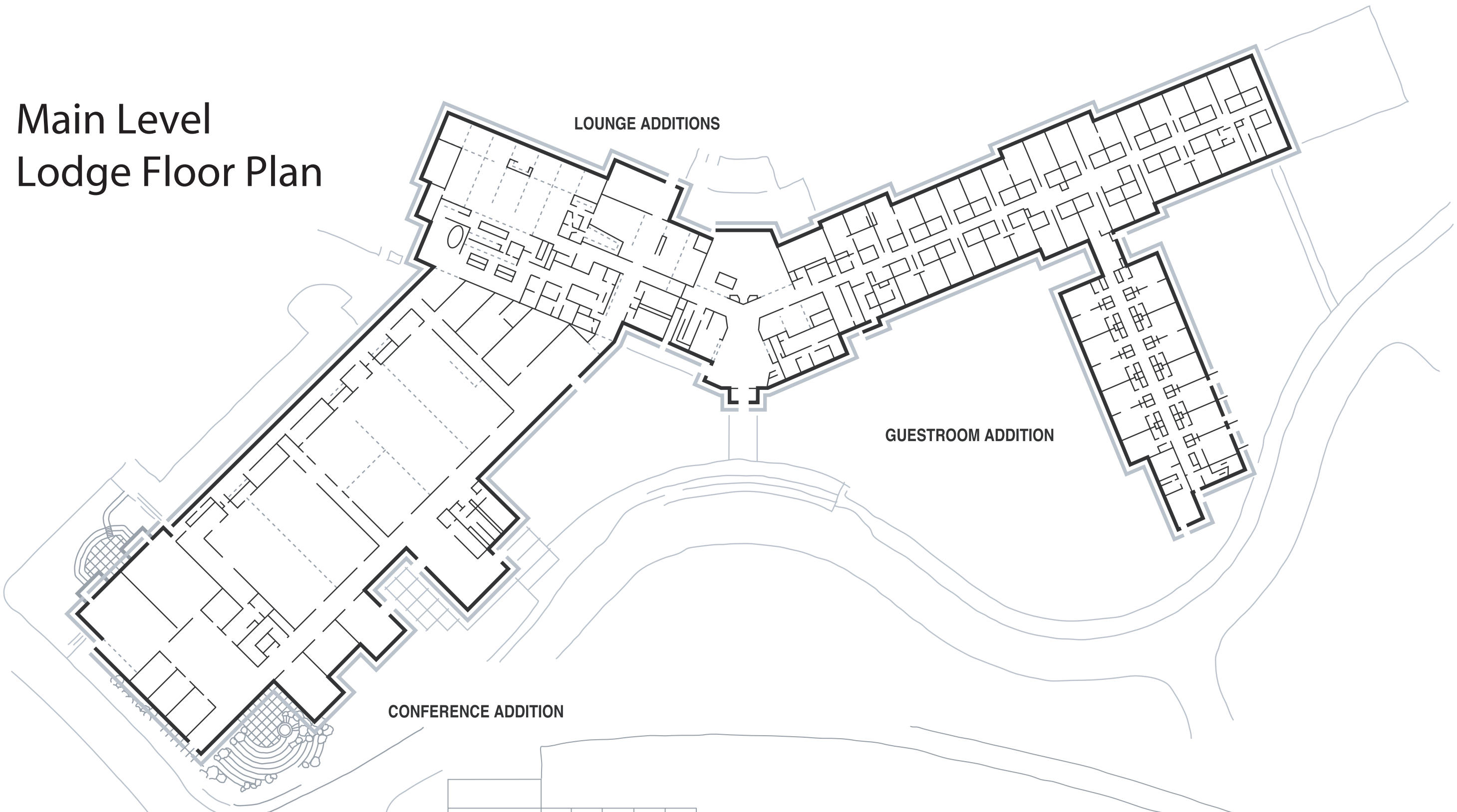
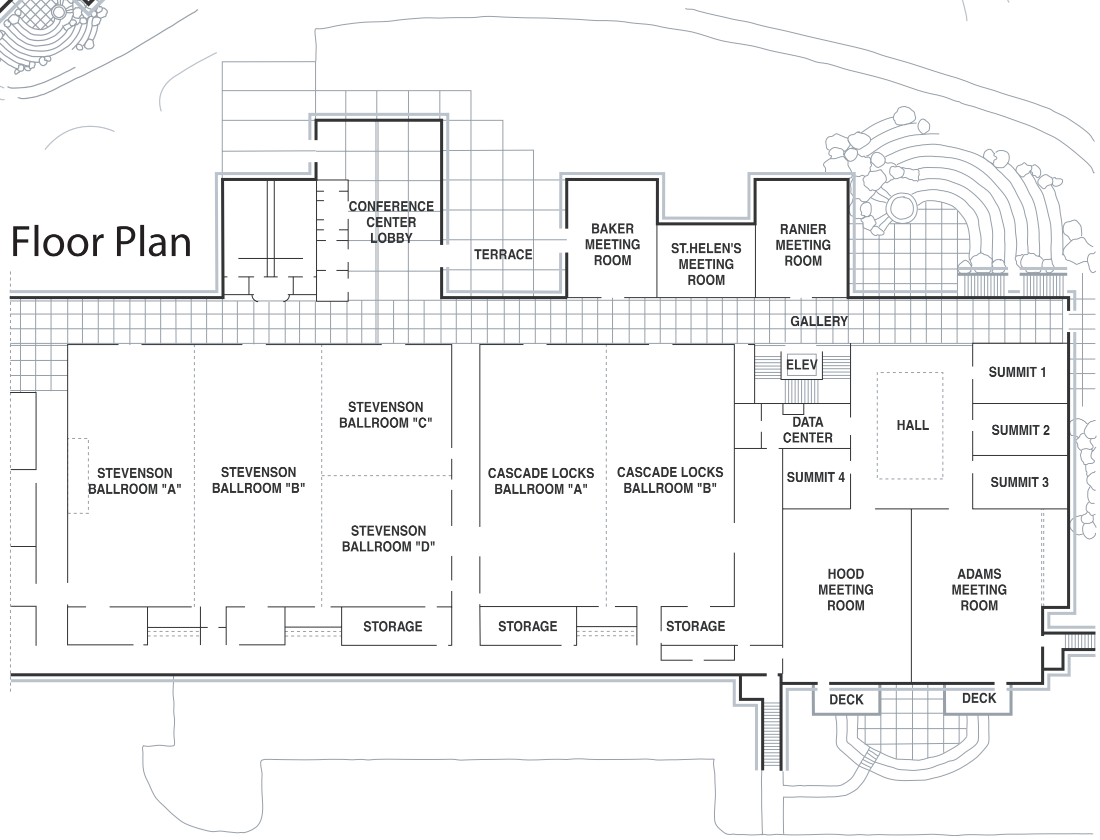
Main Level
Lodge Floor Plan



Main Level
Conference Floor Plan



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THE TUCAN BROADBAND SEISMIC EXPERIMENT: IMAGING THE CENTRAL AMERICA SUBDUCTION FACTORY

Geoffrey A. Abers, Laura Auger, Ellen Syracuse, Gustavo Reyes • Boston University

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The Subduction Factory processes the solids and volatiles entering oceanic trenches, and produces volcanic arcs, deep earthquakes, and long-term modifications to the deep earth. Central America exhibits some of the global extremes in the factory operation: in the Nicaragua volcanic arc, fluxes of geochemical tracers associated with subducting sediment are among the highest on the planet, while in the adjacent Costa Rica arc, many of the same tracers are weak to absent. For this reason, the MARGINS Program has selected Central America one of two focus areas for its Subduction Factory initiative. In advancing understanding of the Subduction Factory, seismic imaging of the downgoing plate, mantle wedge and upper-plate crust form a primary data set for understanding the cycling of volatiles and production of melt. To accomplish this, we deployed in July-August 2004 the TUCAN seismic array (Tomography and other things Under Costa Rica And Nicaragua), of 48 broadband PASSCAL seismographs, operating until early 2006. The array includes two dense transects across the arc at 10 km spacing, in both Costa Rica and in Nicaragua, accompanied by distributed stations sampling arc and backarc along strike over 450 km. From the array data, we have begun applying a wide variety of imaging strategies to constrain structure from both teleseismic signals and signals from earthquakes within the downgoing slab. Overall, the data recovery and quality has been outstanding, with recovery of 90-95%.

Initial data analyses show strong variations in signal propagation amplitudes and travel times reflecting a slow, high-attenuation mantle beneath the arc, and fast / high-Q forearc, consistent with that expected for arc magma production. Both high-frequency and teleseismic signals show strong converted arrivals between P and S. Although the origin of the strongest such phases remains unclear, particularly in regional data, many such signals derive from the top of the downgoing plate, consistent with earlier predictions that subducted crust should remain seismically slow to sub-arc depths. Receiver functions reveal a sharp upper-plate Moho with unexpectedly large along-strike changes in crustal thickness. These variations are not obviously expressed in topography or gravity. Shear-wave splitting of both local and SKS signals shows a preponderance of arc-parallel fast directions, with isolated areas of arc-normal fast directions found at stations in the fore-arc. This pattern resembles that seen in some other subduction zones, but with very high sampling density. These analyses, and their eventual integration with parallel geochemical studies of arc lavas, appear sufficient to characterize subduction here as well as any place on the planet.

IMAGING MANTLE ANISOTROPY IN THE CENTRAL AMERICAN SUBDUCTION ZONE WITH THE TUCAN BROADBAND SEISMOMETER ARRAY

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From Nicaragua to Costa Rica, arc volcanics manifest large geochemical variations. These trends may be explained by several hypotheses, including greater depth and extent of melting, and possibly a greater influence of water fluxed from the subducting lithospheric slab, beneath Nicaragua. To better understand melt generation and transport processes in the Central American subduction zone, we deployed 48 broadband IRIS/PASSCAL seismometers in four intersecting lines across and along the arc in Nicaragua and Costa Rica in July and August of 2004. The array is part of the NSF MARGINS program and will remain in place until March of 2006. Plans for analysis of array data include imaging of velocity, attenuation, and anisotropy in the mantle wedge, subducting slab, and overlying plate with body and surface wave tomography, scattered wave migration, and guided phases in combination with earthquake relocation. Here we report shear-wave splitting observations from local earthquake and teleseismic waveforms, using data recorded at permanent stations from 1995-2003 and at TUCAN stations during the initial months of this experiment. In other subduction zones, the orientation of the fast symmetry axis of anisotropy in the mantle wedge beneath the arc ranges from arc-parallel in many to arc-normal in a few. In some cases, the fast direction of anisotropy varies laterally from the arc to the back-arc, such as the arc-parallel to arc-normal trend observed in Tonga. These observations may be explained by three-dimensional solid flow in the mantle wedge, or, as suggested by recent laboratory studies, a strain field that is closer to two-dimensional corner flow but in which the development of olivine lattice-preferred orientation is influenced by higher volatile content or concentrated zones of partial melt. For local earthquake sources, high quality splitting measurements made so far show a preponderance of arc-parallel fast directions, with isolated areas of arc-normal fast directions found at stations in the fore-arc. Splitting times range from 0.1 - 0.8 s and average 0.3 s. Initial SKS splitting measurements at fore-arc stations yield arc-parallel fast directions. Based on the first few months of data, we anticipate that, when the experiment is completed, shear-wave splitting measurements will sample the subduction zone densely enough to permit inversions for three-dimensional anisotropic structure. Our ultimate goal is to jointly model the distribution of anisotropy with velocity and attenuation anomalies to place better constraints on solid flow and the distribution of melt, volatiles, and temperature within the mantle wedge.

THE ORIGIN OF HOTSPOT VOLCANISM IN THE PACIFIC NORTHWEST

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In the northwestern United States there are two hotspot tracks: the Newberry track and the Yellowstone track. Both are located on the North American Plate with the Yellowstone track parallel to plate motion and the Newberry track oblique to it. While a mantle plume is often cited as the cause of the Yellowstone track, the Newberry track cannot be the product of plate motion over a stationary mantle source. Instead proposed causal mechanisms for the Newberry track include upper mantle process where melt buoyancy driven convection is directed west-northwest, parallel to the hotspot track, by subduction-driven corner flow or alternatively by topography of the base of the lithosphere. In this SKS splitting study, we collected data from the OATS (Oregon Array for Teleseismic Study) array currently deployed along the Newberry track from NW to SE Oregon. Measurements were made for 23 events at 12 OATS stations and show a gradual rotation of the fast polarization direction from NE-SW at the northwest end of the array to E-W to the southeast, consistent with regional observations. Most stations also exhibit null results when the event back azimuth was parallel or perpendicular to the fast direction determined from other events, strongly indicating a single layer of anisotropy. The first order observation is that the SKS splits are not aligned with the Newberry hotspot track. This suggests there is little or no mantle flow oriented along the track and the track is not the product of asthenospheric flow. It therefore seems likely that the Newberry hotspot track is the product of lithospheric processes. Tomographic imaging of the region currently underway and will provide additional constraints mantle processes operating in the region.

JOINT GPS AND SEISMIC INVERSION FOR TIDALLY-MODULATED DISPLACEMENT OF ICE STREAM B, WEST ANTARCTICA

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One technique used experimentally with great success in numerous fields to learn about complex systems is to excite a system, and then watch how the excitation propagates and decays. Specific hypotheses can be elaborated to produce predictions of the outcomes of the experiments, and the outcomes then used to discriminate among the hypotheses. Examples include pump tests or slug tests in hydrogeology, NMR in materials science, high-pressure fluid injection triggering microearthquakes in seismology, and kicking the tire of a used car to see if the door falls off.

Ordinarily, Earth scientists are limited in the ability to excite a system and thus observe the propagation and decay of the excitation, and we must rely on fortuitous events (filling a reservoir to load sensitive crustal regions) or natural sources (large earthquakes causing free oscillations of the planet). The tidal signal on the ice streams provides a beautiful excitation that we have exploited to understand the dynamics of ice flow.

Ice streams are large self-organized regions of the ice sheet of Antarctica (and possibly Greenland) where the interior flow of the ice channelizes into distinct rapid flow bands. The inception of these ice streams, their lateral width control, the flow speed they achieve are all poorly understood but of vital importance in modeling mass balance of the ice sheet. It is likely that much of the control is at the interface between ice and the subglacial environment. Imaging that environment using GPS and seismic measurements will allow the modeling to proceed in a better-constrained manner.

The response of the tidal forcing is seen in both the motion of the ice, with long periods of quiescence interspersed with periods of rapid motion. The motion is correlated to the phase of the tide with slip occuring at high tide and at the following falling tide. In addition to the motion events, there is significant microseismicity that emanates from the base of the ice stream that is associated with the failure of portions of the basal plane. Combining the observations from both the GPS and seismic instruments, along with modeling efforts now underway have given us a fuller picture of the elastic and visco-elastic response of the ice/till/water system than is possible from either instrument alone.

THE PLATE BOUNDARY OBSERVATORY: DATA MANAGEMENT STATUS AND PLANS

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The Plate Boundary Observatory (PBO), part of the NSF-funded EarthScope project, is designed to study the three-dimensional strain field resulting from deformation across the active boundary zone between the Pacific and North American plates in the western United States. The science goals of PBO require that plate boundary deformation be adequately characterized over the wide range of spatial and temporal scales common to active continental tectonic processes.

PBO will meet these needs using 891 continuous GPS sites, up to 174 borehole strainmeter stations (143 of which have been prioritized by the scientific community), and five laser strainmeters, all installed over the next five years. In addition, there will be a pool of 100 portable GPS receivers available for survey-mode observations, and we anticipate incorporating 209 existing continuous GPS sites into PBO with funding under the PBO Nucleus. Currently, 114 of these stations are operating and collecting data, of which 85 are returning data automatically to the PBO data collection center in Boulder on a daily basis. These stations have returned about 40,000 individual raw data files with a cumulative volume of 17.5 GB. PBO GPS data will be processed by two Analysis Centers (at Central Washington University and the University of California, Berkeley) and the PBO GPS Analysis Center Coordinator (at MIT). PBO strainmeter data will be processed by the Borehole Strainmeter Data Analysis Center in Socorro, New Mexico, and PBO laser strainmeter data will be processed by the Laser Strainmeter Data Analysis Center at the University of California, San Diego. These groups will create a wide range of derived data products, including time series of strain and GPS station position, GPS velocity vectors, and strainmeter and GPS processing auxiliary information. All PBO GPS data and data products will be archived at the UNAVCO Facility and the IRIS Data Management Center; all strainmeter data products will be archived at the Northern California Earthquake Data Center and the IRIS DMC. All PBO data products will be made available to the community as rapidly and freely as possible through the PBO Archives and the EarthScope Integrated Data Access system, which is still being defined.

T-PHASE OBSERVED AT DEEP SEAFLOOR BOREHOLES

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We inspected seismic records from two seafloor borehole seismometers in the Philippine Sea and the NW Pacific. Long-term observations from the seafloor boreholes enabled us to cover the whole regional seismicity. Despite their location beneath the deep seafloor (> 5km), we see many T-phases accompanying the seismic events below 10Hz. The distribution of seismic events observed with the T-phases and their T-phase amplitude compared with those of P/S phases, are useful to infer characteristics of acoustic wave propagation in the sea.

INTERDISCIPLINARY STUDIES OF A PERSISTENTLY ACTIVE VOLCANO IN ANTARCTICA

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Mount Erebus is an approximately 1 My old polygenic stratovolcano lying within the Terror rift region (local crustal thickness of approximately 18 km) near the boundary between between cratonic east and extended west Antarctica. The persistently active summit region hosts a long-lived lava lake and erupts a highly chemically evolved tephriphonolite from a diverse set of vents. An incessantly convecting lava lake, eruptive, and lava flow activity are all confined to a multiple vent inner crater with a diameter of just several hundred m that can be readily observed with diverse instrumentation across a wide range of azimuths and at ranges of only a few hundred m. A combination of high public interest in Antarctica science and volcanology has facilitated significant education and outreach activities, ranging from mass media productions to hosting undergraduate students and Earth science teachers on the volcano.

Due to an unusually stable upper conduit system geometry and eruptive forcing system, Erebus lava lake eruptions are remarkably characteristic, and produce highly repeatable signals across a bandwidth spanning many 10’s of s to 10’s of Hz. In the short-period (< 1 s) band, seismoacoustic signals are sufficiently similar between eruptions, for example, that they have been successfully applied to investigate subtle temporal changes in near-summit/conduit seismic Green’s functions manifested in the coda. Broadband seismic observations of lava lake eruptions also show a distinct frequency band of oscillatory and highly repeatable very-long-period (30-5 s) energy associated with conduit system gas and magmatic mass transport. VLP signals both precede and accompany eruptions, during which the upper portion of the lava lake system is removed, and furthermore persist for several minutes through the lava lake refill phase, as the system is recharged from a deeper magma reservoir. Moment tensor inversion indicates an evolving sub-horizontal crack-like source. Different classes of early (gas slug ascent) characteristics in VLP signals suggest multiple regions for gas slug growth with differing ascent characteristics. Video observations correlate these eruption groups with distinct patterns of ejecta. Geodetic observations to date show substantial stability in the upper volcano over the past 5 years, despite variability in eruptive and other inner crater activity. This is consistent with an open conduit system and consequent inability to accrue significant internal volumetric stress changes. Recent geochemical observations suggest that the various inner crater vents may be complexly linked at depth, rather than coalescing in a simple manner to a single shallow magma chamber.

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UPPER MANTLE SEISMIC ANISOTROPY OF THE ROSS SEA, TRANSANTARCTIC MOUNTAINS, AND EAST ANTARCTICA FROM SKS SPLITTING ANALYSIS

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The Transantarctic Mountains seismic experiment (TAMSEIS), a two year deployment of 43 broadband seismographs extending from Ross Island to the interior of East Antarctica, offers an excellent opportunity to study the anisotropic fabric of the Antarctic upper mantle, which is largely unconstrained. We analyze SKS and SKKS phases for shear wave splitting using the method of Silver and Chan (1991). The splitting functions are then stacked to obtain the best fit splitting parameters for each station. Results show that the Antarctic lithosphere beneath the Trans-Antarctic Mountains (TAM) and the adjacent East Antarctic craton are characterized by a uniform region of mantle anisotropy, with fast axes oriented at about N35E to N65E and splitting magnitudes of 0.5 - 1.0 seconds. This is consistent with azimuthal variations of Rayleigh wave phase velocities reported by Lawrence et al [2004]. The Rayleigh wave anisotropy is strongest at periods of about 40 seconds, suggesting the anisotropy is strongest in the uppermost mantle. This suggests that it represents upper mantle lattice preferred orientation that is remanent from past deformational episodes, rather than the current upper mantle flow pattern. Additionally, the continuity of anisotropic directions between the TAM and East Antarctica suggests the fabric is remenant from past deformational episodes, rather than a result of the current TAM uplift. The mapping of upper mantle anisotropic directions offers a possible method for delineating geologic terrains in ice covered East Antarctica.

GPS AND SEISMIC MONITORING OF AN ACTIVELY PROPAGATING RIFT ON THE AMERY ICE SHELF, EAST ANTARCTICA

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Rifts in Antarctic ice shelf rifts are large fractures that penetrate the entire ice thickness and form the boundaries from which large tabular icebergs detach. Despite this important role, very little is known about the mechanisms and controlling forces which lead to rift initiation and propagation. We present here results from two field seasons (2002-03 and 2004-05). In 2002-03 we conducted a pilot study deploying 8 seismometers and 6 GPS around the tip of an actively propagating rift on the Amery Ice Shelf (AIS), East Antarctica. Results from this study show that the rift propagates episodically, in sudden bursts that are not correlated with either tides or winds. This led us to the conclusion that rift propagation is primarily driven by the glaciological stress of the ice shelf. We also present preliminary results from this seasons follow up survey. Although we have not yet received the complete data set, the magnitude 9.3 Sumatra earthquake on December 26th , 2004 (clearly visible in our seismic records) generated a tsunami observed in tide gauges operated around the AIS. This presents a unique opportunity to study the influence of both the tsunami and of large earthquakes on triggering rift propagation. We shall present preliminary results on the influence of these two significant events on the seismicity associated with the rift. Time permitting, we will also compare patterns of seismicity observed during the two field seasons.

INTEGRATED SEISMIC AND GEODETIC STUDIES OF MAGMATIC EMPLACEMENT AT THE SOCORRO MAGMA BODY, NEW MEXICO

Susan Bilek, Richard Aster • New Mexico Tech

Andrew V. Newman • Los Alamos National Laboratory

We have initiated an interdisciplinary study of seismogenic, and geodetic processes driven by magmatic intrusion in and below the continental lithosphere using what is perhaps Earth's most accessible large mid-crustal continental magma body, the Socorro Magma Body (SMB), as a natural laboratory. The SMB resides beneath the central graben of the Rio Grande rift. The magma body likely consists of a low-viscosity asthenospheric basalt associated with regionally thin (35 km) crust, thinned and/or highly altered lithosphere, and possible small-scale upper mantle convection. The body has a nearly flat upper surface at 19 km and has an extent of approximately 3000 square kilometers. Microearthquake, teleseismic, and active source imaging are consistent with a predominantly thin, tabular body with a possibly deeper extent near its northwest edge. The SMB is an active geological feature that is strongly tied to a large fraction of New Mexico seismicity and has been associated with at least several 10's of ky of persistent uplift at an average rate of several mm/year, consistently inferred from geomorphology, GPS, InSAR, and leveling observations. Understanding magmatic, seismic, and geodetic processes of intracrustal intrusions is important for advancing understanding of continental crust/lithosphere formation, rifting, volcanism, and seismicity in extensional regimes such as the western U.S., southern Siberia, western China/Tibet, east Africa, and west Antarctica. This project includes a development of a new comprehensive relocated microearthquake catalog, source mechanism analysis, near-source and teleseismic imaging, geodetic data collection and analysis, and integration of these components to elucidate magmatic processes causing localized earthquake activity and crustal deformation. Research funded by Los Alamos National Laboratory.

SURFACE-WAVE DISPERSION MEASUREMENTS FROM CORRELATIONS OF THE AMBIENT SEISMIC NOISE BETWEEN BROADBAND STATIONS IN NORTH AMERICA

Bensen, Gregory D., Shapiro, Nikolai M., Ritzwoller, Michael H. • University of Colorado

It has been recently demonstrated that cross-correlations between records for several days or months of seismic noise observed at various station-pairs result in coherent broadband waveforms with dispersion characteristics similar to predictions from traditional Rayleigh-wave tomography maps constructed using ballistic surface waves (Shapiro and Campillo, 2004; Sabra et al., 2005). Background seismic noise, therefore, contains a significant component of Rayleigh wave energy that is probably excited by oceanic microseisms and atmospheric forcing. These signals form a wavefield in which the phase is randomized by a multiplicity of sources and by the scattering. Cross- correlations of this random wavefield provide a new source of broadband surface-wave information that may be particularly useful in the context of dense arrays of seismometers, such as PASSCAL, USArray, or other national deployments, that will produce numerous inter-station paths that cannot not sampled with ballistic waves. The usefulness of the new noise-based measurement method to image the Earth's interior has been demonstrated by its first systematic application to records at Californian USArray seismic stations where it helped to construct high-resolution short-period (7-18 s) surface-wave dispersion maps and to image principal crustal geological units (Shapiro et al., 2005). Here, we investigate a feasibility to apply the new noise-based measurement method at larger spatial scales and at periods longer than 20 s by computing cross-correlations and making surface-wave group velocity measurements for paths connecting about one hundred permanent broadband stations in North America.

WATER AS THE IMPORTANT INGREDIENT IN THE FORMATION OF THE WALKER LANE

Glenn Biasi • University of Nevada, Reno

Detailed maps of mantle velocity at shallow depths permit associations to be made with the tectonic and volcanic history and on-going deformation. By using dlnVp and tectonic data sets together, inferrences of mantle physical state can be made with more confidence than considering either class of evidence separately. Having large coverage areas ensures greater consistency of interpretation and in places eliminates alternative choices not addressable beneath smaller seismic arrays. We apply these interpretation methods to consider California and western Nevada, and focus in particular on the origin of the Walker Lane Belt in eastern California and western Nevada. Principle observations include: (1) Large areas of the lowest P-wave velocities in California and southern Nevada are nearly amagmatic; (2) Volcanism concentrates not at lowest velocity regions, but in areas of intermediate (near zero) dlnVp; (3) High velocity regions tend to have little volcanism above them; (4) A detailed inversion above a region of recent volcanism includes both the melt extraction area and the amagmatic low velocity region of southern Nevada, and permits separation of partial melt and hydration mechanisms; and (5) Faulting tends to avoid high velocity regions. Taken together these observations argue that the large low velocity regions of central California and western Nevada in are not partially molten but rather are wet and subsolidus. The Walker Lane Belt is near zero dlnVp, consistent with either melt being entirely removed or possibly being partially molten at very low melt fractions (probably <1/2%). The origin of Walker Lane no doubt includes several elements, but the pattern of faulting, volcanism, and tectonics implicates water as the uniting ingredient. Some water and related metasomatic enrichment may date to Laramide or earlier subduction, but hydration by post-Laramide subduction is responsible for the lithospheric weakness exploited to become the Walker Lane Belt.

SLIP TEASE IN THE ANDAMAN ISLANDS 5000 MPH RUPTURE FOLLOWED BY LEISURELY SLIP IN THE SUMATRA-ANDAMAN M_w9.3 EARTHQUAKE OF 26, DECEMBER 2004

Roger Bilham • University of Colorado

In December 2004 the Nicobar /Andaman Archipelago moved bodily 4-6 m towards southern India as a result of the December 2004 earthquake, flooding some islands and raising others and tilting the axis of the islands down to the east. Observations of these motions take the form of eyewitness photos and accounts, remote imagery, GPS observations out to several thousand km, changes in wavelength of ocean waves, depth sounding, and geoid changes observed by remote imagery.

Whereas the 3-D coverage of the region is currently patchy, a first-order view of the slip and its sequencing can be patched together from currently available data. The surface displacements represent a combination of dip-slip and strike slip motions on the upper surface of the subducting Indian plate, whose interseismic convergence with the Andaman/Burma plate is estimated to lie in the range 15-31 mm/year.

Fault slip in the earthquake varied from 7 m in the north to 20 m in the central and southern segments of the fault, separated by regions of lower slip. An abrupt change in slip amplitude is associated with rupture north of the Andaman spreading center presumably due to a change in slip partitioning. The width of the rupture varied from 120 to 150 km along the curved descending Indian plate, with rupture terminating at the approximate intersection of inter-seismic micorearthquakes and aftershocks. The rupture occurred between the near surface trench and depths of approximately 45 km along most of the arc.

Three clues as to the timing of slip exist: the first in the form of very long period seismic waves (>20 minute period) and free oscillations, the second is the virtual absence of tsunami generation in the north, and the third is the timing of subsidence at Port Blair harbor. They conspire to suggest that the northernmost half of the rupture occurred in the form of a massive M_w=8.9 slow earthquake.

Although stress changes in the earthquake caused subsequent slip to the south in the Nias M_w=8.7 earthquake on March 28th, extending rupture from 1300 km to 1600 km length, no similar stress-induced failure has yet been detected to the north. Rupture may have terminated to the north at a 10 degree releasing bend in the subduction zone. Microseismicity and aftershocks are significantly subdued north of the 15∞N, but there are no direct measurements in the Coco Islands to determine whether this passivity is caused by creep, or whether it represents a contiguous locked patch of the subduction zone.

The rupture passed through three historical rupture zones (1847 M>7.5, 1881w=7.9, and 1941M_w=7.7). Although geodetic evidence for reduced slip in the most recent of these exists in the form of a reduced rupture-width near Port Blair, the GPS data are too sparse to form definite conclusions about slip near the inferred 1847 and 1881 ruptures. The inferred interseismic convergence rate (>31 mm/year), based on plate geometry inferred from the 2004 rupture dimensions, suggests that these two areas had accumulated a slip deficit of 4-5 m before the earthquake. Thus approximately 30% of the the 17±2 m of slip inferred to have occurred on the plate boundary near Car Nicobar could have been contributed from the 1881 rupture surface.

The size and complexity of the rupture suggests that we may need now to re-evaluate the slip potential of nearby plate boundaries. A sober realization is that had slip in the Andaman and Nicobar islands not been slow it would have generated tsunamigenic waves along the entire 1300 km long rupture zone causing broader and far more severe damage on the Indian, Myanmar and Thailand coastlines. This aside, we may perhaps need to re-think conservative estimates of future seismic hazard elsewhere. In the Himalaya, for example, we have assessed seismic hazard, hitherto, in terms of recent history, without the benefit of an extended record that may contain extreme events. The 2004 Sumatra/ Andaman earthquake may be a wake-up call that low-bid seismic forecasts do not serve society well.

SEISMIC REFLECTION/REFRACTION-IMAGING AT THE SAN ANDREAS FAULT

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T. Ryberg • GeoForschungsZentrum Potsdam, Germany

A reflection/refraction 2D survey across the San Andreas Fault (SAF) near Parkfield at the location of the San Andreas Fault Observatory at Depth (SAFOD) provides a detailed characterization of the upper crustal structure at the drill site.

Three-component stations at a spacing of 50m were deployed on a 46 km long line perpendicular to the surface trace of the SAF. P-wave velocities derived by first-break travel time tomography show large vertical and horizontal variations. The major velocity contrast is related to Salinian granitic rocks buried below mostly unconsolidated sediments, and juxtaposed across the SAF with lower velocity Franciscan sediments.

Reflection seismic images of the wavefield were derived by Kirchhoff prestack-migration. They show several steep reflectors down to 5 km depth: An outstanding sharp reflector to the NE of the survey dipping steeply is interpreted to mark the transition from the Franciscan accretionary sediments to the Great Valley Sequence; Less reflective, but still clearly visible are the SAF and the northeastern edge of the Salinian granite ~2 km further SW. The SAF is imaged between 1 and 3 km depth below surface, and a few 100 m offset to the NE of its surface trace with a slight dip of 85∞-90∞ towards the NE.

The images also suggest that the sedimentary wedge between the Salinian granite and the SAF extends 3-4 km deep, where it is probably underlain by the granite.

GPS STRONG MOTION AT A VARIOUS TIME SCALES FROM THE GREAT SUMATRA EARTHQUAKES: CLUES TO PUZZLING PHENOMENA

Blewitt G., Kreemer C., Plag, H.-P., Hammond, W. C. • Nevada Geodetic Laboratory, jointly at Nevada Bureau of Mines and Geology, and Nevada Seismological Laboratory, University of Nevada, Reno.

We present GPS strong motion results from the Great Sumatra Earthquakes of 26 Dec. 2004 and 28 Mar. 2005 using the IGS global network. IGS station coordinates were simultaneously estimated in network-mode as white noise in the geocentric frame at various averaging windows at 1 second, 30 seconds, 5 minutes, and 24 hours. Various intriguing features come to light at various time and distance scales that provide clues to possibly new types of phenomena. To give just three examples at very different time scales:

1 using 24-hour averages, very rapid post-seismic motion is observed at station NTUS. During the weeks following the 26 Dec 2004 earthquake, NTUS moves in a direction almost orthogonal to its co-seismic displacement, where temporal characteristics of the curve suggests at least two driving processes. During the first three weeks following the 28 Mar 2005 earthquake, NTUS motion exceeds its co-seismic displacement in a similar direction to its co-seismic displacement.

2 using 30-second averages, the motion of IISC in India on 26 Dec, 2004 at ~2,700 km from the epicenter initially shows strong motion at the level of 40-50 mm amplitude, but then intrestingly transitions into an unexpectedly long phase of almost constant velocity that in principle might not be detectable on strong motion seismographs, before eventually settling into its post-seismic position approximately 12 mm due east.

3 using 5-minute averages, IISC in India on 26 Dec, 2004 and DGAR at Diego Garcia appear to exhibit a relatively smooth vertical deviation at the 1-cm level in the hours following the first strong-motion detection.

We suggest these strong motion records may hint at new types of phenomena. Specifically, item (1) suggests that lower crustal and mantle rheology is not part of the explanation, and perhaps a fluid response within the lithosphere may be responsible. Item (2) suggests that the northernmost segments of the ~1,500 km rupture zone may have slipped with little seismic radiation westward, which could be evidence of a dynamically detached hanging wall and internal seismic reflection within the hanging wall wedge, as predicted by foam rubber models of thrusting by Brune and Anooshehpoor [Eos, 81, no.28, p.F887, 2000]. Item (3) suggests the discovery of tsunami loading. We had predicted this phenomenon prior to the data analysis. Unlike typical ocean waves but similar to ocean tides, tsunamis propogate baratropically and so should transmit bottom pressure, thus deforming the solid Earth elastically.

Other evidence that will be presented relate to the riddle of the total magnitude of the Dec. 26 event as derived from geodesy versus seismology.

While other explanations are possible for these phenomena, the objective of this presentation is to identify clues that might lead to new discoveries, which in some sense should hardly be surprising given the magnitude and scope of observation on these world-class events.

A STABLE NORTH AMERICAN REFERENCE FRAME (SNARF): FIRST RELEASE

The SNARF Working Group: G. Blewitt, D. Argus, R. Bennett, Y. Bock, E. Calais, M. Craymer, J. Davis, T. Dixon, J. Freymueller, T. Herring, D. Johnson, K. Larson, M. Miller, G. Sella, R. Snay, M. Tamisiea

Starting in January 2004, NSF funded a series of small workshops by UNAVCO's Stable North American Reference Frame (SNARF) Working Group to define the reference frame to be used for EarthScope. Such a frame would be important to describe relative motions of Plate Boundary Observatory sites spanning the North America - Pacific plate boundary. The goal was to facilitate geophysical interpretation and inter-comparison of geodetic solutions through standardization and documentation.

Fundamentally a reference frame is required because GPS alone does not provide unambiguous coordinates: GPS data are relatively insensitive to global rotations of the entire system. Fixing the rotation according to a well-documented scientific rationale and procedure can facilitate geophysical interpretation. Early on, the SNARF working group identified that current frames such as NUVEL-1A have significant deficiencies, particularly as the East African Rift was not taken into account. Moreover, glacial isostatic adjustment (GIA) is known to produce greater intraplate deformations than plate tectonics across a large portion of the North America, and so GIA would need to be considered in the reference frame. Furthermore, research by the SNARF group indicated that GIA models are very sensitive to model parameters, and it is important to define a frame that does not come into systematic conflict with GPS data from well-established sites. For example, models of lateral variations in Earth structure can change predicted horizontal motions by a few millimeters per year in some locations.

Here we report on the anticipated release of the first version of SNARF, including scientific rationale, and procedures, with discussion on how to use the products. Driving the design of SNARF at the highest level are the big questions that EarthScope is being designed to answer. We identified four such questions:

1 Where does the plate boundary begin, and why? What is the extent of the stable plate interior, and how tectonically stable is the plate interior? Is the Colorado Plateau still rotating, and how active is the Rio Grande Rift? Is Alaska rigidly attached to North America (as current empirical evidence is weak).

2 What is the vertical velocity field across North America? What is GIA versus tectonic? What is the role of body forces and mantle dynamics? A deceptively simple question whose answer is completely reference frame dependent is whether the Basin and Range going up or down?

3 What signals are natural versus anthropogenic? What signals are due to ground fluid withdrawal, aquifer deformation, hydrological and atmospheric pressure loading? How do we disentangle these signals from GIA and tectonics? How do we define an unbiased reference frame in light of these effects?

4 How can we design geodetic products that are stable over decadal time-scales and beyond? Will we be able to detect a 5+ year transient? Can we detect the ghosts of historic earthquakes? Is tectonic activity steady state, or does it switch on and off spatially and temporally? Can we confidently compare and understand differences between geodetic rates and geologic rates?

Guided by these questions and the ensuing research, the SNARF Working Group has identified and tackled several major issues, including (1) the production of a GPS velocity field that is accurate (representative) and relatively dense to select a base model for GIA, (2) the selection of frame sites based on geological and engineering criteria, (3) the selection of a subset of datum sites that represent the stable plate interior and will be used to define a no-net rotation condition, and (4) the definition of products to be distributed for general use. The vertical datum of SNARF will be consistent with ITRF2000, in that the center of mass of the whole Earth system is taken to be the origin, and the horizontal datum will differ by a rotation rate that brings the rotation of stable North America to rest.

In this first release of SNARF 1.0, the product consists of (1) a rotation rate vector that transforms ITRF2000 velocity components into SNARF velocities, (2) an initial reference frame, defined as a list of selected sites, epoch coordinates, and site velocities, in the geocentric Cartesian system (X, Y, Z). SNARF will be adopted by PBO Data Analysis Centers which are scheduled to be in production-mode by October 2005. The intention is to incrementally improve SNARF through further research over the next 2-3 years, before handing off the production and maintenance of SNARF to the national geodetic agencies (the National Geodetic Survey and Natural Resources Canada). It is anticipated that SNARF will take on legal status as part of the bilateral North American Reference Frame (NAREF). At that point, NAREF will become the preferred name of the reference frame. Feedback by users of PBO products will be an essential ingredient toward improving the SNARF products

PLATE BOUNDARY OBSERVATORY GPS AND STRAINMETER SITE PERMITTING UPDATE, OBSTACLES, AND PLANS FOR YEARS 2-5 OF NETWORK BUILDOUT

Kyle R. Bohnenstiehl, Chelsea Jarvis • UNAVCO, Plate Boundary Observatory, Boulder

Permitting of GPS and strainmeter sites is a critical path to the construction of the Plate Boundary Observatory. Costs, schedule, and long term occupancy are all variables that must be managed to keep the network operating and producing scientific data. Of all of the variables in the network construction and long term maintenance, permitting poses some of the greatest risks that are difficult to manage. This talk looks at the current status of the permitting of GPS and strainmeter sites, the hurdles that have been encountered, and the corrective actions that have been taken to date. In addition, the talk will look ahead at permitting priorities in years 3-5 of network construction. Cooperation from Federal agencies, state, county, and local government will be addressed and cost and timing issues will be analyzed for each landowner category. NEPA process requirements as they apply to EarthScope facilities will be discussed and the relevance of this process to other large physical science facilities will be presented. Finally, an analysis of critical path risks will be presented with ways that the EarthScope community may be able to help overcome them. In light of the current regulatory climate that exists with public land owners, the lessons learned in permitting PBO are directly applicable to other large, geographically dispersed science projects seeking NSF funds.

OVERVIEW OF ARCHIVING ACTIVITIES AND ARCHIVE INFRASTRUCTURE AT UNAVCO BOULDER

Fran Boler, Lou Estey, David Maggert, Chris Stolte, Jeff Braucher • UNAVCO, Boulder

UNAVCO has operated a GPS data archive since 1992 and currently holds nearly two terabytes (uncompressed) of GPS data. Data files are received and archived regularly from 673 permanent stations. Campaigns are received and archived at a rate of 50-70 per year; with 550 campaigns currently held. The Archive is undergoing expansion due in part to the incorporation of PBO and Nucleus data amounting to 269 stations added so far this year. Approximately 130 additional PBO sites are scheduled for installation and data flow this year, and these will be incorporated into the archiving stream as they come online. Over the next few months the UNAVCO Archive will be finalizing procedures for archiving and making available PBO data products from the Analysis Centers and the Analysis Center Coordinator. In addition, UNAVCO's archiving role for PBO has expanded to include setting up and operating an independent GPS Archive at an offsite location, the IRIS Data Management Center. This secondary archive for PBO will be set up over the next few months, and will ultimately be capable of receiving and archiving PBO data from PBO's secondary distribution center should UNAVCO's Boulder office be incapacitated for any reason. All PBO data and data products will be available from either the primary Boulder Archive or the secondary Archive at IRIS via ftp. To accommodate current and future data volumes with high reliability, scalability and robustness, UNAVCO has moved its archive data collection to a high end storage system, and is in the process of upgrading its backup hardware and software systems.

QC AT THE GOLDEN DCC

Harold Bolton, Ray Buland, Jerry Mayer, Mark Meremonte • U.S. Geological Survey

In order to meet desired operational standards and to satisfy the requirements of the USGS Earthquake Hazards Program (EHP), the USGS has made a commitment to provide the scientific community with a quality data product from the seismic stations of the ANSS. Because a community waveform data product has more potential applications than required by the monitoring/hazard mission, this commitment has placed new demands on the quality control applied to the seismic waveforms within the ANSS.

To begin to meet these new requirements, the leadership of the USGS Geologic Hazards Team (GHT) has created a Data Collection Center (DCC) at the National Earthquake Information Center (NEIC) in Golden, Colorado. This DCC functionally mirrors the operation of the DCC at the USGS Albuquerque Seismological Laboratory (ASL). The primary operation of the DCC revolves around detecting and cataloging data problems by applying quality control (QC) and then repackaging the waveforms as a data product for distribution. The QC'd data from backbone stations of the ANSS are the current primary data product that are being distributed to the IRIS Data Management Center (DMC). This poster will provide a more complete outline of DCC functionality.

Though the DCC at Golden is in its infancy and under active development, the QC staff has uncovered several data issues that generally represent typical problems associated with telemetered data from broadband seismic stations. This poster will also provide notice to the community of these data issues and their associated resolutions.

INCREASED SEISMIC HAZARD IN NORTHERN SUMATRA DUE TO THE M 9.3 AND M 8.7 SUMATRA SUBDUCTION ZONE EARTHQUAKES

Oliver S. Boyd • U.S. Geological Survey, Denver

The static change in stress on the Sumatra transform fault associated with the M 9.3 and M 8.7 Sumatra subduction zone earthquakes is investigated to suggest the likely rupture features for the next large earthquake on the transform fault. The Coulomb stress change exceeds 0.3 MPa (3 bars) on a segment of the northern transform fault that may have accumulated more than 3 m of slip deficit. Potential currently exists for a maximum earthquake between M 7.4 and M 7.8. An earthquake with M 7.8 would include rupture into adjacent fault segments having significant slip deficit. Strong to violent shaking with median peak ground accelerations well in excess of 26% g in Banda Aceh could be felt. Regions closer to the fault in the Aceh and Utara provinces would experience median peak ground accelerations of more than 70% g.

RELATIONS BETWEEN ELASTIC WAVESPEEDS AND DENSITY IN THE EARTH'S CRUST

Brocher, T.M. • U.S. Geological Survey, Menlo Park

Strong ground motion calculations require regional 3-D models of compressional-wave velocity (Vp), shear-wave velocity (Vs), and density. For such models Vs is more important than Vp because strong ground motions are generated chiefly by shear and surface wave arrivals. Seismic tomography and refraction studies, however, often report only Vp so a direct relation between Vp and Vs is highly desirable. To develop empirical curves relating Vp, Vs, and density, I compiled measurements of these properties for a wide-variety of common geological units under a variety of conditions. These data included: wireline borehole logs, vertical seismic profiles conducted using surface sources and downhole receivers, laboratory or field measurements on hand samples, and *in situ* estimates from seismic tomography studies. The resulting Vp/Vs versus Vp curves are characterized by a rapid decrease in Vp/Vs as Vp increases from 1.5 km/s to about 3.5 km/s. This decrease is given by Poisson's ratio = $-0.0024Vp^3 + 0.0491Vp^2 - 0.315Vp + 0.8835$, where Vp is in units of km/s. For Vp between 3.5 and 8.5 km/s, Vp/Vs ratios lie close to the value of 1.73, corresponding to a Poisson's ratio of 0.25, commonly assumed for the crust with two exceptions. The first exception is serpentinite, an important constituent of the crust in northern California, which has anomalously high Vp/Vs ratios between 2.03 and 2.13. Second, ophiolites, mafic and ultramafic rocks, carbonate sedimentary rocks, and dolomites have Vp/Vs ratios of about 1.85. Similar curves were determined for the relation between Poisson's ratio and density. Poisson's ratio decreases gradually from 0.5 for densities between 1.5 and 1.8 gm/cc, decreases rapidly for densities between 1.9 and 2.4 gm/cc, and is close to 0.25 for densities above 2.4 gm/cc.

RECEIVER FUNCTION ANALYSIS OF THE UPPER MANTLE OF NORTHERN CALIFORNIA

Shanna Brown, Harold Gurrola • Texas Tech University

We will present results from common midpoint stacking of receiver functions to image the upper mantle beneath Northern California using data from the Berkley Seismic Network. This network includes a very dense distribution of stations in and around the Bay area thinning to only a handful of stations near the Oregon border. The results discussed in this abstract were based on an image using receiver functions that were low pass filtered at 0.2 Hz. The 660 km discontinuity beneath the southern part of this region, 34 to about 39 degrees, exhibits a similar second arrival at 720 km depth to that observed by Simmons and Gurrola, 2000. This phase is consistent with the depth hypothesized for the garnet-to-perovskite transition. The 660 beneath the northern, and most data poor, portion of this image does not appear be complicated by the deeper phase. Depth variations to the 660 km discontinuity beneath this region do not appear to correlate with any surface tectonic features. The 410 km discontinuity, however, is deepest, implying high temperatures, to the northwest beneath the Modoc and Basin and Range regions. The 410 shallows to the west implying lower temperatures. There are Ps phases in the lithospheric depth range in the northern most part of this image that appear to be consistent with a shallow eastward dipping lithospheric plate about 100 km thick; but at this point our image does not have the resolution to image this region in great enough detail to make strong statements about the position of the slab. We are reprocessing this data at a higher frequency range and will present a higher resolution image in our poster.

IMPLICATIONS OF FAR-FIELD STATIC DISPLACEMENTS FOR THE SIZE AND DURATION OF THE GREAT 2004 SUMATRA-ANDAMAN EARTHQUAKE

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Pollitz, F.F. • U.S. Geological Survey, Menlo Park, CA

Burgmann, R. • University of California, Berkeley, CA

The December 26, 2004 Sumatra earthquake produced significant static offsets at continuously operating GPS stations located at distances of up to 4500 km from the epicenter. We also utilize estimated offsets on the Andaman and Nicobar Islands from campaign GPS measurements. We find a coherent pattern of surface motions that are roughly directed towards the earthquake rupture at distances as large as 4500 km from the epicenter. Sites in southern India moved eastward by as much as 25 mm, decaying to 2-4 mm in the northwest Himalaya. Motions swing in a clockwise sense from southeast Tibet across China towards a southwesterly trend seen for sites in Korea and Taiwan. Displacements of sites just to the south of the rupture in Sumatra, are small and mostly towards the east. Estimated motions in Australia, on the Seychelles Islands, and in Eurasia north of about 40∞ latitude are insignificant.

Mechanical modeling of an earthquake of this dimension requires consideration of the Earth’s shape and depth-varying rigidity. The standard approach of modeling the surface motions from an earthquake using an elastic half-space approximation of the Earth is inappropriate for an event of the magnitude and dimensions of the Sumatra earthquake. We model the event using PREM. Static deformation in a spherical geometry is evaluated using the method of Pollitz (1996). We define the geometry of our earthquake rupture based on constraints provided by the distribution of aftershocks and independent seismic source studies. Forward model comparisons of the Sumatra earthquake show that surface motions calculated with a homogeneous spherical model greatly exceed surface motions of the layered spherical model at very large distances. The magnitudes of the far-field displacements are highly sensitive to fault dip, and each segment is therefore subdivided into two sub-segments in order to capture to first order the dip increase with depth.

We determine > 5 m of average slip along the full >1200-km length of the 130-200 kmñwide rupture, including the ~650 km-long Andaman segment of the megathrust. Comparison of the source excitation derived from the far-field static offset with seismically-derived estimates suggests that as much as 25-35% of the total moment release occurred at periods greater than one hour.

GEODETIC IMAGING OF LITHOSPHERE RHEOLOGY

Roland Bürgmann • University of California, Berkeley

Precise GPS and InSAR surface deformation measurements following large earthquakes provide a glimpse of the active deformation processes and rheology of the Earth's lithosphere. Each large earthquake initiates a rock mechanics experiment in a natural laboratory of lithospheric dimensions. Sudden stress changes associated with the coseismic rupture lead to transient relaxation processes in the crust and upper mantle. Such deformation transients play an important role in fault interactions and earthquake triggering over a wide range of distances and time spans [Freed, 2005]. Postseismic deformation studies complement geologic observations and laboratory experiments to define the kinematics and mechanics of deformation below the seismogenic zone [Handy et al., 2005].

The interpretation of postseismic deformation for rheological parameters of the lower lithosphere is hampered by limits in the distribution and precision of the deformation measurements and an inherent difficulty to separate and identify contributions from several deformation processes (i.e., afterslip, poroelastic rebound and viscous relaxation) to the observed motions. Thus, a vigorous debate persists about what processes are responsible for the observed transient deformation, where the deformation occurs, and what the relevant constitutive parameters of the candidate processes are. A review of results of recent postseismic deformation studies following a number of large earthquakes suggests that either deep afterslip or distributed viscous flow can be dominant, depending on the geologic environment of a fault zone. Poroelastic rebound is clearly observed following a number of earthquakes. It appears that the dominant relaxation process depends strongly on the lithologic and thermal structure of the lithosphere. For example, deep-seated afterslip dominates the postseismic transient deformation after the 1999 Izmit earthquake [Hearn et al., 2002], whereas non-linear viscous relaxation in a relatively hot, and possibly wet upper mantle may be the dominant process following the Mojave Desert (1992 Landers and 1999 Hector Mine) [Freed and Bürgmann, 2004] and 2002 Denali earthquakes. In the case of the Denali earthquake, we find evidence that some upper crustal afterslip also contributed to the deformation [Freed et al., 2005, manuscript in preparation]. The 1989 Loma Prieta earthquake was followed by a ≤ 5-year period of rapidly decaying afterslip on and above the coseismic rupture [Bürgmann et al., 1997; Pollitz et al., 1998; Segall et al., 2000]. However, we now find from an integrated analysis of 1993-2000 GPS and permanent scatterer InSAR data, that a longer-term viscous relaxation signal is apparent, as well.

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THE NATURE OF CONVERGENCE ALONG THE QUEEN CHARLOTTE MARGIN

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The seismic hazard within the Queen Charlotte Islands (QCI) is poorly understood. The present tectonic setting of the region is dominated by the Queen Charlotte Fault (QCF), the transpressive plate boundary (~320o) between the North American and Pacific plates along the western margin of Canada. The plate motion along the fault is primarily right-lateral transform at rates of ~50 mm/a with a small component (10-20 mm/a) of compression across the boundary. Convergence is confirmed by GPS velocities indicating northward oblique to the margin motions of 5-15 mm/a and by the distribution of seismicity in the region of the QCF. The GPS velocities and inland focal mechanisms show that the interaction along the margin is partitioned into shortening just seaward of the coast in the QC Terrace, pure strike-slip along the QCF, and distributed shear inland along the continental margin. Two end-member models have been proposed for the accommodation of the oblique convergence, internal deformation of both plates and underthrusting of the oceanic Pacific plate. A receiver function analysis was performed on the MOBC (in operation since March 1996) and DIB (in operation since March 2004) seismometers in the QCI, as well as on 6 temporary stations that were installed during the summer of 1999. The analysis revealed a low velocity zone (LVZ) beneath MOBC (~50 km inland of the QCF), dipping eastwards at 25o under the continental Moho, with a depth of 37 km, a thickness of 10 km, and velocities consistent with oceanic crust. The modeled structure beneath DIB and the temporary stations is similar to that observed under MOBC with a LVZ increasing in depth eastwards across the QCI, consistent with an underthrust slab of Pacific plate. The largest recorded earthquakes in the region are dextral strike-slip events along the QCF; however, if underthrusting is confirmed, as suggested by the receiver function results, then megathrust earthquakes to M ~8 will also be expected beneath the margin.

SEISMOLOGY EDUCATION PROGRAMS AT THE UNIVERSITY OF PORTLAND

Robert Butler, Ronald Wasowski • University of Portland, Portland, OR

Seismology is a cornerstone of three education programs at the University of Portland:

1 University courses for nonscience majors: Three courses (Earth Systems Science; Natural Hazards of the Pacific Northwest; and Introduction to Marine Science) include seismology as a fundamental component. The Earth Systems course is required for undergraduate majors in the College of Education and we seek to inform these students about ways to include seismology in their future K-12 teaching.

2 Seismology Display: A public display is being constructed in the lobby of the largest classroom building on campus. This display will feature the AS-1 seismometer as well as real-time displays of world and Pacific Northwest seismicity and earthquake information.

3 Seismology education programs for K-12 teachers: (a) A one-day workshop on Earthquakes and Tsunami for teachers in Portland Public Schools is being organized for June 20, 2005. This workshop will capitalize on heightened public awareness about earthquakes and tsunami in the wake of the Indian Ocean tsunami and the tsunami hazard in the Pacific Northwest. (b) ìTeachers on the Leading Edgeî is a NSF sponsored field-based teacher professional development program designed by a collaboration of university Earth scientists and science education specialists, USGS scientists, and K-12 science educators. The inaugural August 5 - 20, 2005 program will feature a field-based and problem solving investigation of active continental margin geology to provide a regional geologic sense of place and an understanding of how plate tectonic processes have shaped Pacific Northwest geology. Program themes include: (1) Convergent margin processes from great earthquakes to continent building through volcanism and accretion; (2) Earth System Science using the John Day Fossil Beds to investigate the 30 million year record of faunal and floral succession and paleoclimate changes; (3) Geophysical studies that illuminate the geology beneath the tree-covered landscape and provide an introduction to anticipated EarthScope discoveries of continents in motion; and (4) Geologic hazards as wondrous but not mysterious aspects of living on the leading edge of our continent. Seismology is a critical framework member for three of these four program themes.

REMOTE GPS OBSERVATORIES IN VLNDEF NETWORK (ANTARTICA):SITUATION AND PROSPECTS.

Alessandro Capra • Polytechnic of Bari, Italy

Today's it is essential to install GPS permanent trackers in order to detect 3D deformation of very small entity, being the measurements result more consistent if long time series of data would be available. Moreover in Antarctica, like in remote areas, the utilization of remote stations allows to reduce time and costs of operations in comparison with periodical network surveying.

The utilization of GPS permanent trackers guarantees even a more stable absolute coordinate determination in actual International reference frame (ITRF 2000 at the moment), overall for the height system establishment.

VLNDEF (Victoria Land Network for DEFormation control) network made by 26 stations and is surveyed since 1999 with the aim to detect regional crustal deformations in northern Victoria Land.

The strategy is now to increase the number of GPS permanent stations, that can be a reference îskeletonî of the network, in addition to the repetition of peridodical network surveying.

TNB1 was installed in 1998 and Cape Hallett in 2004. Next season three new stations (Little Rocks, Mount Keynas and Cape Adare areas) are planned. The characteristics of remote GPS stations in terms of power (wind and solar), remote monitoring and data transmissions that we have adopted are described.

THE 26 DECEMBER, 2004 M=9.0 SUMATRA EARTHQUAKE: IMPLICATIONS FOR CASCADIA

Cassidy, J.F., Rogers, G.C., Dragert, H., Wang, K. • Geological Survey of Canada, Pacific Geoscience Centre, Sidney, British Columbia

The 26 December, 2004 M_w=9.0 Sumatra earthquake, the worlds' largest earthquake in nearly 40 years, ruptured a subduction zone that is similar in many ways, to the Cascadia subduction zone. We compare: 1) the similarities (and differences) of these two subduction zones; and 2) the observations, including rupture characteristics, slip distribution, deformation patterns, and aftershock patterns with those predicted for Cascadia using theoretical modelling and interseismic observations. Both subduction zones are approximately 1200 km in length. Both are relatively young plates, with similar convergence rates and oblique subduction. Slip along the subduction fault during the 26 December earthquake is estimated at 15-20 m, as is predicted for Cascadia. The width of the rupture, nearly 100 km as defined by aftershocks, is remarkably similar to the width of the locked and transition zone predicted for Cascadia. Co-seismic subsidence of up to 2 m along the Sumatra coast is also similar to that predicted for parts of northern Cascadia, based on paleoseismic evidence. In addition to scientific studies, a number of preparedness initiatives are now underway to promote awareness of earthquake and tsunami hazards along the west coast, and plans are underway to upgrade tsunami and earthquake warning systems along Cascadia. Lessons learned from the great Sumatra earthquake and tsunami tragedy, both through scientific studies, and through public education iniatives, should help to reduce losses during future earthquakes in Casca

WAVEFORM SEARCH FOR THE INNERMOST INNER CORE

Vernon F. Cormier • University of Connecticut

Anastasia Stroujkova • Weston Geophysical

Waveforms of the PKIKP seismic phase are inconsistent with the effects of a sharp boundary at 300 km radius of an inner-most inner core of the type proposed by Ishii and Dziewonski. Seismograms synthesized for the distance range 150° to 180° in models having a discontinuity at 300 km radius in the inner core exhibit focused diffractions around the innermost sphere at antipodal range that are inconsistent with observed PKIKP waveforms. A few examples, however, can be found of PKIKP complexity near 165 o, consistent with a triplication created by a 475 km radius discontinuity. A rapid change in the magnitude and variance of seismic attenuation of PKIKP whose rays turn near 475 km is also observed, consistent with an innermost sphere of low, regionally uniform, seismic attenuation. Hence, models predicting waveforms in agreement with observed waveforms have either a transition in elastic and anelastic properties spread over a depth interval greater than 100 km or an innermost sphere of differing elastic properties that exceeds 450 km radius. The weak but suggestive evidence for an innermost inner core may simply represent a transition in fabric, spread over 100 km or more, centered near 450 km radius. This change may signify the end stage of solidification, flow and re-crystallization, resulting in the highest ordering and largest grain sizes of intrinsically anisotropic crystals.

THE EARTHSCOPE PLATE BOUNDARY OBSERVATORY (PBO) RESPONSE TO THE SEPTEMBER 28, 2004 PARKFIELD EARTHQUAKE

B. Coyle, T. Williams, A. Basset, E. Arnitz

On September 28, 2004 the M_w 6.0 Parkfield earthquake occurred on the San Andreas Fault seven miles southeast of the town of Parkfield. Within minutes of the earthquake, the PBO Transform Site Selection Working Group requested reprioritization and immediate installation of five PBO permanent GPS stations which had been scheduled for installation in Parkfield in 2005. Following the UNAVCO Event Response Plan, the UNAVCO President approved the rapid response and field crews were deployed from the PBO Northern and Southern California regional offices. In order to capture post-seismic deformation and any possible sympathetic rupture on fault segments south of the main shock, PBO targeted five stations for installation, focusing on the under-instrumented area south of the epicenter. Field crews began the reconnaissance and permitting process the day after the earthquake and within 72 hours the first station was installed. By the end of the week, they had also received a permit for one more station and submitted permit applications for three additional sites. By the end of the following week, the second permanent station was installed and three survey-mode GPS systems were deployed near to the proposed locations of the other three permanent sites, while permit approval was pending. PBO received permission to install the final three permanent stations on October 29, and completed these installations on November 10. Data from these and all other PBO stations are freely available through the UNAVCO Archive at ftp://data-out.unavco.org/pub/PBO_rinex.

ARRAY ANALYSIS OF CASCADIA DEEP TREMOR

Ken Creager ,Wendy McCausland, Steve Malone • University of Washington

In July, 2004 an episode of non-volcanic deep tremor was recorded on three arrays of short-period three-component seismometers. Each array consisted of 6 to 7 seismometers with an aperture of 500 meters. The arrays straddled the Straights of Juan de Fuca with separation distances of 50 to 80 km. Tremor migrated under the array from south to north. Signals within an array are highly correlated in the frequency band from about 2 to 6 Hz, providing a high fidelity view of the source. However, there is no correlation from one array to the next. We have implemented the following Kirchhoff migration procedure which takes advantage of the correlated phase within each array. First we band-pass filter the seismograms at 2-4 Hz. For each of many target points within the Earth, we calculate the travel time and slowness vector to each array using a high-resolution 3-D model. We stack the waveforms at the appropriate slowness; time shift them according to the predicted travel time; calculate their envelope functions and apply a low pass filter. A source is identified as point in which the resulting time series from the three arrays are similar. This is identified in both the time domain at fixed points, and by viewing analyzing movie of slices of the Earth's interior as a function of time. Examples of each will be shown at the poster, as well as the potential of this approach to determine accurate source depths, which have proven to be an especially difficult to constrain by other methods.

TSUNAMI IN THE INDIAN OCEAN: THE AUSTRALIAN PERSPECTIVE

Phil R. Cummins • Geoscience Australia

Although Australia is generally thought to be at low risk from tsunami, the 26 December 2004 tsunami caused by the Great Sumatra-Andaman Earthquake showed that the Australian coast is not immune to this hazard. The widespread death and destruction caused elsewhere in the Indian Ocean by this tsunami also awakened many Australians to the important role Australia can play in mitigating such disasters, by contributing to both regional warning systems and risk assessments.

This talk will discuss tsunami hazard in Australia, focussing mainly on the hazard to the west and northwestern coasts posed by earthquakes in the Sunda Arc. While the effects of the 26 December 2004 tsunami in Australia were more widespread than any known since the 1883 Krakatoa tsunami, the effects of earlier events, such as the tsunami caused by the Great 1833 Sumatra earthquake, are poorly understood. This particular event was the last to occur in the southeastern part of the Sumatra subduction zone, where strain has therefore been accumulating for the last 172 years. A repeat of this event seems likely within the next 50 years, and perhaps much sooner if stress-trigerring continues to be effective along the Sumatra subduction zone. The effects of the 2004 tsunami can to some extent be useed to help forecast the impact a repeat of the 1833 earthquake may have on Western Australia and the rest of the Indian Ocean, but other potentially important sources of tsunami are much more poorly understood.

Finally, the potential for Australia to contribute to tsunami warning in the Indian Ocean region will be discussed. After the 26 December 2004 Great Sumatra-Andaman Earthquake, Australian seismographic stations provided the first indication to international earthquake monitoring agencies that a massive earthquake had occurred, and the Australian tide gauge at Cocos Islands provided the first instrumental verification of a tsunami (although this was unfortunately too late to provide a warning to those most affected). Improvements in the distribution of and communications to seismographic stations and tide gauges on Australian and neighboring territories could offer a vast improvement to the region’s capability to warn of events like the December 2004 tsunami.

INVESTIGATING UPPER-MANTLE ATTENUATION STRUCTURE USING SURFACE-WAVE AMPLITUDES

Colleen A. Dalton, Göran Ekström • Harvard University

Seismic-wave attenuation is highly sensitive to temperature and should provide an independent set of constraints on the Earth's internal structure that is complementary to the results of elastic velocity tomography. Additionally, large lateral variations in attenuation (1/Q) will cause significant dispersion of waves traveling at different periods and should be considered when constructing and comparing velocity models derived from seismic observations from different portions of the seismic frequency band. However, attenuation in the mantle is a difficult quantity to study due to the various factors that can affect the wave amplitude in addition to anelasticity. These include focusing and defocusing by elastic structure, uncertainty in the source scalar moment and radiation pattern, and inaccuracies in the instrument response. The extraneous effects must be accounted for before the amplitude data can be confidently interpreted in terms of anelastic structure. We study upper-mantle attenuation using amplitude measurements of fundamental-mode Rayleigh waves with periods spanning 50-250 seconds. The amplitudes are corrected for the effects of focusing and source and instrument uncertainty in the inversion process. The maps of surface-wave attenuation that result from this analysis show a strong correlation with surface tectonics for intermediate periods that becomes less prominent at the longest periods (i.e., for waves sampling the transition zone). Extensive testing has established that the patterns of these maps are extremely robust. Retrieved correction factors for the source amplitude are shown to agree with improvements in scalar moment that result from better constraints on earthquake depth for many events. Instrument correction factors, which are also determined from the inversion, are consistent with recently measured instrument gain problems. Phase-velocity maps are a by-product of this study due to the dependence of focusing effects on the second transverse velocity gradient, and we show that the amplitude data provide strong constraints on global phase velocities. A preliminary 3-D model of shear attenuation in the upper mantle derived from more than 250,000 amplitude measurements reveals how the patterns described above vary with depth and demonstrates that dispersive effects on intrinsic S-velocity due to lateral Q variations may be as large as one percent.

QUALITY CONTROL OF GSN SENSOR RESPONSE INFORMATION

Peter Davis, Miaki Ishii, Guy Masters • IGPP/UCSD

The M_w 9.0 Sumatran earthquake of December 26, 2004 provides a special opportunity to validate the accuracy of sensor responses reported for the IRIS Global Seismic Network (GSN). A goal of the GSN is to report instrument responses to an accuracy of 1% in amplitude and 1 degree in phase. This earthquake excited long period free oscillations to sufficient amplitude that modes with low attenuation rates could be observed above ambient noise for several weeks after the event. By examining in detail the pattern of excitation for a subset of modes least sensitive to short wavelength structure, we can test the reliability of published station response information. In particular, we investigate to what extent the amplitude of the radial mode 0S0 was observed to be uniform globally as would be expected to a first approximation by using two different techniques to measure 0S0's amplitude at GSN stations. We find that the amount of scatter in the amplitude observations suggest the above goal of 1% accuracy has not yet been achieved.

SEISMIC MONITORING OF THE JANUARY-FEBRUARY 2005 ERUPTION OF MT. VENIAMINOF, ALASKA.

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Mt Veniaminof, Alaska is a 2507 m high strato-volcano with a 10 km summit caldera that formed about 3700 years ago; the caldera is now ice-filled. An intra-caldera cone with a summit height of 2156 m is the site of the most recent eruptive activity. Mt. Veniaminof is monitored by the Alaska Volcano Obsevatory with a network of 8 vertical component, short-period (T=1s) seismometers and a webcam installed in the town of Perryville (35 km from the volcano). From January 2 to February 21, 2005, Mt. Veniaminof erupted. The eruptive activity was characterized by numerous steam and ash emissions from the intra-caldera cone reaching heights typically 1 km, up to 3-4 km a.s.l. and accompanied by nearly continuous seismic activity. The first stages of the eruption were characterized by weak seismic tremor and low-frequency events occurring at rates of 1 to 2 per minute with durations of 10-20 seconds. The discrete low-frequency earthquakes were well correlated with visual observations of ash plumes at the surface, suggesting the presence of an explosive source at shallow depths. Amplitude and occurrence rates of volcanic tremor and low-frequency events increased over the month of January, while surface activity evolved from discrete, relatively small ash outbursts into more continuous emissions forming ash clouds and ash fall reaching outside the caldera boundary. On February 4, incandescence was clearly visible on the night-time webcam images indicating strombolian activity with ejection of hot blocks and lava from the intra-caldera cone. This activity was accompanied by an increase in the amplitude and occurrence rate of low-frequency earthquakes; a notable feature of the events recorded during this eruptive phase was the similarity of their waveforms. Between February 5 and February 21, seismicity was dominated by volcanic tremor; the activity ranged from tremor bursts with durations of few tens of seconds to continuous tremor lasting hours. Strong and continuous harmonic tremor was observed between February 17 and February 21. The observed seismic activity was consistent with mild explosive activity from the intra-caldera cone, however, Mt. Veniaminof was not visible in the web camera images for almost the entire month of February due to cloudy weather conditions. Tremor energy was confined to the band 0.5-5 Hz. Peaked spectral amplitudes showed a fundamental frequency and a number of integer harmonics. Harmonic tremor exhibited interesting time-dependent features such as spectral gliding: when gliding occurs, the spectral peaks are observed to shift systematically to lower or higher values, while the harmonic structure of the signal is maintained. The occurrence and features of the harmonic tremor at Mt. Veniaminof can be explained in terms of the longitudinal resonance of a volcanic conduit, and spectral gliding may reflect changes in the seismo-acoustic properties of the volcanic fluid, such as bubble concentration. On February 21, seismic and eruptive activity ceased abruptly, marking the end of the eruption. The January-February 2005 eruption of Mt. Veniaminof is the best studied eruption of the volcano to date, and provides a benchmark for comparing future and past eruptive activity.

SURFACE WAVE STUDY OF THE REYKJANES RIDGE: AN INVESTIGATION OF SUB-RIDGE MANTLE FLOW AND MELTING

Delorey, A. • University of Hawaii

Dunn, R. A, Gaherty, J. • Columbia University

The slow spreading Reykjanes Ridge is strongly influenced by the Icelandic hotspot, giving it characteristics not typical of other slow spreading ridges. Two end-member models exist to describe the hotspot's influence. In one model, plume material spreads out in a radial manner under the lithosphere; in the other model, plume material is preferentially channeled down the ridge axis. We analyze Love and Rayleigh wave records for waves that propagated along the Reykjanes Ridge. These waves were generated by regional earthquakes occurring in the North Atlantic to the south of Iceland, and were recorded by the HOTSPOT and ICEMELT arrays and the GSN station BORG, located on Iceland. We show that surface waves traveling along the ridge are laterally focused into a wide low-velocity channel beneath the ridge, the low-velocity channel is consistent with a thin lithosphere, high temperatures, and a small amount of melt in the asthenosphere. The waveforms are sensitive to the magnitude and width of this channel and can be used to tightly constrain its properties. We extract the phase, group, and amplitude information of narrow-pass filtered waveforms over the period range of ~11-80s. Over ~12,000 such measurements are included in an inversion for mantle and crustal shear velocity structure; in addition the joint inversion of horizontally polarized Love and vertically polarized Rayleigh wave data provides a measure of mantle anisotropy. We will present tomographic images of the shear velocity structure of the upper mantle and crust and show that plume material spreads out broadly beneath the lithosphere, affecting the greater part of the upper mantle.

CONTINUOUS DEFORMATION MONITORING ON HAWAIIAN VOLCANOES: TRANSIENT DEFORMATION FOLLOWING THE JANUARY 30, 1997 INTRUSION AT NAPAU CRATER

Emily Desmarais, Paul Segall • Stanford University

Natural hazards in Hawaii are pervasive. Erupting volcanoes, earthquakes and tsunami are prevalent reminders of the consequences of living on an actively growing island. Because we know that catastrophic events will occur again in the future, forecasting when they will occur is imperative for public safety. Eruptions on Hawaii are typically forecast based on observation of rapid changes in tilt and patterns in seismicity. Understanding the mechanics of magma chambers in real time is a critical step toward more precise forecasting of volcanic hazards. The goal of this proposed research is to provide such a real time tool combining Global Positioning System (GPS) and Interferometric Synthetic Aperture Radar (InSAR) data in a time evolving model of the magma chambers and faults in Hawaii. The resulting tool will help reduce public hazards through more effective forecasting and provide important constraints on physical processes on volcanoes. We demonstrate this method by observing the transient deformation following the January 30, 1997 intrusion of Kilauea volcano.

ACCURATE DEPTH DETERMINATIONS OF CENTRAL ANDEAN CRUSTAL EARTHQUAKES AND THEIR RELATIONSHIPS TO TOPOGRAPHIC STRUCTURES

Stephanie Devlin, Bryan L. Isacks • Cornell University

Intracontinental event depths have direct implications on the deformation and strength of the continental crust. Routine calculations of shallow earthquake depths listed in global catalogs, however, are not accurate, so additional analysis is needed to fully constrain the location of a crustal earthquake hypocenter. Focal mechanisms for 120 crustal events above the subducted Nazca plate were assembled from the Harvard CMT catalog and published studies covering over 40 years of seismicity. The time between direct P and the surface reflections (pP and/or sP) on teleseismic seismograms is one of the most reliable methods of estimating the depth of a seismic source. Synthetic seismograms are produced and compared to the observed P waveforms to constrain depths to an accuracy of a few kilometers at best, or at least to determine whether the event is located in the upper or lower crust.

The relationship between high concentrations of crustal earthquakes and proximal topographic features is enigmatic throughout much of the Andes. Topographic expression in seismically active regions is nearly bi-modal. Thrust mechanism events are often visibly associated with regional-scale geologic structures where uplift and thrust features are apparent. In contrast, strike-slip and normal events located in the Altiplano of southwestern Peru are not associated with distinct surface features. What controls the surficial expression of seismic activity in intracontinental settings is not completely understood. Continued integration of accurate earthquake locations and associated topographic signatures enables us to closely study seismicity's influence on landscape evolution.

USARRAY ARRAY NETWORK FACILITY (ANF): METADATA, NETWORK AND DATA MONITORING, QUALITY ASSURANCE DURING THE FIRST YEAR OF OPERATIONS.

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Lindquist, K. • consulting, Fairbanks, Alaska

The deployment of Transportable Array stations for the Earthscope USArray project is underway with 22 Transportable Array stations telemetered as of the end of April 2005. The project will ramp up to 400 real-time telemetered stations deployed at any one time over the next four years. The role of the Array Network Facility (ANF) in the USArray project is to guarantee delivery of all Transportable Array stations (400) and telemetered Flexible Array stations (200) to the IRIS Data Management Center, ensure proper calibration and metadata are always up to date, and provide quality control for all data. In support of these goals, we use the Antelope software package to facilitate data collection and transfer, generation and merging of the metadata, monitoring of dataloggers, generation of noise spectra, and analyst review of individual events. The SRB, and a newly developed Antelope/SRB interface, is used for off-site backup of the data. A freeware package, Nagios, adapted to include Antelope plug-ins, as well as newly developed in-house tools allow network and data flow monitoring. Quality control checks include: daily review by an analyst to look for obvious discrepancies in channel polarization or change in noise characteristics; associations made against regional network and global bulletins to help spot timing errors; spectral noise plots; and daily reports of outages and data gaps.

PROMPT ASSESSMENT OF GLOBAL EARTHQUAKES FOR RESPONSE (PAGER): AN AUTOMATED SYSTEM TO ESTIMATE IMPACT FOLLOWING SIGNIFICANT EARTHQUAKES WORLDWIDE

Paul S. Earle, David J. Wald, Vince Quitoriano, Matthew J. Donnelly • U.S. Geological Survey

The US Geological Survey's National Earthquake Information Center (USGS/NEIC) is developing a system to rapidly assess societal impact immediately following significant global earthquakes. NEIC's near realtime earthquake solutions are being monitored to automatically identify quakes that likely caused human suffering or damage to infrastructure, or that will attract significant media attention. Our goal is to help the USGS fulfill its mission to provide critical earthquake-related information to emergency response agencies, government agencies, the scientific community, the media, and the general public. Currently, it takes several hours to days for the media and other organizations to provide an assessment of a damaging earthquake. Our system, known as Prompt Assessment of Global Earthquakes for Response (PAGER), will estimate the severity of damage caused by an earthquake immediately following its location and magnitude estimation (minutes to an hour). PAGER will assess the situation based on estimated and any observed ground motions, total population exposed to varying degrees of shaking, and vulnerability of the affected region. We expect that an automated summary impact statement and associated alarms can be deployed within seconds of computing the ground-motion estimates, well before ground truth damage estimates arrive. The USGS is collaborating with the US Agency for International Development (USAID) to develop a prototype system. The prototype will estimate ground motions using modifications to the methodology developed for ShakeMap, extended to the entire globe. Since strong-motion recordings will rarely be available for global earthquakes in realtime, we will rely on predicted rather than observed ground motions. Site corrections will be approximated using a combination of elevation and topographic slope (see Wald et al. this meeting) and the exposed population will be determined using Oak Ridge National Lab's Landscan2003 global population database. PAGER will be an iterative system with new alarms issued as better estimates of magnitude, location, fault orientation, finite fault effects, and felt reports become available. We will present details of the assessment algorithm and examples from the prototype system.

AMPLITUDE CALIBRATION OF PERMANENT SEISMIC STATIONS

Göran Ekström, Colleen A. Dalton, Meredith Nettles • Harvard University

The Harvard Seismology Group is funded by IRIS to operate a Waveform Quality Center (WQC) as part of the IRIS Data Management System. The WQC reports on the quality of digital waveforms recorded by the IRIS GSN and other networks with similar instrumentation and is concerned with data problems such as instrument polarity reversals, timing problems, and response function errors. We have recently examined the amplitude calibration of the stations of the GSN, Mednet, Geoscope, Geofon, Canadian Network and the USNSN with a particular interest in catching any systematic problems with instrument gain that could be easily overlooked, especially if one is studying only a single earthquake. To accomplish this, we predict synthetic seismograms for most M=6.5 and greater earthquakes that have occurred since 1991 using the centroid moment tensor solution, and we then calculate the correlation between the synthetic and observed waveforms. For seismograms with a correlation coefficient greater than 0.75, the scaling factor by which the synthetic should be multiplied to best match the observed seismogram is determined. This is done for both the body-wave portion of the seismogram (period of approximately 50 seconds) and the surface-wave portion (period of approximately 150 seconds). An annual median scaling factor is calculated for each channel of each station if the channel provided four or more well-correlated seismograms during the year. The result is a time series of scaling factors for each channel of 361 stations. Many stations show nearly constant scaling factors on all channels for the entire length of time analyzed. For example stations ANMO-IU, KONO-IU, MAJO-IU, and TAU-II exhibit scaling factors close to 1.0 on all channels for the 14-year time period studied. However, there are a number of stations for which deviations of the scaling factors from a value of 1.0 appear to be caused by problems with the instrument. At station HRV-IU, the horizontal components have been steadily losing amplification since 1996, and the current gain may be a factor of two smaller than reported. Station PAB-IU shows a decline in scaling factor from a value of 1.0 to 0.6 on the LHE channel since 1999. The scaling factor for station BJT-IC begins to decrease for the long periods in 2001. At station BRVK-II, a gradual loss of amplification is observed on the horizontal components beginning in 1999 and on the LHZ channel since 2002. Similar trends can be seen for several instruments, and the gradual change with time, and the typically larger loss of gain at long periods, might suggest the presence of a problem with the electronics for older instruments. Instrument correction factors that are retrieved from an inversion of measurements of fundamental-mode Rayleigh-wave amplitude for attenuation and phase-velocity maps and correction factors for each event and station show strong agreement with the instrument-gain problems described above.

UNAVCO EDUCATION AND OUTREACH PROGRAM

Susan C. Eriksson • UNAVCO

In 2004-2005, UNAVCO has made significant strides in establishing a long term education and outreach program addressing the needs of various audiences. A new internship program will commence in 2005 with one UNAVCO intern. Funding for a pilot project through the NSF Office of Education and Diversity in the Geosciences will commence in Fall, 2005. This collaboration among UNAVCO, IRIS, USGS, and several institutions of higher learning will significantly broaden participation of students of underrepresented groups in geophysics. The University of Colorado, a UNAVCO member institution, will join the USGS in Golden in providing mentors for scientific research for undergraduate students visiting Boulder for 10 weeks each summer. Highline Community College, located near Seattle, Washington, will join forces with the Department of Geological Sciences, Central Washington University, to build a bridge program from community colleges to four year geoscience programs.

The PBO Nucleus (existing ëwestern networks') has received NSF funding which will also support a new staff member in education and outreach. Building modules of cutting-edge GPS-based measurement of crustal deformation for three audiences is the theme of this educational project. Researchers from UNAVCO member institutions will work on materials to be used in general education classes such as Physical Geology and other course titles. Existing courses for upper level geophysics majors in member institutions will be modified to share on the web. Lastly, research scientists and teachers of Earth Science in secondary schools will work together on material for earth science classes. All of these materials will be made widely available through workshops, the web, and printed materials.

Longer term planning and articulation of UNAVCO's mission in education and outreach are under the leadership of a new standing committee of the UNAVCO Board of Directors. Building on existing projects such as the Jules Verne Voyager, UNAVCO will continue to strategically build programs for both education to broader audiences as well as provide service to its members.

NEW ZEALAND GEONET: CORE CAPABILITY AND BEYOND

Hilary Fletcher, Ken Gledhill, GeoNet Team

GeoNet is a 10 year project to monitor and collect data on geological hazards in New Zealand, funded by the New Zealand Earthquake Commission, the Foundation for Research, Science and Technology, and is operated by Geological and Nuclear Sciences. The goal of GeoNet is to provide national coverage for hazard detection, research and emergency response as well as to increase the quality, applicability and confidence limits of hazards research. Specifically, the goal of GeoNet is to design, build and operate: a national seismograph network for uniform earthquake location; regional seismograph networks for enhanced monitoring of specific regions and volcanoes; a strong motion seismograph network; a national network (funded by Land Information New Zealand) and more dense regional networks of continuously recording GPS (CGPS) stations to monitor earth deformation beneath the southern and eastern North Island and selected volcanoes; a national landslide emergency response capability.

After four years the GeoNet project has reached an important milestone with almost all of the core national geological hazards monitoring and data collection coverage in place. This includes the national seismograph (35 sites), strong motion (~ 200 sites) and CGPS (30 sites) networks. Data from these networks are telemetered continuously to two independent centres at Wellington and Wairakei, providing backup in the event of a major event near either. GeoNet has a modern data management system, allowing easy monitoring of all stations. Basic data are automatically archived and disseminated to New Zealand and international communities. The GeoNet web site (www.geonet.org.nz) continues to be the portal for GeoNet data and information. Enhancements in the last year have included better maps of recent earthquakes, timeseries plots for the CGPS stations, improved access to the earthquake catalogue and online forms for reporting the felt effects of earthquakes. Additionally, the entire collection of New Zealand strong motion data has been made available. The establishment of the core GeoNet capability has improved the timeliness and accuracy of felt earthquake information and the surveillance of New Zealand volcanoes and other geological hazards. The emphasis of the GeoNet installation program has now shifted to regional monitoring and data collection with the extension of the Wellington Geophysical Network up the east coast of the North Island, continuation of the upgrade of the volcano-geophysical networks, and the start of the installation of the Canterbury Strong Motion Network. More downhole strong motion and building arrays will follow, as well as remote volcano-chemistry monitoring.

A large amount of high quality data is being recorded for research into New Zealand’s tectonic environment and natural hazards. One of our CGPS stations recorded motion of 20 mm in 8 days in December 2002 and another 20 mm in 12 days in November 2004. The cause of these displacements has been attributed to slow slip events on the subduction interface. Other interesting measurements include a swarm of earthquakes that was measured in the Hutt Valley near Wellington during 2003-2004, the two largest events occurring in April 2004. The motion of a CGPS receiver in this region was steadily westward at 25 mm/year from January 2000 to May 2003, when it suddenly slowed down to only 15 mm/yr westward. The earthquake swarm at Upper Hutt and the change in motion at the CGPS station both began at about the same time. These locations are less than 15 km apart and the observations may be related. To explain the two effects requires a slip of about 50 cm occurring slowly over the past year on a deep part of the subduction interface between 30 km and 40 km, in the direction of plate motion.

CISN DISPLAY/QUAKEWATCH - REAL TIME SOFTWARE FOR DISTRIBUTION OF EARTHQUAKE AND TSUNAMI ALERTS

Paul Friberg, Eric Thomas, Kevin Frechette • ISTI, New Paltz/Saratoga Springs, NY

Egill Hauksson, Hugo Rico Jr. • Caltech, CA

Lind Gee • Berkeley University, CA

David Oppenheimer • USGS in Menlo Park, CA

QuakeWatch / CISN Display software suite provides a way to reliably deliver earthquake and tsunami warnings and related information to multiple local emergency responders with a minimum delay. Primary end-users include emergency operations centers, utility companies, and media outlets.

The software operates on all popular operating systems, receives information via the Internet, and can be configured to generate audible and visible alarms as well as short text messages to pagers and cell phones.

The software architecture includes a client GUI known as the CISN Display, and a server component identified as the QuakeWatch Server. All communications use the CORBA standard and all applications are written in Jav. The CISN Display will graphically alert users, in near real-time, of seismicity as well as vital earthquake-hazards information following a significant event. The CISN Display software is highly customizable and includes a full GIS system for end-users to include their own infrastructure layers as maps.

The software will be demonstrated at the poster if an internet connection is available.

CANOE: A BROADBAND ARRAY IN NORTHWESTERN CANADA

Gaherty, J, Wilson, C • Lamont Doherty Earth Observatory of Columbia University

Bostock, M, Langlois, A, Al-Khoubbi, I, Audet, P, Baig, A, Chaput, J, Mercier, J, Nicholson, T, Oueity, J • University of British Columbia

Garnero, E, Ford, S, Schmerr, N, Thorne, M, Yoburn, J • Arizona State University

Revenaugh, J, Courtier, A • University of Minnesota

Avants, M • University of California, Santa Cruz

Barstow, N • IRIS-PASSCAL Instrument Center, New Mexico Tech

The Canadian Northwest Experiment (or CANOE) is a nearly sixty broadband-instrument array extending from the Slave Craton in the Canadian NWT, across the Canadian Rockies in northern British Columbia and Yukon and south to Edmonton Alberta where the FLED (Florida to Edmonton) PASSCAL array terminated (Figure 1). The array crosses 4 Ga of geologic time and a series of compressive orogens undisrupted by later periods of extension or extensive hotspot volcanism. Coupled with excellent shallow structural control from Lithoprobe active-source transects, CANOE offers an unparalleled window into deep continental lithosphere structural expression and history. The array also offers excellent deep-mantle sampling of the central Pacific and Hawaii. A subset of the array was installed in May, 2003. The remaining two-thirds of the array were deployed in May and June of 2004 and will remain until October, 2005. Array endpoints are anchored by permanent stations of the CNSN that are available through the IRIS DMC; typical station spacing within the array is less than 50 km. Data are recorded continuously at 20 samples per second on a mixture of Guralp 3T, 3ESP and 40T instruments. Instruments for CANOE were provided by PASSCAL/IRIS. The members of CANOE wish to thank the PASSCAL Team for training, extensive field assistance and critical logistical support. Support for this experiment was provided by the Geophysics program of the National Science Foundation, as well as Canada's Lithoprobe program.

SEISMIC VELOCITY, Q, GEOLOGICAL STRUCTURE AND LITHOLOGY ESTIMATION AT A GROUND WATER CONTAMINATION SITE

Fuchun Gao, Gian Luigi Fradelizio, Alan Levander, Colin Zelt

A high resolution seismic velocity model has been determined by waveform tomography applied to two vertical seismic profiles (VSPs) and a 2D surface seismic dataset from a ground water contamination site at Hill Air Force Base (HAFB), Utah. The dataset has useful energy between ~10Hz and ~250Hz, but significant energy even goes up to ~350Hz. The target dimension measures 21.4m wide and 15m deep. Features as small as ~1.5m are recovered in the model. The structural details in the model correlate well with a post-stack depth-migrated image, using the 2D data recorded at the surface between the two VSP boreholes (Figure 1). Using the final waveform tomography velocity model as an initial model, we determine Q value in the target area using further iterations of waveform tomography. Q values vary from 10 to 50. Large Q values (~50) are identified near the right borehole. The good correlation (Figure 1) between the model, the lithologic logs available, and the depth migration makes it possible to geologically interpret the details in the model. This study further shows it is possible to lithologically characterize the material in the model by utilizing a physical relationship between effective seismic velocity and physical rock properties of mineral grains such as bulk/shear modulus, density, Poisson's ratio and porosity. A 1D velocity model is averaged from the 2D model. By modeling the 1D velocity model, 1D profiles of porosity and degree of consolidation are determined, given knowledge of other parameters from published lab experiments and on-site surveys. The porosity ranges from 0.1 to 0.3. The ratio between the local radius and grain radius, which is a measurement of consolidation, varies between 0.10 and 0.55 in the estimated profile.

INFRASOUND FROM THE 2004-2005 EARTHQUAKES AND TSUNAMI NEAR SUMATRA

Milton Garces, Pierre Caron, Claus Hetzer • University of Hawaii, Manoa

Multiple infrasound arrays in the Pacific and Indian Oceans that are part of the International Monitoring System (IMS) observed three distinct waveform signatures associated with the December 26, 2004 Sumatra earthquake and tsunami. The infrasound stations observed (1) seismic arrivals (P, S and surface) from the earthquake, (2) T-phases, propagated along SOFAR channel in the ocean, and coupled back to the ground, and (3) infrasonic arrivals associated with either the tsunami generation mechanism or the motion of the ground above sea level. All signals were recorded by the pressure sensors in the arrays. The seismic and T-phase recordings are due to the sensitivity of the MB2000 microbarometers to ground vibration, whereas the infrasound arrivals correspond to dispersed acoustic waves propagated through atmospheric waveguides. It appears that the arrival of the tsunami, as well as oceanic infragravity waves following the tsunami, were not observed by the infrasound stations. A similar (but not identical) sequence of arrivals was observed at Diego Garcia during the March 28, 2005 Sumatra earthquake and the April 10, 2005 Mentawai earthquake, suggesting that ground motion efficiently generates infrasound in the Sumatra region. We show the prominent features of the arrivals, present infrasonic source location estimates, and consider whether infrasound may be used in conjunction with other technologies as a discriminant for tsunami genesis.

PRELIMINARY RESULTS OF ACTIVE AND PASSIVE SOURCE SEISMIC INVESTIGATION OF THE NORTH WEST BASIN AND RANGE.

Gashawbeza, E., Lerch, D.L., Colgan, J.C., Klemperer, S.L., Miller, E.L. • Stanford University

The lithospheric processes that cause or enable continental crust to extend and which operate during extension are still relatively poorly understood and continue to be controversial topics. Characterizing these processes in more detail is a fundamental step towards advancing our knowledge of continental rifting, the formation of passive margins, and the evolution of sedimentary basins worldwide. The Basin-&-Range province (BRP) of western North America is a world-class laboratory to study continental rifting. Despite relatively low supracrustal extension, the crust in northwestern Nevada appears to be among the thinnest in the Basin and Range, raising the possibility that the region underwent flow of a ductile middle or lower crust away from the area to more extended regions to the south. To investigate this hypothesis, NSF-EarthScope and ACS-Petroleum Research Fund have funded a 260km seismic refraction-reflection and passive source studies in September 2004. By combining data both from teleseismic and explosion sources we will be able to constrain Moho depth, velocity structure and reflective nature of the crust and also possible detection of crustal anisotropy which allow us to gain more knowledge on deformation-related fabrics and thus deformation history and mechanisms within the lower crust. In this paper we have presented preliminary results of the new data.

ST. ELIAS EROSIONAL/TECTONICS PROJECT (STEEP): SEISMIC COMPONENT

Roger Hansen, Natalia Ratchkovski, Josh Stachnik, Steve Estes

This five year, multi-disciplinary study addresses the evolution of the highest coastal mountain range on Earth - the St. Elias Mountains of southern Alaska and northwestern Canada. This orogen has developed over the past few million years as the Yakutat block, a continental-oceanic terrane, has attempted subduction beneath the eastern end of the Aleutian arc-trench system. The ~500 km-long, 150-km-wide St. Elias mountain range is the product of the dynamic balance between rapid uplift induced by crustal convergence and rapid exhumation by a regional system of large, fast-moving temperate glaciers. Most sediments are deposited either on a broad shelf or in deepsea fans and provide a complete record of the tectonic, climatic, erosional, and eustatic events that have accompanied the orogeny. Such a fresh and currently active mini-orogen is ideal for the integrated project we propose here.

The overarching goal of our project is to develop a comprehensive model for the St. Elias orogen that accounts for the interaction of regional plate tectonic processes, structural development, and rapid erosion. Our focus is on the partitioning of deformation within the system from upper mantle flow to near-surface faulting and exhumation. Three basic questions guide us:

1 What is the nature of the upper mantle interactions that drive this orogenic system? In particular, is the orogen driven by passive subduction of a microplate or by forceful subduction driven by the Pacific plate; is continental crust being subducted; and how does upper mantle flow respond to the plate interaction?

2 How does the sedimentary cover respond to interaction of the three-plate/microplate interaction as it is stripped from basement along large-scale fault systems? That is, is the microplate behaving as an indentor or is it forcing lateral escape of the cover as the collision progresses? At what depth, and with what geometry do these separations occur?

3 How do surface processes, particularly areas of rapid glacial erosion, affect localization of deformation and slip-partitioning? Specifically, is the spatial association of large glaciers with areas of active deformation coincidental, or is the active deformation localized by rapid exhumation?

To address these questions we propose an integrated onshore-offshore study involving active source and passive source seismology, GPS-based geodetic studies, geologic studies, surface process studies, geochronology, and geodynamic modeling. Question 1 (crustal structure and upper mantle) will be addressed by a large-scale passive seismic study as well as offshore seismic profiling. These studies collectively will constrain the geometry and kinematics of the large-scale plate/microplate interactions in the system. Question 2 (sedimentary cover response) will be addressed through a combination of geologic studies onland, analysis of offshore seismic data (both existing data and the new data to be acquired in this study), GPS-based geodesy, and thermochronology. Question 3 (erosion/tectonics linkage) will be addressed by adding additional data from surface process studies and modeling.

This poster will concentrate on the seismicity of the region and the plans for the passive seismic experiment utilizing the IRIS PASSCAL Program instruments. As part of this project we will prototype a USARRAY seismic station that can operate and telemeter data in the harsh environment of Alaska with little built infrastructure, harsh weather conditions, lack of sunlight in winter months, and rugged terrain with large animals.

EARTHSCOPE FACILITIES INFORMATION SYSTEM

Christian Guillemot • EarthScope

As part of EarthScope commitment to provide timely information on the progress of instrumentation deployment through the construction phase of the facilities, a web-based application tool is being developed to facilitate the reporting and updating of station meta data. This information along with operational status changes will be updated through the normal reporting process and made available on the EarthScope website. The intuitive, easy-to-navigate tool will contain geospatial, operational, and pictorial information for each of the installed seismic, GPS, and drilling facilities, and may also serve as an entry point to the existing data archives for each station. To promote cross-browser compatibility, well-established scripting technologies are being used, with no additional requirement on the part of the user to import or download additional software. Text-based information will be pre-loaded by the client browser and will be available for viewing after a single page refresh. Additionally, search and sort capabilities will be implemented.

GPS INSTALLATION PROGRESS IN THE PACIFIC NORTHWEST REGION OF THE PLATE BOUNDARY OBSERVATORY

Hafner, K., Gray, P., Austin, K • Plate Boundary Observatory, PNW Region, Ellensburg, WA

The Plate Boundary Observatory (PBO), part of the larger NSF-funded EarthScope project, will study the three-dimensional strain field resulting from active plate boundary deformation across the Western United States.

The PBO plan for the Pacific Northwest (PNW) region, calls for the installation of 149 continuous GPS stations by the year 2008. These sites are largely distributed along the Cascadia Subduction Zone and at Mt. St. Helens. As of April 2005, the PNW Region of PBO has installed 20 GPS monuments. All but two of these installations are located in the state of Washington, and seven of these GPS sites were installed within the Mt. St. Helens National Volcanic Monument. The 2004-2005 eruption of Mount St. Helens, Washington, began with a small earthquake swarm on September 23, 2004. Activity peaked on September 24, gradually declined throughout the day, and then increased dramatically before culminating in a series of phreatic explosions on October 1-5. In response to this increased level of activity, the PBO Standing Committee and Magmatic Systems Site Selection Working Group requested reprioritization and immediate installation of five PBO permanent GPS stations on and around the flanks of Mt. St. Helens to monitor deformation associated with this volcanic crisis. Up to this time, permitting of these sites with the USFS was moving slowly. As a result of the increased activity, PBO was able to secure 5 permits within a few weeks. Field crews reached the volcano on October 12, 2004 and began assembly of the power systems and equipment enclosures. Each enclosure was slung by helicopter to a site where a GPS antenna and radome were fixed to existing EDM towers. Four sites were completed in two days and the fifth site was installed at the end of October once the weather had improved. The PBO Data Management and IT Group responded quickly to a request by USGS personnel that data downloads occur once per hour rather than once every 24 hours. Both hourly and daily data files are freely available through the UNAVCO Archive at ftp://data-out.unavco.org/pub/PBO_rinex.

Monitoring of the volcano, including data analyses from the newly installed sites, showed that one of the PBO sites located high on the SE flank of the volcano moved 4 cm SE between mid-November 2004 and January 2005. This was most likely due to growth of the new lava dome against the SE crater wall. As a result of this activity, the PBO obtained two additional permits from the USFS, and these sites were installed at the beginning February, 2005.

During Year 2 of the PBO project, the pace of installations increases dramatically. As of January 2005, the PNW office is completely set up, and fully staffed. By the end of September 2005, a minimum of 41 GPS monuments will have been completed. Installations will be focused in Southwest Oregon, on the Olympic Peninsula and at remaining sites on Mt. St. Helens (subject to USFS permit acceptance).

AN INTERACTIVE MAP TOOL FOR EARTHSCOPE EDUCATION AND OUTREACH

Michael Hamburger, Anne Hereford • Indiana University

Lou Estey, Susan Eriksson, Chuck Meertens • UNAVCO, Inc.

Marianne Weingroff • Digital Library for Earth System Education/UCAR

William Holt, Glenn Richard • Mineral Physics Institute, Stony Brook University

We present a new, interactive, web-based map utility that can make EarthScope-related scientific results accessible to a large number and variety of users. The tool provides a user-friendly interface that allows users to access a variety of maps, satellite images, and geophysical data at a range of spatial scales. The EarthScope Voyager map tool allows users to interactively create a variety of geographic, geologic, and geodynamic maps of the EarthScope study area. The utility is built on the Jules Verne Voyager suite of map tools, developed by UNAVCO for the study of global-scale geodynamic processes. Users can choose from a variety of base maps (including Face of the Earth and Earth at Night satellite imagery, global topography, geoid, sea-floor age, strain rate and seismic hazard maps, and others), add a number of geographic and geophysical overlays (coastlines, political boundaries, rivers and lakes, earthquake and volcano locations, and stress axes, etc.), and then superimpose both observed and model velocity vectors representing a compilation of 5170 geodetic measurements from around the world. A remarkable characteristic of the geodetic compilation is that users can select from some 26 frames of reference, allowing a visual representation of both 'absolute' plate motion (in a no-net rotation reference frame) and relative motion along all of the world's plate boundaries. For the EarthScope Voyager, we are in the process of adding a number of EarthScope-specific features, including maps of proposed and installed USArray and PBO instruments, detailed maps of EarthScope focus areas, and Did You Know educational modules, which provide examples of EarthScope-related scientific results linked to EarthScope study areas. Two versions of the tool are available: (1) a Java-based map tool EarthScope Voyager, a server-based map creation system which allows users complete control over base maps, overlays, and map scale; and (2) EarthScope Voyager, Jr, an HTML-based system that uses pre-constructed GIF maps and overlays, allowing the system to rapidly create and display maps to a large number of users simultaneously. The tool allows users to zoom among at least four map scales. In addition, we are developing a number of companion educational materials, including Exploring our Dynamic Planet, a Javascript-based interface that can incorporate the map tool, explanatory material, background material on EarthScope, and curricular activities that encourage users to explore Earth processes using the new EarthScope Voyager tool. The map tool and associated educational materials can be viewed through the Jules Verne map portal http://jules.unavco.org.

FIRST MAGNET RESULTS: SITE AND NETWORK PERFORMANCE ASSESSMENT AND FUTURE PROSPECTS FOR ESTIMATING SLIP RATES ON WESTERN BASIN AND RANGE FAULTS

William C. Hammond, Geoffrey Blewitt, Cornè Kreemer • University of Nevada, Reno

The Mobile Array of GPS for Nevada Transtension (MAGNET) has been in operation for 17 months, and can now have its performance evaluated with respect to other GPS networks in the Basin and Range. MAGNET occupies the northern Walker Lane Belt, extends from the Sierra Nevada microplate and Reno, Nevada area eastward past the Central Nevada Seismic Belt, and northward past Honey and Pyramid Lakes. The network has recently been expanded to 60 sites with average station spacing of ~20 km, through which we cycle 34 identical Trimble 5700 GPS receivers with Zephyr antennas. Occupation times vary between several weeks to months, but on average each site is sampled over 50% of the time. The oldest sites now have velocities that can resolve deformation across the northern Walker Lane, and provide geodetic velocities that are useful for evaluating regional crustal deformation. To evaluate the performance of MAGNET we will present time series and preliminary velocity estimates for the sites with the longest history. We will compare the coordinate repeatabilities and velocity uncertainties to other GPS sites in the Basin and Range. Furthermore, we will address analytical issues in commonmode spatial filtering of daily reference frame noise in a network with irregular but frequent sampling. The upcoming deployment of Plate Boundary Observatory permanent GPS stations in the northern Walker Lane will complement MAGNET and further refine our knowledge of present strain patterns in the most rapidly deforming (and most densely populated) areas of the Province.

In anticipation of geodetically determined crustal deformation patterns in the western Basin and Range becoming increasingly well resolved, we will also evaluate prospects for estimating slip on faults in the Western Basin and Range, Walker Lane and Reno/Caron metropolitan area. While the number and precision of geodetic velocities available for this region continues to increase, our ability to quantitatively estimate the partitioning of slip onto specific faults is limited by the large number and close spacing of the faults and the complex geometry of the fault systems. Furthermore, post-seismic transient motions that do not necessarily reflect steady tectonic loading can give an incorrect impression of the distribution of potential fault slip. Viscoelastic relaxation models suggest that the postseismic response from the at least six M>6.8 earthquakes in the 20th century that define Central Nevada Seismic Belt (CNSB) may have fundamentally altered the pattern of geodetically detectable dilatational strain. This transient deformation might amount to as much as 3-4 mm/yr velocity gradient within this zone that totals ~10 mm/yr across the CNSB and northern Walker Lane.

To address these issues we are developing a block model for this region that is constrained by geodetic velocities with the effects of viscoelastic postseismic relaxation of the lower crust and upper mantle removed. To achieve this, the results of a recent modeling study of the CNSB relaxation will be subtracted from the velocities before they are used to infer the loading by tectonic strain. Model geometry in specified by the faults in the U.S.G.S Quaternary Fault and Fold Database and other published and in progress studies. As data we use MAGNET velocities in addition to all the other published GPS velocity vectors in the western Basin and Range, placed into a self-consistent reference frame.

THE SEISMICITY OF EASTERN SIBERIA, 1960-2004

Hans E. Hartse, Lee K. Steck • Los Alamos National Lab, Los Alamos, NM

Kevin, G. Mackey, Kazuya Fujita • Michigan State University, East Lansing, MI

Through years of collaborations with regional network operators, Michigan State University researchers have obtained hard-copy bulletins, electronic bulletins, station information, and other seismological information from across eastern Siberia, Sakhalin Island, and the Kamchatka Peninsula. Recently, we have been parsing and merging this information into a uniform set of database tables, and now have a comprehensive seismic bulletin of eastern Siberia covering the years 1960-2004. For our poster, we will compare our seismicity bulletin to the view of Siberian seismicity available from teleseismic bulletins. We will also provide examples of research we are now undertaking using our bulletin.

PBO FACILITY CONSTRUCTION: BOREHOLE STRAINMETER NETWORK STATUS

M. Hasting, R. Mueller, W. Johnson, P. Gibicar • Plate Boundary Observatory

The Plate Boundary Observatory (PBO), part of the larger NSF-funded EarthScope project, will record the three-dimensional strain field resulting from active plate boundary deformation across the Western United States. PBO is a large construction project involving the reconnaissance, permitting, installation, and maintenance of 875 permanent GPS stations and up to 175 Borehole Strainmeter (BSM) stations in five years. PBO has a demanding 5-year installation schedule, for both GPS and BSM installations, with 16 BSM stations scheduled for installation this year.

Year 1 of the project saw a reprioritization of the BSM station deployment scheme to better record slow earthquakes in the Pacific Northwest (PNW) and plate boundary deformation along the entire Cascadia Subduction Zone. As such the PBO Siting Committee increased the station density from 4 to 12 BSM stations in the PNW for FY05 and created three more BSM arrays south of the Olympics and north of the Mendocino triple junction, scheduled to be installed in FY06-08. Year 1 activities also consisted of designing and specifying the system requirements, permitting 16 BSM sites on the Olympic Peninsula, Vancouver Island, and Parkfield regions, specifying drilling requirements, contracting drilling operations, ordering equipment, and commencement of drilling operations.

Siting and permitting efforts in the PNW were completed in August 2004 with permits acquired for 4 sites with a total of 8 stations. Two sites (4 stations) located on Vancouver Island still need to be permitted but siting has been competed and paperwork is in the hands of the Canadian Government. Reconnaissance and permitting for Parkfield was completed in July 2004. Additional reconnaissance is being conducted in both the PNW and California for future stations.

Initial Drilling/Coring operations on the Olympic Peninsula started in November 2004 and were completed in March 2005. Drilling/Coring is accomplished in three phases; 1) hammer drilling a 8î diameter borehole to 400-500ft and then cementing a 6-5/8î casing in the borehole, 2) rotary drilling through the cement shoe plus 40-100ft below the casing, and 3) coring 40-100ft into the rock to find suitable installation zones. The first two phases were completed in January 2005. The third phase started in mid January 2005 and should be complete by mid March 2005. Drilling and coring operations for Vancouver Island and Parkfield are scheduled to start in July and be completed by the end of September 2005.

A BSM station consists of a 4 component tensor strainmeter manufactured by GTSM Technologies, a 3 component 2Hz borehole gimbaled seismometer, a Paroscientific digiquarts pore pressure transducer, a Setra model 270 barometer and a rain gauge. Some stations will also have a PBO GPS antenna attached to the top of the casing as part of the 875 GPS station network. The strainmeters will be installed at depths between 450ft and 800ft with the seismometer installed about 30ft above the strainmeter. The pore pressure transducer will be installed in a 2î PVC pipe with a 10ft screen section somewhere in the aquifer above the seismometer. Data from the strainmeter and rain gauge will be recorded on the strainmeter recording system while the seismometer, pore pressure and barometer will be recorded on a separate 24bit digitizer. Strainmeter data will be sent, via the Internet, to UNAVCO/PBO while seismic data will be sent to the Array Network Facility.

Installation of the first BSM station, located on the Olympic Peninsula, is now scheduled to take place by June 2005. The remaining 15 stations will be installed over the summer and into the fall and should be completed by the end of the first quarter FY06.

THE EARTHSCOPE INTEGRATED DATA ACCESS SYSTEM

Christel Hennet, Christian Guillemot • EarthScope

Tim Ahern • IRIS

Greg Anderson, Susan Eriksson • UNAVCO

William Ellsworth • U.S. Geologocal Survey

Fred Pieper • IAGT

EarthScope has the mandate to provide seamless, single point access to all EarthScope data, data products, and tools, and to make all information open and accessible to a wide range of users, the scientific and educational communities, Government agencies, the media and public, and informal education services.

A key task for EarthScope is the development of the system for seamless, single-point access to all the data products. We call this system the EarthScope Integrated Data Access System (IDAS). While the EarthScope office will have primary responsibility for development of the IDAS, each EarthScope element will develop, operate, and maintain the infrastructure needed to make that element's data products accessible to the IDAS.

The IDAS system will integrate the data handling interfaces (DHI) already in use at each EarthScope facility. These applications run on a variety of software and hardware platforms in a distributed environment. Without the IDAS, the current lack of integration requires a data requester to become familiar with the application interface used for data retrieval at each data center. For instance, a simple EarthScope ìcombinedî data query from a community user may involve completely different programmed interfaces at PBO and USArray, thus making the transaction process difficult to automate and placing the burden of integrating this information on the user. In turn, data users will be placing a burden on the various data archives to make data compatible with various developers of EarthScope products and tools.

To minimize the differences between existing hardware and software platforms we intend to build a layer around the data handling interfaces which will effectively link these heterogeneous data management systems without having to modify the underlying legacy systems. We believe this approach will be the most effective in leveraging EarthScope's existing capabilities and will minimize the additional cost required towards developing a seamless access interface.

At present, the EarthScope Data Working Group anticipates that the IDAS will be largely based on web services. The term web services in general refers to a set of protocols and standards used for exchanging information between software applications over computer networks, to allow applications to work together regardless of the computer language in which they are programmed or the kind of computer system on which they operate. A specific web service-enabled application is one that can be found and accessed remotely via a computer network, using the protocols of the web services framework.

The IDAS system requires tight coordination among the EarthScope elements to develop solutions that will satisfy the architecture requirements for interoperability, encapsulation, and availability. In addition, flexibility will be built into the IDAS applications to quickly adapt to the variety of new data products, data tools, and data portals that will be generated by the broad scientific and educational community as EarthScope evolves.

THE CERRO MERCEDES PROJECT: A MULTIDISCIPLINARY STUDY OF A BACK-ARC LOCALITY IN THE CENTRAL AMERICAN SUBDUCTION ZONE

Alissa A. Henza, Vadim Levin, Michael J. Carr • Rutgers University

Waldo Taylor, Guillermo E. Alvarado • Instituto Costarricense de Electricidad and Red Sismologica Nacional

Mauricio Mora • Universidad de Costa Rica

Near the border between Costa Rica and Nicaragua the Central American volcanic front changes in several ways. From Nicaragua to Costa Rica, the geochemistry reveals diminished signal from the subducting slab. In the same region, the dip of subducting slab decreases from near vertical to 40∫. In Costa Rica, the overlying plate is composed primarily of remnants of the Caribbean Large Igneous Province (CLIP) formed by the Galapagos hotspot. Additionally, fairly thick (~40 km) crust is reported in northern Costa Rica.

The collection of mantle xenoliths at Cerro Mercedes, a small volcanic cone roughly 70 km behind the Central American Arc, has allowed for direct sampling of the mantle wedge beneath Costa Rica. Cerro Mercedes is the only known xenolith locality along the Central America Arc, and joins the ranks of only a dozen arc-related xenolith localities worldwide. Initial geochemical analyses indicate that these xenoliths originated in a mantle hotter than beneath Japan and colder than beneath the Cascades, implying that the Cerro Mercedes xenoliths may lie between end members seen in other arc environments. Their mineral composition (lacking garnet) suggests relatively shallow depth of origin for the xenoliths. Additionally, electron backscatter diffraction (EBSD) measurements indicate that the crystal axes of olivine in the xenoliths have a strong preferred orientation. This preferred orientation, created during deformation in the mantle, implies that seismic wave speed in the upper mantle region beneath Cerro Mercedes is highly anisotropic. While analyses of rock samples help to constrain the conditions in the xenolith source area, they reveal little about the regional characteristics of the upper mantle. In particular, given their shallow origin and the supposedly thick crust in the area, it is unclear whether our mantle nodules are remnants of the material directly involved in subduction processes (i.e., parts of the actively deforming wedge) or if they are pieces of the CLIP mantle lithosphere, and reflect the strain history of this 100+ Ma oceanic plateau.

To better understand the nature of the source region of our rock samples and how it relates to the regional processes, we have established a small broad-band seismic array near Cerro Mercedes. Three stations, set ~5 km apart, will operate for one year. The data collected will be used to estimate the crustal thickness in this area and the presence and degree of anisotropy at various depth levels. Combining this information about the crustal and upper mantle structure with the information gathered from the xenoliths, we expect to develop a very detailed description of the state of the upper mantle in this back-arc mantle xenolith locality.

ESTIMATION OF A TIME-DEPENDENT STRAIN RATE FIELD IN SOUTHERN CALIFORNIA USING CONTINUOUS GPS STATIONS IN THE SCIGN NETWORK.

Daniel Hernandez, William E. Holt, Lada Dimitrova • State University of New York at Stony Brook

Richard A. Bennett, Cuiping Li • University of Arizona, Tucson

A. John Haines • University of Cambridge, Cambridge, United Kingdom

We used time-varying velocity estimates [Li et al., 2005] to investigate time-dependent strain rates in the southern California region. Our goal is to develop a tool for recognizing strain transients and for testing their spatial and temporal coherence. From the continuous velocity series we determine time-averaged velocity values in 0.1 year increments. For each velocity field solution we determine a self-consistent model velocity gradient tensor field solution for all of southern California using bi-cubic Bessel interpolation of the GPS velocity vectors. For each solution we plot up the dilatation strain rates, the shear strain rates, and the rotation rates. We also investigate the departures of the model strain rate field and velocity field from a master solution, obtained from a time-averaged solution for the period 1999-2004. In addition, we estimate the departures of the time variable velocity gradient tensor field from other master solutions, including models that incorporate plate motion constraints and Quaternary fault data. We created a movie of the time-dependent strain rate field, using the solutions from each time epoch, to view the spatial and temporal changes in the dilation and shear strain rate field in southern California. In the present solution several time-dependent changes are noteworthy, including the regions surrounding the Hector Mine and Landers earthquakes, the Salton Trough region, and the LA Basin region. Results to date suggest a tremendous amount of promise in using this tool for investigating temporal variations in the deformation field. Our results quantify the magnitudes of the strain rate changes and provide some bounds on their spatial coverage. Ultimately this tool will enable us to separate out tectonic signals from other non-tectonic sources, such as hydrologic and atmospheric.

IMAGING REGIONAL CRUSTAL HETEROGENEITY FROM SEISMIC CODA OF SINGLE-STATION RECORDS FOR CLUSTERED EVENTS

Tae-Kyung Hong, William Menke • Columbia University

The seismic properties of crustal heterogeneity can be studied by using either migrating diffracted waves from teleseismic body waves or coda waves from local events. The former images individual heterogeneities and the latter provides a stochastic description of the medium. These approaches require either array recording or dense great-circle path coverage. Thus, they are limited to studying local heterogeneities close to seismic stations. We propose a technique to image lateral variation of crustal heterogeneity at local and regional distances using seismic coda of single-station records for clustered events. As the coda is composed of scattered waves originated from heterogeneities at various directions, the heterogeneities at off the great-circle azimuth connecting the source and the receiver can be imaged. All waves leaving the sources can be sorted by the initial radiation direction and phase velocity by beamforming clustered event records. Coherent scattered waves in coda are obtained by slant-stacking for every radiation direction, and the locations of scatterers are determined from the phase velocity and the travel time. We apply this technique to regional seismic records for Balapan nuclear explosions, which were recorded at the Borovoye seismic station, Kazakhstan at epicentral distances of ~690 km. The crustal scatterers revealed from scattered waves display high correlation with variation of geological structures such as surface topography, crustal thickness, sedimentary layer thickness. We quantify the strength of heterogeneity in terms of normalized scattering intensity, quality factor, and scattering coefficient. The proposed technique shows promise for the study of active tectonic region where clustered events are naturally suited and seismic survey is limited due to lack of existing stations. Such regions include subduction zones and mid ocean ridges.

CRUSTAL DEFORMATION IN THE NORTHERN APENNINES, ITALY

Sigrun Hreinsdottir, Richard A. Bennett, RETREAT Geodesy Group

To study the pattern of present-day crustal extension and shortening in the northern Apennines region yearly GPS campaigns, starting in 2003, were scheduled in northern Italy as a part of the multidisciplinary RETREAT project. The GPS network consists of both new fixed-height leveling monuments and preexisting monuments. We analyze data from the first two campaigns together with data from continuous GPS stations around northern Italy. In addition we analyze older GPS data measured by Italian agencies and collaborators. Here we will present the estimated velocity field.

THE CORDILLERA OF WESTERN NORTH AMERICA: AN EXAMPLE OF A SUBDUCTION ZONE BACKARC AND CONTINENTAL MOBILE BELT

R.D. Hyndman, S. Mazzotti • Geol. Survey Canada, Sidney, B.C., University of Victoria, Victoria, B.C.

An important problem of continental tectonics is resolved by recognizing that all subduction zone backarcs are hot and have uniformly thin weak lithospheres over considerable widths, i.e., what is the origin of long-lived active ìmobile beltsî contrasted to the stability of cratons and platforms. At many continental margin plate boundaries there are broad mobile belts with a long history of distributed deformation. Mobile belts make up nearly a quarter of the continents; the Cordillera of western North America is a good example. They are mobile because they are sufficiently weak to be deformed by the forces developed at plate boundaries. We conclude that mobile belts are weak because they are hot, and they are hot because they are in present or recent backarcs. Some of the deep temperature indicators include: heat flow, temperature-dependent upper mantle seismic properties (Moho refraction velocity, Pn, tomography Vp, Vs, and Q, effective elastic thickness Te, thermally supported high elevations, seismic estimates of lithosphere thickness, and upper mantle xenoliths. Most continental backarcs are found to be very hot, not just extensional and rift zones. Moho temperatures over wide areas are consistently 800-900C and lithosphere thicknesses are 50-60 km, compared to 400-500C and 200-300 km for cratons. The temperature differences result in current or recent backarc lithospheres, such as the Cordillera, being more than a factor of 10 weaker than cratons. The consequences of the high temperatures include the ongoing complex histories of deformation in response to changing plate boundary forces, including the current complex and distributed deformation and seismicity of western N. America. Also, hot weak former backarcs are the locus of most deformation during continent or terrane collision orogeny, i.e., the vice or inherited weakness model. Backarcs and former but recent backarcs like the N. Am. Cordillera may be hot because shallow asthenosphere convection results from viscosity reduction by water rising from the underlying subducting plate. The time constant for lithosphere cooling and thickening after subduction stops appears to be several 100 m.y. This may be the time required for dehydration and viscosity increase in the backarc upper mantle, and therefore slowing of the backarc convection.

PBO COMPONENT OF EARTHSCOPE: A CONSTRUCTION AND DATA MANAGEMENT UPDATE

Mike Jackson, William Prescott, Karl Feaux, Greg Anderson, Dave Mencin, Kyle Bohnenstiehl, Freddy Blume • Plate Boundary Observatory

Construction of the Plate Boundary Observatory (PBO), the Global Positioning System and strainmeter component of the larger NSF-funded EarthScope project, is well underway. Through the PBO project, UNAVCO has committed to installing 875 new and upgrading 209 existing permanent GPS stations; installing up to 174 borehole strainmeters with 3-component seismometers; installing 5 long baseline laser strainmeters; and to supporting 100 portable campaign GPS systems. Currently, about 130 of the permanent GPS stations are constructed with about 120 stations returning data automatically to the PBO data collection center in Boulder on a daily basis. Eight boreholes have been drilled on the Olympic Peninsula, six of which are suitable for instrument installations which are scheduled for June through August 2005. The first of five long baseline laser strainmeters will come on line in June 2005. To date, about 25 existing permanent GPS stations have been upgraded to PBO standards through the UNAVCO PBO Nucleus project.

PBO GPS data will be processed by two Analysis Centers (at Central Washington University and the University of California, Berkeley) and the PBO GPS Analysis Center Coordinator (at MIT). PBO strainmeter data will be processed by the Strainmeter Data Analysis Center in Socorro, New Mexico, and PBO laser strainmeter data will be processed by the Laser Strainmeter Data Analysis Center at the University of California, San Diego. These groups will create a wide range of derived data products, including time series of strain and GPS station position, GPS velocity vectors, and strainmeter and GPS processing auxiliary information. All PBO GPS data and data products will be archived at the UNAVCO Facility and the IRIS Data Management Center; all strainmeter data products will be archived at the Northern California Earthquake Data Center and the IRIS DMC. All PBO data products will be made available to the community as rapidly and freely as possible through the PBO Archives and the EarthScope Integrated Data Access system.

Frequent updates on the activities of the PBO can be found at http://pbo.unavco.org/ and http://www.earthscope.org/

EARTHQUAKE HAZARDS RESEARCH AND EDUCATION AT THE COLLEGE OF CHARLESTON

Steven C. Jaume (Corresponding Author), Briget C. Doyle, Norman S. Levine • College of Charleston

The College of Charleston is a large public four-year and Master's degree-granting institution with a long history, and is located in a seismically-active region of the eastern United States. The Department of Geology and Environmental Geosciences at the College of Charleston is one of the largest Bachelor's degree granting earth science departments in the southeastern USA, and its faculty are actively involved in regional seismic hazard research. Graduate and undergraduate students at the College participate in this research, both during coursework and in faculty-supervised research projects. Recent activities in this area include a revised ìCharleston Earthquake Walking Tourî, which began as a class project in one of the Geographical Information Systems courses. The tour guides one through the historic districts of Charleston, pointing out evidence of damage related to the M~7 1886 earthquake. The Charleston County Emergency Preparedness Division will be printing 5000 flyers of the tour and distributing them to county schools. Undergraduate geology and physics students also participate in NEHRP-funded earthquake hazard research, including an analysis of seismograms from newly installed ANSS stations (presented at 2004 SSA) plus refraction and microtremor studies of site conditions. Funding has also been received to support student research on the distribution of damage resulting from the 1886 earthquake, based on information in an insurance report (Stockdell et al., 1886). In the spring of 2005, the College hosted the highly successful Third Annual Southeast HAZUS User's Group Conference and Exhibition. Training sessions in the use of the newest versions of HAZUS-MH were conducted in computer and distance learning classrooms at the College. Following the conference, the College of Charleston was designated by FEMA as a HAZUS-MH training site for the southeastern US.

HIGH FREQUENCY EARTHQUAKE GROUND MOTION SCALING IN KOREAN PENINSULA

Young-Soo Jeon, Robert B. Herrmann • St. Louis University

Duk-kee Lee • Korea Meteorological Administration

Vertical and horizontal component velocity seismograms from the Korea Meteorological Administration (KMA) network of Korea are used for this study of high frequency ground motion scaling. We analyzed a data set consisting of about 3500 three component waveforms for Korea, hypocentral distances less than 600 km. We performed the regressions of Fourier velocity spectra and peak filtered ground velocities for the Korean peninsula, and inland Korea for different combinations of vertical and horizontal components.

The regression results for Korea are parameterized by $Q(f) = 330 f^{0.40}$ and typical geometrical spreading for both Korean peninsula and inland Korea. The oceanic events do not introduce any bias in determining the wave propagation functional. A kappa = 0.005 sec, and stress drop of 200 bars for Korean peninsula and kappa = 0.005 sec, and stress drop of 300 bars for inland Korea are selected for spectral parameterizations. A simple modification of the two-corner model of Atkinson (1993) yields better fit to Korean excitations in the high frequency ranges compare to those of Brune (1970, 1971) model which showed the lack of fit at moderate size magnitude events.

MODELS OF AFTERSLIP FOLLOWING THE 2004 PARKFIELD AND 2002 DENALI EARTHQUAKES

Kaj M. Johnson, Roland Burgmann • University of California Berkeley

We develop 3D afterslip models for the 2004 Parkfield and 2002 Denali earthquakes. The coseismic stress change from the earthquake triggers slip that is governed by an assumed constitutive relationship between stress and slip. For shallow Parkfield afterslip, we assume the lip is governed by rate- and state-dependent friction. For the deeper Denali afterslip we assume deformation in a viscous shear zone with power-law rheology. For both earthquakes we compare model predictions of surface deformation with GPS time series. The Parkfield data are consitent with slip on a velocity strengthening fault with rate and state parameters A=0.005, B=0.002, and critical slip distance, d_c =0.02 meters. The Denali data is inconsistent with afterslip in a linear viscous shear zone. The data clearly require a nonlinear rheology.

EPISODIC TREMOR AND SLIP ALONG THE NORTHERN CASCADIA MARGIN: RECENT OBSERVATIONS AND PROGRESS

H. Kao, H. Dragert, G.C. Rogers, J.F. Cassidy, K. Wang • Geological Survey of Canada

The motions of continuous GPS stations located along the northern Cascadia Margin are characterized by saw-tooth functions consisting of accelerated north-eastward displacements for periods of 13 to 16 months, followed by transient south-westward displacements over periods of one to two weeks, superimposed on steady, linear north-eastward trends over the past decade. These motions have been modelled by a combination of long-term locking on the shallow subduction interface and repeated temporary locking, followed by slip of a few centimetres, on the deeper plate interface between the Juan de Fuca and North America plates. The episodes of slip are accompanied by seismic tremors with distinct frequency characteristics, which led to the naming of the phenomena as Episodic Tremor and Slip (ETS). Although the processes involved in ETS are not fully understood, the most recent observations indicate that both slip and tremors migrate horizontally along strike of the subduction zone at a rate of ~10 km/day, and generally from southeast to northwest for the northwest Washington/southern Vancouver Is. region. Evidence is accumulating that tremors occur over a wide depth range, but show no pattern of vertical migration. Furthermore, tremor source regions may correlate with bands of strong seismic reflectors resolved in previous structural studies, suggesting that the generation and migration of fluids may be involved in this dynamic behaviour. The extended vertical distribution of tremors opens the question of whether tremor and slip are spatially distinct but strongly linked phenomena, or whether surface displacements during ETS episodes are the result of distributed shear throughout the volume defined by tremors.

NEAR-REAL-TIME DETERMINATION OF RUPTURE PLANES FOR LARGE AND INTERMEDIATE-SIZED EARTHQUAKES USING SOURCE-SCANNING ALGORITHM

Honn Kao, Shao-Ju Shan • Geological Survey of Canada, Pacific Geoscience Centre

Recent advance in seismological instrumentation and rapid expansion of broadband seismic networks, especially in regional scale, have made near-real-time determination of moment-tensor solutions possible for large and intermediate-sized earthquakes. However, with a given double-couple solution, it is difficult to distinguish the actual rupture plane from the auxiliary plane without additional information such as the distribution of aftershocks and/or mapping of the fault trace on surface, which often become available at a much later time. In this study, I present a method to delineate the rupture plane from seismic waveforms recorded at local/regional distance using the recently developed Source-Scanning Algorithm. The method uses the preliminary origin time and hypocentral location as a priori constraints to calculate a suite of station corrections. These corrections are then applied during the source-scanning process to recover the distribution of seismic sources in the hypocentral region. Because the method relies on seismic waveform data only, near-real-time determination of an earthquake's rupture plane is possible even there is no signature of surface breakage. Experiments with both synthetic and real earthquake datasets show that the method is robust. In each case, the delineated rupture plane matches remarkably well with one of the two nodal planes shown on the corresponding double-couple solution.

SLOWNESS ANOMALIES OF PKP PHASES RECORDED IN ALASKA: IMPLICATIONS FOR INNER CORE ANISOTROPY

Keith D. Koper, Veronica Parker • St. Louis University

The Eielson, Alaska seismic array (ILAR) is well situated to record PKPdf waves from earthquakes occurring in the South Sandwich Islands (SSI) region. Such ray paths are nearly aligned with Earth's rotation axis and are useful for constraining models of inner core anisotropy. The many previous studies of PKPdf waves traversing the SSI-Alaska corridor generally find waves that arrive several seconds fast, with highly attenuated and often complicated shapes. Simple laterally homogeneous models of inner core anisotropy cannot explain these observations, and it may be the case that mantle

heterogeneities are biasing the SSI-Alaska PKPdf waves. In this study, we take advantage of the small-aperture of ILAR to make independent measurements of differential PKPdf-PKPbc travel times and differential PKPdf-PKPbc horizontal slowness vectors for 37 SSI earthquakes that occurred from 1996-2004. Anomalies in slowness (ray parameter and backazimuth) of a phase reflect heterogeneous Earth structure in a manner complementary to travel time anomalies. We find a mean differential travel time residual of 3.3 s, a mean differential ray parameter of 2.0 s/deg, and that PKPdf waves arrive from a backazimuth rotated approximately 25 degrees counterclockwise relative to corresponding PKPbc waves. We use a niching genetic algorithm to generate a suite of nearly 10,000 radial Earth models that are consistent with both the differential travel times and differential ray parameters. These isotropic models represent a 2D slice through a 3D cylindrically anisotropic model of the inner core, making an angle of approximately 25 degrees with respect to Earth's rotation axis. Our modeling indicates that (1) mantle heterogeneities are not responsible for the properties of PKPdf from SSI-ILAR, (2) the lower several hundred kilometers of the outer core has a slightly lower velocity, and/or velocity gradient, than current reference models, and (3) the outer inner core along this path in nearly isotropic with a transition to strong anisotropy (>8%) occurring at a radius of 600-900 km.

VARIATION OF CRUSTAL THICKNESS AND POISSON'S RATIO IN CONTINENTAL LITHOSPHERE

Minoo Kosarian, Charles J. Ammon • Pennsylvania State University

Although much progress has been made over the last decades towards understanding Earth's structure, many questions regarding the details of lithopsheric structure remain unanswered. There is agreement on the general structure of the lithosphere, but interesting and important discrepancies are common in many areas. The purpose of our study is to gain a better understanding of patterns in lithospheric structure. A key component of the study is a survey of diverse crustal structures and tectonic environments. Such a survey provides an opportunity to confirm and revise seismic models of the crust and upper mantle. We investigate lithospheric structure throughout the Middle East, Europe, and North Africa using a simultaneous inversion of receiver functions and surface-wave dispersion. We collected seismic data from available permanent and temporary three-component broadband seismic stations throughout the region. We have gathered observations from one 166 stations recording a total of about 6,000 teleseismic earthquakes and processed more than 90,000 seismograms. The distribution includes 72 stations in the Middle East, 57 stations in Europe, 37 stations in central and north Africa. We have examined receiver functions for 120 of stations in the period of 1990-2004, and have combined them with dispersion measurements from global and regional tomographic models (Pasyanos and Walter, 2002; Ekstrom et al., 1997) to extract important constraints on the subsurface. We also applied the receiver function stacking procedure of Zhu and Kanamori [2000] to estimate Vp/Vs and crustal thickness. This analysis provides reasonable constraints on thickness and Poisson's ratio for each station and helps identify stations situated in complex structures, where simple plate-layered interpretations fail. For most stations crustal thickness and Poisson's ratio vary as a function of back azimuth, indicating non-isotropic plane-layered structure. A comparison of the crustal thickness and Poisson's ratio estimates for the crust beneath these stations will be presented; also we will show a comparison of our results with present global crustal models.

INTERGRATING GLOBAL SEISMOLOGY INTO AN UNDERGRADUATE GEOLOGY CURRICULUM

Glenn C. Kroeger • Trinity University, San Antonio, TX

Despite the exciting results from global seismology in the past two decades, a typical undergraduate student in geology may not encounter it in their curriculum past an initial exposure to P and S waves and core shadow zones in an introductory physical or environmental geology class. While some of the introductory texts include boxes highlighting recent discoveries, these optional readings are seldom supported by any followup exposure in upper division courses.

Each year, the amount of material stuffed into traditional undergraduate courses grows but the 4-year length of an undergraduate education remains fixed. At many smaller institutions, faculty expertise is concentrated in the traditional areas of geology; mineralogy and petrology, sedimentology and stratigraphy and structural geology. There is often no obvious place in existing courses for a more detailed look at global seismology and interior Earth structure nor anyone with a vested interest in creating the needed space. Often the only place is in an elective course taken by only a small percentage of geoscience majors.

At Trinity University, we have adopted the view that exposure to this area of the discipline in advanced courses is important for ALL geoscience majors and deserves a place in the required curriculum. We have created a tectonics course that focuses on cutting edge research in geophysics and geochemistry and has a significant component of earthquake and global seismology. IRIS materials including posters, one-pagers and sections of IRIS proposals are used in the course. I will discuss some of our efforts and materials and how IRIS might facilitate the spread of global seismology into more undergraduate curricula by developing educational materials for upper division geology courses taught by non-seismologists.

THE CHANGING FACE OF THE UNAVCO FACILITY CAMPAIGN POOL

Chuck Kurnik, Victoria Andreatta, Freddy Blume, Jim Greenberg, David Phillips • UNAVCO

Over the past several years, the UNAVCO Facility has been upgrading the Campaign Equipment Pool with state-of-the-art GPS equipment: Trimble 5700, R7, NetRS, and the Topcon GB-1000. These receivers have much higher memory capacity and lower power requirements than the previous generation of UNAVCO Pool GPS receivers (Trimble 4000), which are being phased out of the Pool. As a result, the type of equipment sent out on campaigns is changing: smaller power systems and less-frequent downloading are required. Because of these technological improvements, the new equipment can be used in traditional GPS campaigns, as well as long-term/semi-continuous applications. Power systems, monumentation, and system boxes available from the Pool are also adapting to support longer occupation times. It is important that the UNAVCO Community be aware of the configurations and capabilities of the new equipment so that the equipment selection process for campaigns can proceed smoothly. For further information, visit: http://www.unavco.org/facility/project_support/project_support.html

POSTSEISMIC DEFORMATION FOLLOWING THE 2002 DENALI FAULT EARTHQUAKE.

Christopher F. Larsen, Jeffrey T. Freymueller • University of Alaska

GPS data of postseimic deformation following the 2002 Denali Fault Earthquake will be presented.

NEAR-FIELD 1-HZ GPS RECORDINGS BEFORE, DURING, AND AFTER THE PARKFIELD EARTHQUAKE

Kristine M. Larson, Andria Bilich • University of Colorado

Data from thirteen near-field 1-Hz GPS sites are available for the Parkfield earthquake. Although this event is smaller magnitude than other recent 1-Hz GPS seismology studies (Denali, San Simeon, Tokachi-Oki), the sites are located much

closer to the rupture. These data also provide information on postseismic response in the region. Since the size of the eathquake is small, it is important that GPS error sources are minimized. We have developed methodologies to improve 1-Hz GPS position estimates that we will describe here. The data span approximately 12 hours before and after the earthquake.

SEISMIC ANISOTROPY AT THE KRAFLA GEOTHERMAL FIELD IN NORTHERN ICELAND

Jonathan Lees, Jose Rial, Charley Tang • University of North Carolina

We deployed an array of 20 PASSCAL L-28 4.5-Hz sensors for 39 days during the summer of 2004 at the Krafla Geothermal field. The Krafla Geothermal field is located approximately 60 km East of Akureyri in northern Iceland. We registered approximately 5 micro-earthquakes per day at a sampling rate of 500 Hz. The high sample rate is required to exploit newly developed methods using the frequency-dependence of shear-wave splitting (SWS). The array covered an area approximately 5 km North/South by 4 km East/West. During the experiment, hydrothermal injection of water into the geothermal reservoir was halted for ten days during which seismic activity decreased. When injection resumed, seismic activity returned to its previous intensity. SWS measurements exhibit a strong correlation to fracture locations, sizes, and orientations in the geothermal field. These fractures control the directions of fluid migration in the subsurface. We show examples of crack density estimation from Coso, where they commenced injection is the converse of density estimates at Krafla, where injection was halted.

DEPTH MIGRATED PDS CONVERSION IMAGES OF THE UPPER MANTLE

Alan Levander, Fenglin Niu, Sangwon Ham • Rice University

We present images made from receiver function data recorded in three different upper mantle tectonic regimes: the Kaapvaal craton, the Japanese subduction zone, and the western U.S. orogenic plateau. The seismic data are migrated using a 2.5D prestack Kirchhoff depth migration algorithm that uses 2-D velocity models developed from tomography for the migration velocity models. The Kaapvaal craton image has been made from 9 earthquakes recorded along a 2000 km long array. Both of the transition zone discontinuities stand out very clearly. The amplitudes and thicknesses of the discontinuities estimated from the image are in agreement with predictions of global reference models. Above the transition zone are a number of events extending 100’s of kilometers as slab-like structures which may form the bottom of the Kaapvaal craton.

In Japan we make use of a number of earthquakes recorded at the very dense Hi-Net array, which consists of more than 500 borehole seismographs. The migrated receiver function images show the transition zone discontinuities very clearly, as well as the slab subducting beneath Hokkaido. The uplift of the 410 discontinuity predicted for slab penetration is clearly seen in the migrated image. The slab appears to stall above the 660 discontinuity.

Across the Jemez lineament, an image made from 7 earthquakes recorded at a 225 km long seismic array shows a complex set of upper mantle sill-like structures extending from the Moho to a depth of about 125 km. From active source seismic data we estimate that the upper mantle contains about 1 percent partial melt. Amplitudes in the receiver function image suggest that this is true in all the sill structures in the upper mantle. We relate the sill structures to recent volcanism and uplift along the lineament. Across the Cheyenne belt we image remnants of a Paleoproterozoic slab that stalled in the upper mantle during the latest stages of island arc accretion to the Wyoming Province protocontinent. The stalled slab, first identified in tomography images (Yuan and Dueker, 2005) appears as a complex system of north-dipping converters in the migrated image to depths of about 125 km.

JUST ADD WATER: RECEIVER FUNCTION ANALYSIS OF OBS DATA.

Vadim Levin • Rutgers University

Spahr Webb • Lamont-Doherty Earth Observatory of Columbia University

William Menke • Columbia University

Studies of near-surface earth structure utilizing compressional-to-shear converted seismic waves (known collectively as receiver function analysis) have become progressively more popular in the last decade, with a variety of modifications developed for applications ranging from shallow crustal surveys to the studies of the transition zone. A fundamental premise of all these methods is that the observed wavefield is acquired at the boundary separating rock and air (aka the free surface of an elastic half-space). Consequently, modeling software, as well as the intuition of technique's practitioners, is generally set up to treat all energy in the receiver function as either upgoing or multiply scattered within the elastic halfspace. Data collected with ocean bottom seismographs presents an added complication to the interpretation of receiver functions, as the time series constructed via standard source equalization means likely contain scattered energy from the water column.

In this poster we show that treating this extra signal properly is essential for correct interpretation of the seafloor receiver functions. We also show that, in spite of the extra complications, receiver functions from OBS data may be developed to relatively high (0.5 Hz) frequency, and thus may be used to probe for relatively small-scale vertical structure of the ocean lithosphere.

We use data from 9 4-channel OBS packages (3-component seismic sensors and a pressure sensor) deployed in the Pacific for about a year. We use multi-taper spectral correlation methodology of Levin and Park (2000) to construct averaged radial receiver functions for individual sites. We show that receiver functions may be confidently recovered over a broad range of frequencies, giving sufficient information for forward modeling. We document, through both empirical analysis and computer simulations, the influence of multiply-scattered water waves in the receiver function time series. Finally, we develop 1-D models for the structure of the ocean lithosphere that match features of the receiver functions not associated with water reverberations.

THREE DIMENSIONAL MECHANICAL MODELING OF THE SAN ANDREAS FAULT SYSTEM

Li, Qingsong, Mian Liu • University of Missouri

The California plate boundary fault zone consists of a main fault (the San Andreas Fault (SAF)) and many secondary faults (the San Jacinto Fault, Hayward Fault, Garlock Fault etc.). Since1800, three large historical earthquakes (1857 M7.9, 1906 M8.25, and 1989 M7.1) ruptured the San Andreas Fault. At the same time, more than a dozen M>7.0 earthquakes occurred on the secondary faults. Studies of geological and geodetic fault slip rates show that the relative plate motion between the North America and Pacific plates is apportioned on main and secondary faults in the California fault zones, and that fault slip rates vary along the strike of each fault. We have constructed a 3D visco-elasto-plastic finite element model to explore the stress evolution in the California fault zones. The model results indicate strong influence of the geometry and spacing of faults on fault slip rates and perhaps the seismicity. We found that the big bend of the SAF in southern California causes off-main-fault stress concentration, which explains the distribution of large historical earthquakes outside the SAF in southern California. We also predicted the reversal codependence of slip rates between the southern most SAF and the San Jacinto Fault as indicated by neotectonics data. The predicted surface horizontal velocity in California, driven by plate boundary loading and postseismsic viscous relaxation, is consistent with the first-order features of the GPS data.

ANALYSIS OF TIME-DEPENDENT VELOCITY IN SOUTHERN CALIFORNIA USING CONTINUOUS GPS STATIONS IN THE SCIGN NETWORK

Cuiping Li, Richard A. Bennett • University of Arizona

Daniel Hernandez, William E. Holt • State University of New York at Stony Brook

We analyzed a subset of continuous GPS (CGPS) time series data from the Combined SCIGN Velocity and Time Series Solution [Herring, 2004], which is based on data from southern California Integrated GPS network (SCIGN) and similar neighboring CGPS networks for the time period of January 1996 to February of 2004. Our analyses concentrate on the time period between the October 1999 Hector Mine earthquake and February 2004. The Combined SCIGN solution in many ways resembles forthcoming Plate Boundary Observatory (PBO) GPS Data Products, in that it consists of a weighted least-squares combination of loosely constrained, 24-hour batched, GAMIT and GIPSY phase data analyses. As a first step toward developing analysis tools to investigate the time-dependence of CGPS deformation results, we have begun testing methods to estimate time-dependent velocities from the Combined SCIGN GPS time series for each coordinate component at each station. Each position time series is cleaned using a outlier detection algorithm applied to the postfit residuals following a cubic smoothing spline model. The weighted root-mean-square scatter of the time series data about the time-dependent models is typically less than 1 mm, ranging between 0.4 and 1.2 mm. Velocity variations are typically largest for sites located in the vicinity of the Hector Mine earthquake, but significant rate variations are observed throughout the region. Our goal is to develop a tool for recognizing strain transients and for testing their spatial and temporal coherence.

PRELIMINARY INTEGRATION OF REAL-TIME GPS AND SEISMIC DATA

Kent Lindquist • consulting, Fairbanks, Alaska

Yehuda Bock, Frank Vernon, David Honcik, Jennifer Eakins • University of California, San Diego

We have written a new data acquisition program, ryo2orb, which acquires near-real-time Global Positioning System (GPS) data from an RTD data server in Geodetics RYO format and places them on an Antelope orbserver. Once on an orbserver these geodetic data may be saved as time-series (usually in SEED format) in a Datascope database of css3.0-compatible schema, alongside the continuous data from a seismic network. Data may be converted automatically from Earth-Centered, Earth-Fixed (ECEF) coordinates to geodetic latitude, longitude, and height. In order to help manage the total packet transmission rates, the ryo2orb module allows optional time concatenation of contiguous samples and/or multiplexing of stations from a given network. This module promises to significantly simplify the routine analysis of side-by-side geodetic and seismic data from large earthquakes. We present initial results from running this utility at the University of California, San Diego (UCSD) on a subset of real-time (latency < 1 s) GPS data, sampled at 1 sample per second, from the Southern California Integrated GPS Network (SCIGN).

CRUSTAL THICKNESS OF THE EASTERN SOUTH AMERICAN PLATFORM

Simon Lloyd, Suzan van der Lee • Northwestern University

Marcelo Assumpção • University of São Paulo

We perform receiver function analysis using teleseismic waveforms recorded at new temporary broadband seismic stations, deployed on the Eastern South American Platform. They were installed for the Brazilian Lithosphere Seismic Project (BLSP02), to enhance the otherwise sparse seismic station coverage. The South American Platform is a complex structure of several cratonic fragments separated by collisional belts, and represents most of South American Precambrian geology. Our analysis provides new constraints on the crustal thickness of this region. We estimate the crustal thickness using simple 2 layer models that reproduce the observed arrival times of the converted P-S phases. These models are computed using a grid search method, whereby individual phase arrivals are stacked in the depth-poisson ratio domain. The largest Moho depths of 44 and 43 km are obtained at stations in the northern Mantiqueira collisional belt and southern Paran· Basin, respectively. The station deployed in the S„o Francisco Craton yields a crustal thickness of 39 km and for the remaining four stations, which are located on the Guyana and GuaporÈ Shields, ParnaÌba Basin, and on the Atlantic margin of the Paran· Basin, a crustal thickness of 36 to 37 km is determined. Our calculations place the Moho discontinuity within about 4 km of the value found in Crust2.0 for six locations. However, for two locations the difference is significantly higher (6 and 12 km). This suggests that Crust2.0, despite being partially based on estimated and interpolated data, is generally a good approximation. Nevertheless, we show that the actual crust can differ significantly from Crust2.0 predictions. Hence, our new data on crustal thickness provide new important information for improving existing models, and will be useful for further studies aiming at unravelling the early history and evolution of the South American continent.

THE SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Community Modeling Environment (SCEC/CME), Digital Library of Synthetic Waveforms for Southern California

Philip Maechling (SCEC), Thomas H. Jordan (SCEC), Marcio Faerman (SDSC), Reagan Moore (SDSC), Joanna Muench (IRIS), Steve Doubleday (Less Computing), the SCEC ITR Collaboration

The Southern California Earthquake Center (SCEC), in collaboration with the San Diego Supercomputer Center, the Information Sciences Institute, the Incorporated Research Institutions for Seismology, and the U.S. Geological Survey, is developing the Southern California Earthquake Center Community Modeling Environment (SCEC/CME) under a five-year grant from the National Science Foundation's Information Technology Research (ITR) Program jointly funded by the Geosciences and Computer and Information Science & Engineering Directorates.

Recent advances in earthquake science, combined with the increased availability of Terascale computing resources, have made it practical for the first time to create fully three-dimensional (3D) simulations of fault-system dynamics. These physics-based simulations can potentially provide enormous practical benefits for assessing and mitigating earthquake risks through seismic hazard analysis (SHA).

The SCEC/CME system is an integrated geophysical simulation modeling framework that automates the process of selecting, configuring, and executing models of earthquake systems. By facilitating the investigation, modification, and adoption of these physics-based models, the SCEC/CME can improve the scientist's system-level understanding of earthquake phenomena and can substantially improve the utilization of SHA. As a part of the SCEC/CME Project, SCEC has developed a digital library containing a collection of synthetic waveforms for historic and scenario earthquakes in southern California.

One set of simulations conducted by the SCEC/CME collaboration was the TeraShake simulations, a set of large scale earthquake simulations occurring on the southern portion of the San Andreas Fault. The 600km x 300km x 80km simulation domain includes all major population centers in southern California, and is modeled at 200m resolution using a rectangular, 1.8 giganode mesh. The simulated duration is 250 seconds, with a temporal resolution of 0.01seconds, maximum frequency of 0.5Hz, for a total of 22,728 time steps. The simulations were run at the San Diego Supercomputer Center (SDSC) on 240 processors of the IBM Power4, DataStar machine. TeraShake has generated more than 40 TB of surface and volume output data. The data is registered with the SCEC Digital Library supported by the SDSC Storage Resource Broker (SRB). Derived data products of interest include the surface velocity magnitude, peak ground velocity, displacement vector field and spectra information. Data collections are annotated with simulation metadata to allow data discovery operations on metadata-based queries. High resolution 3D visualization renderings and seismogram analysis tools have been used as part of the data analysis process.

Another collaboration effort between the Pacific Earthquake Engineering Research Center (PEER) and the SCEC project, called 3D Ground Motion Project for the Los Angeles Basin, has produced 60 earthquake simulation scenarios. The earthquake scenarios comprise 10 LA Basin fault models, each associated with 6 source models. The surface output data of these simulations is registered at the SCEC Digital Library supported by the SDSC Storage Resource Broker.

Seismologists and earthquake engineers can access both the TeraShake and the Los Angeles Basin collections using a Scenario-Oriented Interface developed by the SCEC/CME project. An interactive web application allows users to select an earthquake scenario from a graphical interface, choosing earthquake source models, and then use the WebSim seismogram plotting application and a metadata extraction tool. Users can click on a location and obtain seismogram plots from the synthetic data remotely archived at the digital library. A metadata extraction tool provides users a pull-down menu, with metadata categories describing the selected earthquake scenario. In the case of TeraShake, for example, users can interact with the full resolution 1 TB surface online data, generated for each simulation scenario.

The SCEC Community Digital Library also includes a 25TB Freshet Kernel collection for velocity model inversion studies, based on earthquake sensor data. New efforts planned for this coming year include 16 new TeraShake spontaneous rupture scenarios and more than 400 Probabilistic Seismic Hazard Analysis simulations based on 1.1 million CPU hours granted to SCEC/CME on the Teragrid and SDSC DataStar.

The SCEC/CME has collaborates with IRIS on the development of the Synthetic and Observe Seismogram Access (SOSA) a DHI-based data access tool that allows users to retrieve and compare observed and synthetic seismogram from IRIS and other data centers as well as the SCEC digital library.

THE CALIPSO PROJECT AND THE ONGOING ERUPTION OF SOUFRIËRE HILLS VOLCANO, MONTSERRAT: WHAT WE KNEW BEFORE WE STARTED, WHAT WE HAVE LEARNED SINCE, AND WHAT WE CAN EXPECT IN THE FUTURE

Glen S. Mattioli • University of Arkansas

Monitoring and scientific infrastructure at the SoufriËre Hills Volcano (SHV), Montserrat was recently enhanced by the CALIPSO Project (Caribbean Andesite Lava Island-volcano Precision Seismo-geodetic Observatory), an integrated array of borehole and surface geophysical instrumentation installed at four sites between late 2002 and early 2003. Each CALIPSO site contains a borehole strainmeter, tiltmeter, seismometer, and surface cGPS unit. GPS measurements have been acquired at SHV since 1995.

The GPS vertical deformation field was used to define epoch boundaries for elastic half-space inversions. Deformation epochs correlate well with volumetric surface flux: during the two major periods of significant dome growth (late 1995 - early 1998 and late 1999 - mid 2003), the vertical field showed significant subsidence with respect to the earth's center of mass; in contrast, during periods of little surface flux (early 1998 - late 1999 and mid 2003 - present), all GPS sites showed uplift with respect to the earth's center of mass. Component velocities and associated uncertainties were calculated for each period with a piece-wise linear model. Elastic inversions for the first three epochs favor a shallow, NW sub-vertical dike and a deeper source approximated by a Mogi source. Periods of uplift correspond to an inflating, and subsidence, to a deflating Mogi source. Calculated depths range between 6 and 13 km, with the recent observations favoring a deeper source, supporting a temporal evolution of the mid-crustal pre-eruption storage zone from 1995 to 2005. A higher temperature origin of later extruded magmas at SHV is supported by some petrological data, which could reflect an influx of basaltic magma into the mid-crust from some deeper storage zone. The inferred deep Mogi source at 12-13 km, active since 1999, could reflect such a basaltic source region, but the mechanism and details of transition from ~6 to 13 km are poorly understood. CALIPSO borehole strainmeter response for the July 2003 collapse, however, suggests that the shallow source also remains active. The SEA-CALIPSO ëoffshore-onshore' seismic tomography experiment aims to image crustal sources and elucidate this complexity.

Additional manifestations of the 12-13 July 2003 massive dome collapse (est. ~210x106 m3 (DRE)) and subsequent explosions of SHV also were captured by the CALIPSO array. Prior to peak collapse, pyroclastic flows of increasing intensity were observed during the day, finally entering the ocean at the Tar River Valley Delta (TRVD) at 18:00LT. Strainmeters at three sites recorded correlated oscillatory wave packets with periods of ~250-500s, with the strongest oscillatory signal seen at Trants, the site nearest to the TRVD. A lag of ~9m between volumetric strain relative to the seismic signal is observed. GEOWAVE, hydrodynamic tsunami simulation model, was used to recreate the geometry and energetics of a pyroclastic flow entering the sea at the TRVD creating a tsunami. Instrument response to the wave field was modeled assuming a Boussinesq line surcharge in the offshore region near Trants. Strong correlation of the simulated signal with the actual strainmeter data demonstrates the sensitivity of the strainmeters to geophysical processes not envisioned with its design or installation of CALIPSO, and allows for these complex long period signals to be understood as a volcanic process.

PLATE BOUNDARY AND INTRAPLATE REGIONAL DEFORMATION AND RATES OF SEISMICITY: MAKING THE MOST OF GPS DATA TO CONSTRAIN SEISMIC HAZARD

S. Mazzotti, R.D. Hyndman • Geological Survey of Canada, Pacific Geoscience Centre

The large increase in availability of precision GPS data, notably by the EarthScope Plate Boundary Observatory, provides exceptional opportunities for improving our estimates of seismicity rates and seismic hazard. One application of GPS is to constrain the rupture area and strain variations during the seismic cycle of large faults (e.g., Cascadia subduction thrust or San Andreas system). We focus here on a second application, i.e., to relate widespread distributed strain to earthquake statistics on a regional scale. We derive earthquake recurrence times and magnitudes by assuming that GPS data are representative of the long-term seismic strain release in a defined seismic zone. This approach works well in regions of distributed deformation along numerous faults (e.g., much of North America outside of the plate-boundary fault zones).

Through the concept of seismic moment, we quantitatively convert GPS-measured regional strain rates into earthquake recurrence times and magnitudes using the following assumptions:

(a) We can define a typical length over which crustal strains are not affected, to a first order, by spatial and temporal variations related to the earthquake cycle.

(b) We must define the shape of the earthquake magnitude-frequency distribution. Extreme cases are 1) large ìcharacteristicî earthquakes (e.g., Cascadia megathrust), where there are few if any small events, and 2) standard G-R recurrence with a well-behaved distribution with slope of ~1.

(c) The crustal deformation is fully seismic to a defined depth, for example the thermally controlled transition depth from stick-slip to creep.

(d) The maximum magnitude (and moment) must be estimated, for example, from the lengths of the largest faults and empirical area vs. magnitude relations.

We apply this method to three tectonic regions to show that the integration of GPS strain and earthquake statistics can be used to address regional tectonics and seismic hazard. Our first example is the northern Cascadia forearc (Puget Sound, Washington and British Columbia), a broad zone of N-S shortening accommodated by numerous thrust and strike-slip faults. There, regional GPS strain rates agree well with strain rates estimated from earthquake statistics and paleo-seismic data. The results are inconsistent with ìcharacteristic earthquakeî models. The second example is the northern Canadian Cordillera (Yukon and eastern Alaska), where we again find similar deformation rates from GPS data and earthquake statistics. The two types of data constrain a tectonic model of deformation for the Cordillera and provide important constraints to seismic hazard in this active mobile belt. Our third example is the lower St Lawrence Valley (Quebec), one of the most active seismic zones in intraplate North America, where we use GPS measurements of regional crustal strain to constrain the recurrence statistics of large earthquakes. High-resolution GPS data allow us to resolve intraplate strain rates to a few nano-strain per year and show the relation between intraplate seismicity and the deformation due to postglacial rebound in southeastern Canada and northeastern U.S.

MEASURING CRUSTAL THICKNESS OF THE ANDES USING DEPTH PHASE PRECURSORS

McGlashan, N.A. • Cornell University

Orogenesis is primarily a result of crustal thickening by shortening. The general amount of thickening can be indicated through the use of Isostasy. Localities where there is a pronounced discrepancy between the isostatic and observed crustal thickness suggests a more complex geodynamic evolution involving methods such as crustal delamination, slab break-off and lower-crustal flow. These are not fully understood and further study of locations where their occurrence is inferred will help us improve our comprehension of such processes. Anomolous chemical signatures in outcrop can provide awareness of locations where these events may have occurred but high resolution geophysical experiments are the only way of definitively imaging the deep crust and fingering the occurrence of such processes. Unfortunately the cost of such experiments severely limits the ability to provide good coverage of complete orogenies. Seismic stations located at teleseismic distances from the Andes, however, can provide important clues to the thickness of the crust by using precursors to depth phases reflections, specifically pmP. The use of precursor phases builds on the work of Beck and Zandt (1994) and Flanagan and Shearer (1998). A rough framework of crustal thicknesses throughout most parts of the Andes has been generated and correlated with available data. The advantage in this method lies in it¥s cheapness and ability to function in areas where midcrustal features can perturb conventional seismological techniques e.g. receiver functions above the APVC. This method can also be used to pinpoint areas where further high resolution experiments would be of greatest value.

GEOPHYSICAL MEASUREMENTS IN PBO STRAINMETER BOREHOLES ON THE OLYMPIC PENINSULA: IMPLICATIONS FOR THE THERMOMECHANICAL REGIME OF THE NORTHERN CASCADIA FOREARC

J.R. McKenna, D.D. Blackwell • Southern Methodist University

The Plate Boundary Observatory (PBO) component of the EarthScope Initiative has drilled 8 of the planned 12 boreholes for strainmeter emplacement in the northernmost Olympic Peninsula and represents a unique opportunity to make borehole geophysical and heat flow measurements to better constrain the thermomechanical regime and hence earthquake hazards of the northern Cascadia forearc and to test several hypotheses including: (1) the use of repeated temperature logging and other geophysical logs to better characterize the thermal-hydrologic regime to make more precise heat flow determinations in open hole situations; (2) whether or not in situ heat production estimates of basement derived from spectral gamma ray logs are comparable to measurements made on core in the laboratory, and its implications for the heat flow-heat production relationship; (3) implications of new thermal data for the rheology of the forearc and the thermally delineated transition zone along the megathrust and their relationship to episodic tremor and slip (ETS); and (4) the use of acoustic televiewer and full wavefield sonic logs to characterize the orientation of fractures downhole and compare it to the regional stress field. PBO strainmeter installations represent the only realistic chance for new heat flow data collection in the context of EarthScope Initiative. All the Pacific Northwest PBO strainmeter sites are situated within a forearc heat flow low, but two potential sites are placed near the transition from >45mWm-2 to <40 mWm-2. This difference of about 5-8 mWm-2 should be measurable, and would represent one of the few subduction margins where adequate terrestrial heat flow data exist to support detailed modeling. The acquisition of a suite of other geophysical logs (e.g., full wavefield sonic, spectral gamma, and acoustic televiewer) in addition to temperature/resistivity/spontaneous potential will maximize the information pertaining to the in situ mechanical/hydrologic regime, allowing more precise heat flow determinations, investigation into the heat flow-heat production relationship, and the comparison of regional measurements of stress with those obtained downhole. The repeated temperature measurements will help constrain thermomechanical models of the region by assessing the level of shear heating present along the main subduction thrust and determining the mean forearc geothermal gradient. Both are critical for better constraining the rheology of the forearc and thus the downdip position of the effective transition zone (ETZ) and exploring its relationship to ETS, and understanding the physical processes controlling earthquakes and consequently earthquake hazards.

AN ASSESSMENT OF PROPOSED UPGRADES TO THE ANSS BACKBONE AND GSN

D.E. McNamara, P. Earle, R.P. Buland, H. M. Benz • U.S. Geological Survey

In this work we assess three proposed upgrade scenarios to the Advanced National Seismic System (ANSS) and the Global Seismograph Networks (GSN) using three different measures of network capability. The three measures of network capability are: 1) minimum M_w detection threshold; 2) response time of the automatic processing system and; 3) theoretical earthquake location errors. The three proposed upgrades scenarios include: 1) the installation of six additional ANSS backbone stations within the United States; 2) the installation of a nine station network surrounding the Caribbean Sea and; 3) upgrading fifteen GSN tape-based stations to real-time telemetry. For each upgrade scenario we demonstrate that considerable improvement in network magnitude threshold, response time and earthquake location error can be achieved. We also demonstrate that the technique used in this analysis is valuable for quantifying seismic network capability improvements and a useful tool for network design planning.

CONTRIBUTION OF POST-CRITICAL REFLECTIONS TO GROUND MOTIONS FROM MEGA-THRUST EVENTS IN THE CASCADIA SUBDUCTION ZONE

A.F. McNeill, G.D. Spence, G.C. Rogers, J.F. Cassidy • University of Victoria

We examine the contribution of post-critical reflections at the oceanic Moho to ground motions from mega-thrust events in the Cascadia subduction zone. In a previous study [Cohee et al., 1991], 2-D finite difference wave simulations indicated the Moho post-critical reflection as a primary component of the S-wave field at large epicentral distances from a hypothesized subduction zone thrust earthquake in the Puget Sound-Portland region. A further study [McNeill et al., 2004], found that maximum ground motions at large epicentral distances from a mega-thrust event resulted from post-critical reflections at the oceanic Moho or the continental Moho. We employ pseudo 3-D modeling using P-SV, SH pseudo-spectral synthetic seismograms, as well as, ray tracing amplitude calculations. Double couple line sources and point sources are initiated within a structural model for the Cascadia subduction zone that incorporates an updated Juan de Fuca slab geometry. We define areas in which the Moho post-critical reflection is a primary component of the seismic wave field. Furthermore, we quantify the significance of post-critical reflections to ground motions within the Pacific Northwest urban corridor [Portland, Seattle, Vancouver, Victoria].

VOLCANO SEISMOLOGY: A TOOL TO MONITOR AND UNDERSTAND EXPLOSIVE VOLCANISM

S.R. McNutt • Alaska Volcano Observatory, UAF Geophysical Institute

Explosive volcanic eruptions are generally characterized by high silica content of the magma (>54 percent SiO2) and high water content (4-5 wt. percent). The parent magma starts out as basalt which is then modified by removal of crystals by fractional crystallization, or addition of high-SiO2 crustal material into a magma chamber. Another important factor is the ascent rate of magma to the earth's surface. If the rate is slow, gases are lost to the surroundings and the eruptions are effusive, forming lava flows and domes. If the ascent rate is fast, then the gases expand quickly and violently, disrupting the magma and causing explosive eruptions. A small percentage of basaltic eruptions have thus been explosive; a well known example is the 122 BC eruption of Mount Etna. Common precursors to explosive eruptions include increased seismicity, concentrated deformation, evidence of heating, and changes in degassing.

Seismic precursors consist of swarms of earthquakes and the appearance of different types of events. A commonly observed sequence consists of background seismicity, onset of swarms of high-frequency events reaching a peak rate, followed by relative quiescence, occurrence of low-frequency or long-period events and volcanic tremor, then eruptions accompanied by explosions and strong volcanic tremor, and finally, deep high-frequency events. Each of these types of seismicity may be linked to dominant processes which evolve with time as magma ascends. This pattern has been observed prior to eruptions from Volcanic Explosivity Index (VEI) 2 to VEI 5, for sequences lasting a week up to 10 months, and for eruptions of basalt, andesite, and dacite. Data extracted from a database of volcanic earthquake swarm parameters show a correlation between swarm duration and the VEI of the eventual eruption, and between the magnitude of the largest event and the VEI of the eventual eruption. The swarm duration and maximum event magnitude do not, however, determine whether an eruption will occur. False alarms are common and intrusions are accompanied by similar seismic activity with the exception of shallow volcanic tremor. The earthquake swarm duration and magnitude of the largest shock may be extrapolated to indicate the expected earthquake magnitude and swarm duration for precursors to VEI 7 and 8 eruptions, for which there are no historical examples.

During eruptions, strong volcanic tremor is recorded with reduced displacement (DR; a normalized metric) proportional to VEI. Several factors are known to modify tremor DR for similar sized eruptions. Fissure eruptions produce stronger tremor than eruptions from cylindrical conduits, likely a geometric effect. Eruptions with higher gas content produce stronger tremor than lower gas content, because of greater potential energy of the expanding gas. Phreatic eruptions produce stronger tremor and larger craters than magmatic eruptions, probably because of more efficient conversion of thermal to mechanical energy. Data on DR versus VEI may also be extrapolated to VEI 7 and 8 eruptions. The likely tremor would be very strong and long lasting.

Many of the trends discussed above were gleaned from seismic monitoring programs. The data were then used retrospectively to infer physical processes and to answer scientific questions. In contrast, many temporary seismic networks have been deployed to perform topical studies such as tomography. Seismic studies at volcanoes have benefited greatly from the inclusion of other types of data, especially geodetic data such as GPS and InSAR. These provide powerful additional constraints on mechanical behaviour of volcanoes. The increased seismic and GPS instrumentation being installed under the Earthscope program will provide better data for the next generation of investigators.

VISUALIZATION OF EARTH SCIENCE DATA

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D. Murray, J. McWhirter • UCAR Unidata Program

As part of the NSF-funded GEON Information Technology Research project, UNAVCO is participating in a collaborative effort to develop advanced tools for visualization of multidimensional earth science data and models. These tools help researchers conducting integrative science to access and interpret distributed and diverse datasets needed to meet the challenges of projects such as EarthScope. GEON cyberinfrastructure includes not only visualization tools, but also computational resources that facilitate data discovery, retrieval, standardization and interoperability. As part of this effort, UNAVCO has been adding earth science capabilities to the Integrative Data Viewer (IDV), an extensible and flexible software framework developed by UNIDATA for analysis and visualization of atmospheric data and models. New features include the display of earthquake locations and 3D focal mechanisms, GPS velocity vectors with error ellipses, strain rate axes, and access to seismic tomography and mantle geodynamic models. The IDV Java application is fully interactive and allows the user to create, probe, and manipulate 2D and 3D displays including contour plots, vertical and horizontal cross-sections, 3D isosurfaces, vector plots, point data symbols and numeric values. Users can share views stored as IDV xml state files or during real-time collaborative sessions across the web. The IDV can easily be configured to project images in 3D stereo on the GeoWall.

The IDV accesses data files from local file systems or OPeNDAP, WMS (Web Map Service), and HTML webservers. The IDV primarily uses netCDF, a self-describing binary file format, to store multi-dimensional data, related metadata, and source information. To facilitate data exchange, UNAVCO has developed format conversion software and is in the process of making this available as a webservice. UNAVCO is also hosting a range of converted geophysical datasets on the UNAVCO/GEON POP node. Although the IDV is an advanced tool for research, its flexible architecture has been exploited for educational purposes with the Virtual Geophysical Exploration Environment (VGEE) development. We will demonstrate the capability of the IDV and will solicit input on possible new visualizations and additional data types that would benefit the UNAVCO and IRIS communities.

HIGH-RESOLUTION IMAGING OF CASCADIA SLOW EARTHQUAKES WITH GPS, SEISMOMETERS, AND LONG BASELINE TILTMETERS.

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Bilham, R. • University of Colorado

Flake, R., Suszek, N, Szeliga, W., Miller, M.

As measured with GPS, periodic Cascadia megathrust creep events typically exhibit horizontal offsets of only 5 to 8 mm, embedded in time series with intrinsic scatter of 1-3 mm. This provides a geodetic signal to noise ratio (SNR) of only 3-5, which begs the question of what might be learned from higher-resolution instrumentation. Seismic tremor correlated with these events provides, in theory, a finer-scale detection of slip onset and distribution, but in practice, tremor too has limitations: correlation across several stations depends on fortuitous station and event distribution and is susceptible to masking by noise. Its evanescent nature, waveform complexity, and sub-km Fresnel zone (for 5-hz signals) also limit its applicability. As a result, neither GPS deformation nor tremor has proven particularly effective to date at constraining the basic source processes that control or trigger transient plate interface creep. Many first-order questions about slow events thus remain open: What is the mechanistic relationship between tremor generation, location, and duration, and slow slip; Is transient creep localized to a single dislocation plane as conventionally thought, or instead a distributed shear zone, as tremor depth estimates seem to suggest; Do non-double-couple components of energy release accompany transient surface deformation and tremor bursts, as might be expected from volcano analogues.

To answer these questions, we have deployed hybrid slow earthquake observatories composed of co-located long-baseline tiltmeters (LBT), GPS receivers and L4 3-component seismometers. To date, two have been built (October, 2004) within the southern Puget Sound region of Washington State, near a region of active transient deformation, and two more are currently (Spring, 2005) under deployment in the northern Puget Sound. One more cluster will be installed in summer, 2005. The long baseline tiltmeters are based on the original Michaelson (1922) design and comprised of buried, half-filled 8î diameter PVC tubes 500 meters in length and level throughout their lengths to Ωî. Shaevitz variable-inductance pickups mounted on deep-anchored pylons measure pipe water levels to roughly a micron, producing intrinsic tilt measurements of 0.1 nanoradian, telemetered once per minute. At the corner vaults L4 seismometers are buried at ~3 meters depth and sample at 40 sps, three instruments per cluster. Existing and incipient nearby GPS stations from the PANGA and PBO arrays complete the detection package.

The two tiltmeters currently in operation since October 2004 show remarkable long term stability and ultra-low instrument noise levels once tilts from solid-earth tides are estimated and removed. Although these latter signals have amplitudes of several hundred nanoradians, both their amplitudes and phases are stable through time and are easily estimated and removed. Residuals have sub-nanoradian scatter over timescales of a few days, the rough onset time of slow earthquakes here. Model tilts computed from slip distributions inverted from GPS offsets measure as high as 50 microradian, indicating an effective SNR for LBT detection of slow earthquakes in excess of ~10,000. In conjunction with the seismometers, these instrument suites will therefore provide the highest-resolution imaging of slow earthquake source processes yet available, at timescales from seconds to days, while the GPS will constrain the total moment release, at least for events above the detectability of GPS. We particularly anticipate resolving the detailed relationship between sequences of tremor and nanoradian near-field (static) tilts during the next slow event, forecast for summer 2005.

SHALLOW CREEP ALONG THE SUPERSTITION HILLS FAULT FROM 1992-2000 AS OBSERVED BY INSAR

R. J. Mellors, A. Van Zandt, O. Rojas • San Diego State University

Data from 87 ERS-1 and ERS-2 interferograms (descending orbit, track 356, frame 2943) covering the Western Salton Trough and spanning a time period from 1992 to 2000 are analyzed to measure surface deformation. After eliminating interferograms with obvious atmospheric interference, we stack 67 of the remaining interferograms. Several areas of groundwater subsidence in the Western Salton trough are visible as well as clear indications of tectonic deformation are observed along the Superstition Hills/Elmore Ranch faults are observed. The amplitude and sense of motion are in agreement with published creepmeter observations from 1992-1994. The northern edge of the deformation is obscured by an area of subsidence associated with known groundwater extraction. Forward modeling (elastic half-space) of the deformation using the known geometry of the faults matches the observed signal well and indicates a substantial component of shallow (less than 5 km) slip. After spatial filtering, we invert the InSAR data to determine deformation as a function of time along the fault. The deformation time history is useful in distinguishing tectonic deformation from groundwater signals in this area. The signals are also compared with GPS groundtruth measurements.

EARTHSCOPE OUTREACH: ENGAGING SUPPORT FOR A NATIONAL PROJECT

Charna E. Meth • EarthScope

EarthScope's success requires broad interaction with the scientific and educational communities through workshops, national meetings, publications, press, and an extensive website that provides seamless access to all EarthScope data. Such interaction is necessary to enfranchise the broad community and achieve EarthScope's goal of taking a multi-disciplinary approach to understanding the structure and evolution of continents and the properties that control earthquakes and volcanoes. As one of the National Science Foundation's highest-profile projects, EarthScope also has a responsibility for demonstrating the value of the public investment in basic research.

Within our first 18 months, EarthScope has participated in dozens of professional meetings and conferences, including the American Geophysical Union Fall Meeting, the American Association for the Advancement of Science Annual Meeting, and the Geological Society of America Annual Meeting. Through an exhibit booth, oral and poster presentations, and special sessions, EarthScope's extensive presence at national meetings expands awareness of the project and promotes use of EarthScope data and instrumentation.

The EarthScope exhibit booth was also featured at last year's Coalition for National Science Funding exhibition and reception in Washington, DC. Invited by the American Geological Institute, the American Geophysical Union, and the Geological Society of America, EarthScope helped showcase research sponsored by the National Science Foundation. The event drew over 370 participants, including Congressional staff, Members of Congress, and White House leaders. Following the exhibition, EarthScope was invited back to the Capitol by the House Committee on Science to present emerging results from the Parkfield 6.0 Earthquake and the Mount St. Helens eruption. The briefing displayed data collected from EarthScope and USGS instrumentation and explained how earthquakes and volcanoes are improving our understanding of the continent.

In September 2004, EarthScope partnered with the US Geological Survey to invite Congress, the National Science Foundation, and the media to Parkfield, CA. The participants toured the San Andreas Fault and the SAFOD drill site, met the scientists and engineers, saw demonstrations of geodetic and seismic stations, learned about EarthScope's progress and plans, and heard how scientist and educators will use EarthScope data. Over 80 people participated in the event, including NSF Director Arden Bement, Congressman Sam Farr, and national and international press. In his opening remarks, Director Bement praised the event, stating that it exemplified how ìto keep policymakers and the general public informed of what we are learning and its relevance.î The event increased awareness of EarthScope and Geosciences among policy-makers and generated over a dozen articles in the media plus footage for two documentaries in production.

Press coverage continues to be an important means for communicating with the general public. EarthScope's involvement with the press has resulted in articles published in local (e.g., San Jose Mercury News), national (e.g., The New York Times), and international (e.g., Apple News [China]) newspapers, in popular science magazines (e.g., Discovery Magazine), in Geoscience magazines (e.g., Geotimes), and in cross-discipline magazines (e.g., Physics Today). Local (e.g., King 5 News Seattle), national (e.g., The News Hour with Jim Lehrer), and international (e.g., BBC News) television programs have also produced segments featuring EarthScope.

As EarthScope continues, outreach to the broad scientific and educational communities will remain a priority ñ both to achieve our scientific and educational goals, and to help maintain public interest in the Geosciences.

LESSONS LEARNED ABOUT EXPLOSIVE VOLCANISM AND SEISMICITY FROM THE 2004-2005 ERUPTION OF MOUNT ST. HELENS

Seth C. Moran • U.S. Geological Survey

On 23 September 2004 a swarm of volcano-tectonic (VT) earthquakes heralded the reawakening Mount St. Helens (MSH) after 18 years of quiescence. On October 1 the first small explosion occurred, with four others following over the next four days. Several of these happened during daylight hours and were broadcast live nationwide, perhaps creating an impression that MSH was building towards a larger explosive eruption. However, these explosions were instead followed by the steady-state growth of a new dome in the southern part of the 1980 crater that has continued to the present. The relatively steady-state extrusion has been punctuated by just two explosions, one on 16 January 2005 and another on 8 March 2005. All seven explosions to date have been phreatic in nature, with no evidence of any magmatic component. Overall, the MSH 2004-2005 eruption has been remarkably devoid of explosive activity, a result of the gas-poor, or ìflatî, nature of the erupted magma.

Given the relative lack of explosive activity, it would seem at first glance that MSH has little to tell us about the nature of explosive volcanism and, by extension, seismicity associated with explosive volcanism. At second glance, however, MSH does have several important things to contribute. One such contribution comes from the nature of MSH seismicity. The steady dome growth has been accompanied by hundreds of thousands of shallow low-frequency (LF) events. The LF events have been remarkably regular in time, and many have had similar waveforms. LF events are commonly thought to be caused by movement of gas and/or fluids in cracks and have often been associated with explosive activity. The characteristics of the MSH LF events instead suggest that they are directly related to stick-slip behavior along the margins of the conduit as the mostly crystalline dacitic magma feeding the 2004-2005 eruption squeezes through the uppermost part of the conduit. Strong supporting evidence for the stick-slip nature of the LF events comes from the ~1-2-meter-thick layer of striated fault gauge that covers much of the erupted dome as it emerges from the conduit. Thus the current eruption highlights another possible mechanism for LF events (one that has been inferred for several other dome-building eruptions) that does not require the presence of gas and/or fluids in cracks.

A second contribution comes from the March 8 explosion, by far the largest of the seven explosions to date. The explosion lasted ~20 minutes and produced an ash cloud up to ~11 kilometers (36,000 feet) above sea level that lightly dusted several communities in eastern Washington. It was preceded by a relatively subtle 2-hour-long period of broadband tremor apparent on stations up to 8 km from MSH that gradually increased in amplitude up to the explosion. The explosion was accompanied by tremor appearing on stations 15 km distant. It also produced the first observed notable infrasonic signals on a two-microphone array since its installation in early November 2004 at a site ~500 meters from the vent. Ballistics and ash from the explosion consisted entirely of fragmented dome rock. The absence of pumice is primary evidence for the phreatic nature of the March 8 explosion. The explosion appears to have been produced by the interaction of meteoric water, perhaps derived from the melting of glacial ice, with magma at shallow depths within the conduit. The 2-hour-long buildup of tremor prior to the explosion could reflect boiling of groundwater trapped along the margins of the conduit. This buildup represents a relatively rare instance of a seismic precursor prior to a volcanic explosion, and provides an example of a signal that could enable future short-term forecasts of similar explosive events at MSH.

A final contribution comes from the relative absence of seismicity associated with most of the other explosions. All of the early explosions were heralded by instantaneous drops in earthquake activity, and the explosions themselves produced little to no seismic noise at stations outside of the crater. Although not a novel observation at volcanoes, the seismically quiet nature of most of these explosions highlights the fact that not all explosions produce seismic energy and that reliable explosion detection may require having a station very close (< 1 km) to the vent. Thus MSH has given us distinctly mixed messages regarding explosive volcanism: on the one hand, some explosions may be predictable over a relatively short time frame; on the other hand, some explosions are not seismically detectable, let alone predictable.

PARALLEL 3D FINITE-DIFFERENCE MODELING OF TELESEISMIC WAVEFIELDS

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Three-dimensional finite-difference modeling in realistic recording environments could be an efficient tool for verifying interpretations and planning teleseismic experiments. With broad availability of Beowulf clusters, such modeling has become practical and could quickly become a standard tool of teleseismic waveform investigations, and in Receiver Function work in particular. We present a parallel 3-D visco-elastic finite-difference modeling code using a 64-processor Opteron cluster. The code implements the method by Bohlen (2002), implemented using the Parallel Virtual Machine and fully integrated into the seismic processing environment by Morozov and Smithson (1997).

As a first example of application of this method, we modeled the wavefields created by an onset of a teleseismic P-wave onto a subduction zone structure and recorded by a linear array similar to the PASSCAL 1993 Cascadia deployment. Recordings in active subduction zone environments have resulted in several spectacular receiver function interpretations, in particular using the later, back-scattered modes. However, as Morozov (2004) suggested, in such a strongly heterogeneous crustal setting, scattering from the trench zone could result in wavefields occupying the same time and moveout intervals as the backscattered P- and S- waves from the subducted oceanic plate, and therefore difficult to distinguish from the latter. The finite-difference modeling confirms this conclusion. The synthetics show strong scattering from the trench zone, dominated by the uppermost-mantle and crustal P-waves propagating at 6.2-8.1.km/s and slower. With similar time and moveout values, and also similar or greater amplitudes, these scattered waves override the backscattered modes in the synthetics. Unlike the converted-wave amplitudes, the amplitudes of the trench-scattered waves decay with the distance from the trench. Such decreasing amplitudes are usually observed in the data, and under minimal assumptions (i.e., without invoking slab dehydration), these observations support the interpretation of trench-zone scattering. Thus, the modeling suggests that backscattered-mode RF imaging may not be warranted in the noise environment caused by scattering from the strong crustal heterogeneity of the subduction zone.

Finite-difference modeling could be useful for planning teleseismic experiments, in a way it is routinely done in the oil exploration industry. 3-D teleseismic finite-difference modeling can be performed relatively quickly, with resolution adequate for quantitative comparisons with the data, and would require lass than 1% of the time and cost of the field work. Synthetic datasets could be used in order to test and calibrate the imaging methods, including the 3-D pre-stack depth migration, and to estimate the resolution and projected image quality.

IMAGING SPATIAL AND TEMPORAL PATTERNS OF DEFORMATION AT PARKFIELD, CA USING GEODETIC DATA

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Parkfield, CA is one of the few seismically active locales in which geodetic data have been collected throughout the earthquake cycle. With these observations it is possible to image the spatial, and in some cases the temporal, character of the variety of deformation processes evident on the San Andreas fault in this area. These include ongoing steady creep and the transition to locked behavior, transient aseismic deformation, coseismic slip, and postseismic response. By providing a measure of strain accumulation and release on the fault, the geodetic data also permit assessment of the extent to which earthquakes at this location obey some simple models of earthquake recurrence.

In this talk I will present the results of several studies, both completed and ongoing, which image the crustal deformation at Parkfield through inversion of geodetic data. The results of these studies show that 1) A large portion of the San Andreas fault near Parkfield experienced little or no interseismic creep at depth during the period 1966-2004, 2) A transient slip rate increase occurred on the fault in the mid-1990s, apparently in response to moderate seismicity near the hypocenter of the 1934 and 1966 Parkfield M6 earthquakes, 3) A large part of the Parkfield fault segment has little slip deficit after two earthquake cycles, although southeast of Cholame, CA the deficit may exceed 1.5 meters, and 4) Deformation at Parkfield is inconsistent with the simple, but oft-cited time-predictable model for earthquake recurrence. After two months of postseismic slip, it appears that the 2004 M6 Parkfield earthquake is also inconsistent with the slip predictable model, however a longer portion of the postseismic period must be observed in order to evaluate this. Ongoing study of the substantial postseismic deformation following the 2004 earthquake is focused on exploring the temporal evolution of afterslip.

A CALL FOR THE DEVELOPMENT OF EXTENSIVE SEAFLOOR GEODETIC TOOLS FOR INVESTIGATING MEGA-THRUST EARTHQUAKES AND OTHER GEOLOGICAL PROCESSES

Andrew Newman • Los Alamos National Laboratory

Jian Lin • Woods Hole Oceanographic Institution

Seth Stein • Northwestern University

Motivated by the massive earthquake along the Burma Trench and resultant devastating tsunami of December 2004, we are renewing a call for more extensive scientific research on developing low-cost and effective seafloor geodetic measurement techniques. Direct rupture models and aftershock activity of the December earthquake suggests that this event ruptured up to the shallow trench, along what was likely a previously locked and aseismic zone (Newman and Bilek, EOS-Spring AGU, 2005). This is anomalous because a significant number of large subduction zone earthquakes do not rupture shallower than about 10-20 km depth, in what is generally considered a stably-sliding and weak zone. Identifying whether these zones globally are strongly locked, conditionally stable (failing in slow and silent earthquakes), or freely slipping is currently only achievable through extensive seafloor geodetic surveys.

Unfortunately, seafloor geodesy is a relatively new, challenging, and expensive field that has been overlooked by much of the community in favor of easier and less costly terrestrial measurements. In light of the recent event and the general lack of current observations of seafloor deformation, we fell the scientific community should renew its interest in determining the feasibility, cost effectiveness, and applicability of making various types of seafloor geodetic measurements from 1-10 cm level accuracy. Techniques that have been previously developed and are currently in use include examples of GPS-acoustic systems (e.g., Spies et al., PEPI, 1998; Gagnon et al., Nature, 2005); fully acoustic systems (e.g., Fujimoto et al., Earth Plan. Sp., 1998); pressure sensors (e.g., Fox, JGR, 1990; Chadwick et al., 2005); tiltmeters (Tolstoy et al., PEPI, 1998; Anderson et al., JGR, 1997); gravity meters (Zumberge and Canuteson, Proc. Int. Ass. Geod., 1994); and fiber-optic extensometers (Zumberge, Ocean Eng.,1997). Other potential techniques include bathymetric interferometry (similar to InSAR), borehole strainmeters, and dilatometers. In most all of these systems there are numerous issues that need to be considered including: relative/absolute measurements, cost, power consumption/generation, signal attenuation and scatter, changes in path velocity, data relay, monumentation and retrieval, and system lifespan. Some of the existing technical challenges can be addressed in the framework of the upcoming NSF ORION (Ocean Research Interactive Observatory Networks) initiative, IODP, and other major programs. In addition to understanding the state of locking along the shallow interface of subduction zones, these techniques can be uniquely used to determine the ongoing kinematics of plate flexure, ridge spreading, transform faulting, underwater volcanism, shelf stability, and ocean bottom sediment transport processes. Techniques may additionally be useful for industry studies for subsidence/uplift due to hydrocarbon withdrawal, enhanced oil recovery, and sub-oceanic carbon sequestration. It would be beneficial for the community, possibly through UNAVCO and IRIS and support from NSF, NOAA or USGS, to organize workshops to further discuss the feasibility, development, and effective deployment of seafloor geodetic techniques.

UMKC SEISMICNET: AN EDUCATIONAL OUTREACH INITIATIVE USING REAL-TIME SEISMIC DATA, MUSEUM DISPLAYS, AND CLASSROOM DEMONSTRATIONS

Tina M. Niemi • University of Missouri-Kansas City

The Department of Geosciences at the University of Missouri-Kansas with a departmental focus on Urban and Environmental Geosciences has recently joined IRIS as an Educational Affiliate. We propose establishing the UMKC SeismicNet by installing a three-component, broadband seismograph that will feed real-time seismic data via the internet to classrooms, a museum display, and our partner public and charter schools. The goal of the UMKC SeismicNet is to use seismic data to teach basic scientific principles across the K-16 curriculum and to raise public awareness of the earth and environmental sciences. Seismic data from the UMKC SeismicNet will help stimulate discussion, classroom exercises, and projects on topics such as plate tectonics, volcanic eruptions, epicenters and magnitude, forces, wave propagation, elastic properties, natural disasters, ground shaking, building failures, earth materials, soil, and geography. We plan to implement this project through: 1) demonstrations utilizing the desktop display units and integration of real-time seismic data into undergraduate courses, 2) establishing a public seismographic display model in the UMKC Geosciences Museum, and 3) the initiating an outreach program to Kansas City public and charter schools through in-service teacher training that focuses on earthquakes. Using real-time seismic data in K-12 classes will help to meet key content standards (e.g. force, velocity, acceleration, pendulum, wave motion) and pedagogical aspects (e.g. hands-on, problem solving, real world) of the National Science Education Standards in physics, earth science, computers, and geography. To help implement our project, we plan to adapt the IRIS curricular materials to focus on our geographic region. Furthermore, the IRIS Museum Lite Display program will greatly facilitate our efforts to bring seismographic data to the public in the UMKC Geosciences Museum.

UPPER MANTLE STRUCTURE UNDER THE TRANSANTARCTIC MOUNTAINS AND EAST ANTARCTIC CRATON FROM BODY WAVE TOMOGRAPHY

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Douglas Wiens, Jesse Lawrence, Patrick Shore • Washington University

The Transantarctic Mountains (TAM) represent a major lithosphere boundary between the two major blocks forming Antarctica, West Antarctica and East Antarctica. In this study, results from a body wave tomography study of upper mantle structure beneath the TAM and part of the East Antarctic Craton are presented. The data for this study come from the TAMSEIS project, which consisted of 41 broadband seismic stations deployed across the TAM and into the interior of East Antarctica between 2001 and 2003. P and S relative travel times are inverted for upper mantle structure using the method of VanDecar. Results show a pronounced low wave speed region centered under Ross Island that extends to depths of about 200-300 km and that spreads out laterally under the edge of the TAM but does not extend a significant distance under the TAM or into East Antarctica. In addition, the low wave speed region does not appear to extend northward along the coast of the Ross Sea. Receiver functions are also stacked to image the 410 and 660 km discontinuities. Preliminary results show that the 410 and 660 can be imaged under the polar ice cap and that the transition zone does not appear to have been thinned. These results support models for TAM uplift invoking thermal buoyancy forces, at least locally surrounding Ross Island, but leave open the question of pervasive heating of the TAM lithosphere along the entire mountain front.

GENERALIZED CAPABILITY TO SIMULATE SEISMIC WAVE PROPAGATION USING DISTRIBUTED COMPUTING AND INFORMATION TECHNOLOGIES: A WORKFLOW COMPONENT OF THE SCEC COMMUNITY MODELING ENVIRONMENT

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Simulation of wave propagation is a fundamental component of seismological research. Calculation of synthetic seismograms is used within studies of seismic sources, earth structure, and ground surface response, and serves as a corroboration tool when calculated waveforms are compared to observed seismograms. The Southern California Earthquake Center (SCEC) is using synthetic wave propagation within new methods for deterministic seismic hazard analysis. The SCEC Community Modeling Environment (CME) is a collaboration between earthquake and information technology researchers whose goal is to construct a framework within which to conduct physics-based seismic hazards analysis. This framework will allow for the coupling of 3D earth and fault representations, regional stress and deformation fields, rupture dynamics models, wave propagation simulation, and strong ground motion site responses. These elements are the subjects of active research and so the SCEC/CME framework is designed to accommodate evolving research products.

Within the SCEC/CME we define seismic wave simulation as a modular task which can be performed one or many times depending on the needs of a greater research workflow. We have assembled a framework whereby with a simple request description we can generate synthetic seismograms and/or earth volume wavefronts. This framework allows for choices in Southern California earth (velocity) models, different wave propagation codes, and arbitrary source locations. We utilize high performance compute facilities via Grid computing, digital library resources, provenance metadata, and workflow composition tools.

Seismic wave propagation can be calculated within the following earth models: SCEC Community Velocity Model v2.2 and v3.0 (Magistrale et al., 2000; Kohler et al., 2002), Hadley-Kanamori model of Southern California (Dreger and Helmberger,1993), a high resolution Los Angeles basin model (Suss and Shaw, 2003), plus user choices of constant velocity and one-layer-over-halfspace models. Wave propagation codes include 3D finite difference stress-velocity formulations of Graves (1996) and Olsen (2000), and a 3D finite element implementation (Bielak and Bao, 1998). Double couple point sources of arbitrary location and magnitude are permissible; finite fault sources are currently under incorporation. PGV and PGA intensity maps are routinely constructed from the synthetic seismograms. Visualization of propagating wavefronts within earth volumes is possible.

Computation is performed using remote high performance (cluster) facilities using Grid computing communication tools. A workflow composition tool is used to specify user parameters which define the simulation and then create and execute the list of action items needed to perform the simulation. Output results from the simulation can be archived within a digital library system (the Storage Resource Broker) housed at SDSC. Seismological metadata are used to communicate simulation information and compute history. The simulation framework is currently being improved with the usage of more formalized information technology components.

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TECTONIC STRUCTURE AND SURFACE WAVE DISPERSION IN EURASIA AND NORTH AFRICA

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LLNL has performed a large-scale study of surface wave dispersion across Eurasia and North Africa. The spatial resolution of the inversion has been improved by increasing path density and adopting a variable smoothness conjugate gradient method for the group velocity tomography (Pasyanos, 2005). This technique allows us to achieve higher resolution where the data allow without producing artifacts. The current results include both Love and Rayleigh wave inversions across the region for periods from 7 to 100 s at 1∫ resolution. Short period group velocities are sensitive to slow velocities associated with large sedimentary features such as the Caspian Sea, West Siberian Platform, Mediterranean Sea, Bay of Bengal, Tarim Basin, and Persian Gulf. Intermediate periods are sensitive to differences in crustal thickness, such as those between oceanic and continental crust or along orogenic zones (Zagros, Himalayas) and continental plateaus (Tibet). At longer periods the group velocities are sensitive to structures in the upper mantle. Fast velocities are consistently found beneath cratons (W. Africa, Baltic, Congo, Indian) while slow upper mantle velocities occur along rift systems, subduction zones, and collision zones. At these periods, there are indications that the slow velocities associated with rift zones are deeper-seated than in convergence zones, where the slow velocities are confined to the mantle wedge. A significant correspondence can also be found between fast velocities and older crust, which is underlain by thick, cold lithospheric material. Two exceptions seems to be the Sino-Korean Paraplatform, which has had its lithospheric mantle more recently affected by nearby subduction, and the Benue Trough in Cameroon, which is the remnant of a failed rift system. There is a significant correlation between lithospheric thickness and 80 s Rayleigh wave group velocities. The thicknesses of the continents are derived from the 1300∫ C isocontour from Artemieva and Mooney (2001), whereas the thicknesses of the oceanic lithosphere are derived from the oceanic age. The correlations here are quite significant, with older, thicker lithosphere about 0.35 km/s faster than a younger, thinner one.

PROCESSING OF SEISMIC NETWORK NOISE WINDOWS FOR DETECTION OF SOURCES BELOW THE SINGLE-STATION DETECTION THRESHOLD: AN EXPERIMENT AT THE ANZA NETWORK.

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Conventional practice in the detection, location, and characterization of small local events entails the use of single-channel arrival detection, the association of multiple-station detections, and the location and characterization of each event, based on these associated arrivals. At smaller magnitudes, arrivals are lost in the noise, and insufficient detections are obtained to identify and locate an event. Thus each network has a magnitude below which only a small fraction of events are detected and catalogued. Two strategies are available for lowering this network threshold. [1] Single-instrument (1 or 3 channels) data processing to lower the single-instrument detection threshold; [2] All-station processing, to utilize the multichannel time series. We show numerical experiments in which migration-stacking of data flow from the Anza network is used to create subsurface 3-d images of seismic emission. Any experiment involves a specified time window. When the window is a few seconds, the experiment is scanning for individual events... thus looking at events which are just below the usual detection threshold. Windows of minutes to hours can be used, and the stacking generalized to entail stacking over such windows. Thus, detection of the emission of seismic energy by large numbers of micro-events is achieved by this time averaging. A reliable velocity model of the subsurface is required, as with conventional event detection. Implementation involves a variety of discretionary analysis options for noise balancing, bandpass selection, and stacking. It represents a fruitful area for exploratory data analysis.

Following studies by Archambeau, we have detected emission from a pre-event time window, from the location of a well-detected m1.5 event. The seismic energy studied represents a portion of the noise window with partial coherence across the network. We conjecture that this represents in effect a proxy monitor of creep in the tectonically active subsurface. This data experiment is a particular realization of the idea that the data flow from the growing number of networked broadband stations can be more fully utilized by network processing of the noise intervals which constitute the greatest percentage of data going into the global archives.

NOVEMBER 20, 2004 (M_W=6.2) QUEPOS, COSTA RICA EARTHQUAKE AND AFTERSHOCK ACTIVITY

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The Costa Rica seismic network OVSICORI (Observatorio SismolÛgico y VulcanolÛgico de Costa Rica) at the National University located a M_w=6.2 earthquake that occurred on November 20, 2004 at 08:07 UTC near Quepos in the central Pacific part of Costa Rica. The event was felt through all the country with the Modified Mercalli scale (MM) felt reports of (VII) at Parrita and Damas, (VI) at Jaco and Quepos, (V) at Puntarenas and the Central Valley. The majority of the damage was located at Parrita and Damas, and the event caused local liquefaction and small surface cracking.

The seismic activity was relocated using a 3-D velocity model and a double difference technique. The mainshock and majority of the 93 (first 10 days) aftershocks are associated with a local fault striking NW with a dip angle of 77 degrees, dipping NE. The focal mechanism was primarily normal faulting with a minor component of right-lateral strike-slip (Harvard CMT). The main event was relocated with a focal depth of 25 km and occurred in an area about 100 km inland from the Middle America trench in the deepest part of the crust, with the aftershocks distributed to the surface. The closest station, Quepos, was located 15 km from the epicenter. The local fault is part of the fault system that delineates the upper plate between the Caribbean and Panama Block and the associated subduction of the Cocos plate from the west.

SURFACE WAVE TOMOGRAPHY FROM AMBIENT SEISMIC NOISE

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Cross-correlating one month to one year of ambient seismic noise recorded at USArray stations in California yields hundreds of short period (6 sec - 18 sec) surface-wave group-speed measurements on inter-station paths. This fundamentally new type of measurement is used to construct tomographic images that reflect the principal geological units within California, with low-speed anomalies corresponding to the main sedimentary basins and high-speed anomalies coincident with the igneous cores of the major mountain ranges. This method promises significant improvements in the resolution and fidelity of information about crustal structures that result from the analysis of surface waves. This is particularly intriguing at regional scales in the context of the Transportable Array component of USArray, but also at continental scales when applied to backbone network stations (e.g., USArray backbone, USNSN, ANSS, GSN, etc.). Preliminary maps of surface wave disperson across the US at periods ranging from 15 sec to 150 sec are now emerging and are providing increasingly high resolution information about the upper mantle beneath the US.

It may seem initially surprisingly that deterministic information about the Earth's crust and mantle can result from correlations of ambient seismic noise, but random fluctuations can, in fact, yield the same information as provided by probing a system with external forces. In seismology, external probing through active seismic sources (e.g., explosions) may be prohibitively expensive and earthquakes are both infrequent and inhomogeneously distributed. In some applications, merely ``listening'' to ambient noise may be a more reliable and economical alternative.

WHAT WILL USARRAY DATA LOOK LIKE? - SPECTRAL ELEMENT SIMULATIONS ON LLNL HIGH PERFORMANCE COMPUTERS

Arthur Rodgers • Lawrence Livermore National Laboratory

Jeroen Tromp • California Institute of Technology

The USArray component of EarthScope will record broadband seismic waveform data across the continental United States. The temporary stations comprising the Transportable Array (ìBigfootî) will be deployed on a grid with dense spacing (~70km) and a wide aperture (~1400km). This experiment will result in an unprecedented sampling of broadband data over a large footprint. It can be expected that these observations will allow the continuous tracing of broadband waveform effects due to three-dimensional structure, such as body-wave triplications, focusing and caustics and surface wave reflections and refractions. We present synthetic seismograms of large earthquakes to illustrate the expected sampling of USArray, with particular emphasis on the Transportable Array. Seismograms are computed with the Spectral Element Method (SEM; Komatitsch and Tromp, 1999, 2002). This code (specfem3D) simulates seismic waves in fully three-dimensional (3D) Earth models, including topography, bathymetry, ellipticity, rotation and self-gravitation. Simulations were run on high-performance computers at LLNL, using hundreds to CPU's. We compare simulations for both local/regional and teleseismic events using the 1D PREM (Dziewonski and Anderson, 1981) and the 3D S20RTS (Ritsema and van Heijst, 1999) models. We are working to generalize the code for the use of other 3D Earth models.

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SEISMO-ACOUSTIC SIGNALS OF EXPLOSION EVENTS AT TUNGURAHUA VOLCANO, ECUADOR

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More than 2,000 explosions were recorded on Tungurahua volcano in a 43 day-long field campaign conducted in summer 2004. Four stations with seismic and infrasonic sensors were deployed at distances of 3.2 to 13.5 km from the single active crater of this andesitic strato-volcano, covering three different azimuths. Pressure amplitudes of explosion events span three orders of magnitude from 0.1 to 180 Pa at the closest station. Large explosion signals are accompanied by 3 km-high ash columns. Cluster analysis of infrasound waveforms reveals that explosions have at least four clusters or families of events, without any temporal pattern. Inversion of seismic arrivals and waveform polarization pinpoint the epicenter of these explosions inside an area of 400 m around the crater. Since, these methods did not provide for this case an accurate determination of source depths; we used large delay times between seismic and infrasonic signals at the three closest stations, constraining the Tungurahua's explosions sources at depths shallower than 200 m below the crater floor.

EFFECTS OF 3D VELOCITY AND ATTENUATION IN THE TONGA-FIJI SUBDUCTION ZONE

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The current understanding of subduction zone temperature and composition is limited. Much of our resent knowledge of subduction zones comes from earthquake locations, geochemical measurements, and lab based experiments. Recently, two studies of the Tonga-Fiji subduction zone have presented tomographic images of velocity and attenuation (Roth et al., 1999; Zhao et al., 1997). Roth et al.(2000) then combined these two tomographic models of the Tonga-Fiji subduction zone to derive an empirical relationship between changes in velocity and attenuation. This relationship agrees well with two independent, experimental data sets (Jackson et al., 1992; Sato et al., 1989) The experimental studies indicate that a simple increase in temperature will cause the velocity to decrease as the attenuation increases. Using the tomographic velocity model and the empirical relationship between velocity and attenuation we create synthetics seismograms for the Tonga-Fiji subduction zone to test whether a simple increase in velocity accurately depicts this subduction zone.

To construct the model we use the compressional tomographic model of Zhao et al. (1997) to create a shear velocity model using a simple Vp/Vs ratio. Following Roth et al. (2000) these tomographic models are combined with the empirical relation between velocity and attenuation to create an attenuation model. Again, these models are constructed under the assumption that attenuation scales with velocity due to a simple change in temperature. The resulting synthetics are compared to recorded data to validate the tomographic velocity model and the empirical relation between velocity and attenuation. Any mismatch in this comparison will provide a basis for further refinement of the tomographic models and the velocity-attenuation relation. These types of studies are an important step towards a fuller understanding of the composition and evolution of the subducting plate, mantle wedge, and back-arc spreading center. They may also offer insight into the role of water, melt percentage, viscosity, and flow pattern within the mantle wedge.

The synthetics are created using the SPECFEM3D global code (Komatitsch and Tromp 2002a,b) with the new addition of a three-dimensional attenuation operator. Attenuation is simulated by using a set of standard linear solids over the desired frequency range as described in Liu et al. (1976). The addition of such an operator slows the creation of the spectral element mesh, but does not inhibit simulation or solving step significantly.

Our initial results at a minimum period of 11 seconds suggest that the attenuation structure plays a minor role for the present source-receiver geometry. The addition of 3d velocity structure does distort the recording significantly in amplitude and phase.

STRAIN ACCUMULATION OF THE CENTRAL SAN ANDREAS FAULT: IMPACT OF LATERALLY VARYING CRUSTAL PROPERTIES

Gina M. Schmalzle, Timothy Dixon, Rocco Malservisi, Rob Govers

Major strike slip fault systems, such as the San Andreas Fault, have a common characteristic: lateral juxtaposition of geologically dissimilar terrains. Terrains on opposite sides of the fault may vary in their material properties. The Carrizo segment of the San Andreas Fault is a prime area to study the effects of asymmetry imposed by strike slip faulting because it is a straight segment and exhibits relatively simple seismic behavior. We present new GPS data on the Carrizo segment to quantify the asymmetry, as well as a series of numerical models designed to investigate possible causes of asymmetry. The maximum asymmetry is about 6 mm/yr, developed at distances ~35 km or less from the fault. Our models are implemented with the finite element technique, and investigate differences in elastic layer thickness and variable material properties of the upper crust. Available data are well fit by a simple model with a weak zone (upper and middle crust) 10-20 km wide on the northeast side of the fault. Seismic data in the area support this model.

SEISMIC, GEODETIC, AND FLUID FLOW CONSTRAINTS ON SEISMOGENIC ZONE PROCESSES IN COSTA RICA

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Large or great subduction zone thrust earthquakes nucleate within the seismogenic zone, a region of unstable slip on or near the plate interface. The mechanical behavior of convergent margin seismogenic zones is not well understood, partly due to this region's location below sea-level at most subduction zones. In northwestern Costa Rica, the seismogenic zone lies directly beneath the Nicoya Peninsula, allowing for near source studies of its behavior. The 1999-2001 collaborative Costa Rica Seismogenic Zone Experiment (CRSEIZE) consisted of a joint seismic, geodetic and fluid flow investigation of the southern portion of the Middle America Trench. CRSEIZE included two seismic transects near the Nicoya and Osa Peninsulas in Costa Rica that consisted of both land and ocean bottom (OBS) broadband and short-period stations and fluid flow meters co-located with OBS; velocities at 46 GPS sites throughout the country were also determined.

Results from this experiment include distinct patterns of interseismic strain accumulation and interplate microseismicity in northern Costa Rica. Geodetic locking of the plate interface occurs between 8ñ15 km depth below sea-level while shallow interplate microearthquakes begin deeper, between 15-18 km below sea-level, in a region that appears to be freely slipping. We interpret the up-dip limit of the shallow geodetically locked region as the frictional stability transition from stable sliding to stick-slip behavior, while the up-dip limit of interplate seismicity and the freely slipping zone most likely correspond to a change in mechanical properties along the plate interface. We postulate that increased pore fluid pressure resulting from basalt dehydration reactions and/or decreased permeability in the upper plate may lead to fault weakening. A three-station permanent GPS network installed on the Nicoya Peninsula after CRSEIZE recorded a creep event that consisted of several cm of ìearthquakeî slip initiating at shallow depth on the plate interface (~10-20 km) and propagating down-dip over ~ 1 month period. Slip in this event is concentrated within the portion of the seismogenic zone we previously identified as freely slipping and characterized by abundant microseismcity. Silent earthquakes or creep events have been recorded at other subduction zones; however, at most of these, including the Cascadia margin, slip occurs below the seismogenic zone in a transition regime between stick-slip and stable sliding frictional behavior, making the Costa Rican event unique. Evidence for previous creep episodes come from CRSEIZE measurement of fluid flow made across the Nicoya Peninsula. Three periods of correlated flow signal are identified on three instruments located ~30 km apart on the subduction forearc. We propose that repeated plate boundary creep events force flow through a fracture network in the subsurface that is recorded by the fluid flow meters at the surface. These and other CRSEIZE results are contributing to our understanding of seismogenic zone processes.

SOURCE IMAGING USING TELESEISMIC P WAVES

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The disastrous 2004 Sumatra earthquake and tsunami demonstrated the need for more rapid earthquake source characterization methods in global hazard monitoring. Ideally these methods should be based on the first arriving P waves, which cross the Earth in less than 20 minutes, rather than the slower surface waves often used in long-period inversions. However, traditional body-wave magnitude scales saturate for P waves and most finite source modeling techniques are not suited for real-time processing. We have developed a new method for imaging earthquake rupture that backprojects short-period P-wave energy directly to the source region. Using the Japanese Hi-Net array, we show that the 2004 Sumatra rupture spread over its entire 1300-km-long aftershock zone by propagating northward at roughly 2.8 km/s for about 8 minutes. Bursts of high-frequency radiation are observed near 80 and 300 s into the event. Comparisons with aftershock areas of other great earthquakes suggest a moment magnitude of ~9.3 for this earthquake, whose rupture, in both duration and extent, is the longest ever recorded. Our technique can also be applied using GSN and other global seismic stations; we have successfully imaged the 2001 Tibet and 2002 Alaskan earthquakes by using subsets of the global station coverage. In both cases, we obtain results roughly comparable to published slip models. The advantage of our approach is that it could be implemented in real-time monitoring systems to obtain results within 20 minutes after the earthquakes without any prior assumptions regarding fault geometries. We have also analyzed the March 28, 2005, Sumatra earthquake. Preliminary results suggest that the rupture was bilateral, but that the maximum moment release was south of the hypocenter.

Our method uses waveform cross-correlation to align the first-arriving P-waves and correct for small time shifts caused by 3-D velocity structure. This calibration ensures a coherent stack at the earthquake hypocenter but will become less accurate at increasing distances away from this point, especially at high frequencies. Aftershocks provide additional calibration points, which, in principle, can improve the accuracy of the method for extended ruptures. However, the method often works quite well using timing corrections based on the mainshock arrivals alone, making it suitable for rapid source imaging.

GIANT SUMATRAN EARTHQUAKES: PAST, PRESENT AND FUTURE

Kerry Sieh • California Institute of Technology

The giant Aceh-Andaman earthquake resulted from rupture of more than a thousand km of the Sunda megathrust, from about 3° N to about 14° N. Rupture of an adjacent section of the megathrust, from about the Equator to 3° N, produced the giant Banyak Islands earthquake just three months later. I will review our field observations of uplift and submergence and near-field GPS measurements that constrain models of these ruptures.

The remainder of the Sumatran section of the Sunda megathrust has a history of prior activity that helps us anticipate what might happen in the future. Records of vertical deformation from coral microatolls indicate that the 70-km-long section, from about the Equator to 0.7° S has experienced significant ruptures only twice in the past 250 years. The largest coseismic rupture in this period was a 2.5 meter slip, which generated the M 7.7 earthquake of 1935. A smaller rupture in about 1797 may have been aseismic. Long paleogeodetic records indicate that about 70% of the slip along the 1935 locked patch is aseismic. Paleogeodetic and GPS data reveal that this section of the megathrust is locked to a depth of only about 30 km and that the shallowest part of the subduction interface may well be slipping aseismically.

From about 1° S to 2° S the coral record and GPS measurements indicate that the megathrust is locked currently to depths of 40 to 50 km and has not ruptured in the past 400 years. This suggests the potential for a 20-meter slip event. From about 2° S to 3.5° S, the current locking depth is 45 to 55 km. This section has experienced large ruptures about every two centuries. The most recent emergences occurred in about 1380, about 1605 and in 1797 and 1833. The latter two are known from sparse historical records to have generated large, destructive tsunamis along the west coast of Sumatra. Forward modeling of the patterns of emergence on the outer-arc islands indicate that the magnitudes of the 1797 and 1833 earthquakes were about 8.2 and 8.7, respectively. Little is known about the megathrust south of 3.5° S, but the 1833 rupture may well have extended to Enggano island, at about 5.5° S. Locking of this section of the megathrust since 1833 implies the potential for about 9 meters of slip. Given the paleoseismic recurrence times of about two centuries between 2 and 3.5° S and the lack of large ruptures between 1 and 2° S since the 1600s, it seems likely that another giant megathrust earthquake will occur south of the Equator within the next several decades.

SEGMENTATION AND LONG-TERM BEHAVIOR OF THE SUNDA MEGATHRUST IN SUMATRA FROM PALEOGEODESY AND GEODESY

Kerry Sieh • California Institute of Technology

Rupture of most of the Sunda megathrust north of the Equator produced the tsunamis and great earthquakes of December 2004 and March 2005. Rupture of about 600 km of the megathrust south of the Equator resulted in the tsunamis and great earthquakes of 1797, 1833 and the 16th century. Paleogeodetic and geodetic measurements constrain the source parameters of these events. They also delimit the locked and unlocked regions of the megathrust. These data paint an interesting picture of segmentation and long-term behavior of the Sumatran plate margin. South of the Equator the locked patches are well along in their cycle of strain accumulation; recurrence characteristics are well enough established to show that the next great earthquakes there are likely to be no more than a few decades away.

THE SAN FERNANDO VALLEY HIGH SEISMOGRAPH PROJECT

Gerry Simila • California State University, Northridge

Following the 1994 Northridge earthquake, the Los Angeles Physics Teachers Alliance Group (LAPTAG) began recording aftershock data using the Geosense PS-1 (now the Kinemetrics Earthscope) PC-based seismograph. Data were utilized by students from the schools in lesson plans and mini-research projects. Over the past year, several new geology and physical science teachers are now using the AS-1 seismograph to record local and teleseismic earthquakes. This project is also coordinating with the Los Angeles Unified School District (LAUSD) high school teachers involved in the American Geological Institute's EARTHCOMM curriculum. The seismograph data are being incorporated with the course materials and are emphasizing the California Science Content Standards (CSCS). The network schools and seismograms from earthquakes in southern California region (2003 San Simeon, 2004 Parkfield) and worldwide events (e.g. Alaska 2002; Sumatra 2004,2005) are presented. In addition, CSUN's California Science Project (CSP) and Improving Teacher Quality Project (ITQ) conduct in-service teacher (6-12) earthquake workshops.

EVALUATION AND IMPACT OF IRIS/USGS MUSEUM DISPLAYS

Meagan Smith • University of Toronto

John Taber, Michael Hubenthal • IRIS Consortium

IRIS data has had an important impact on the public understanding of geophysics as well as on research advances. One example of this is the IRIS/USGS museum display program, where 16 million museum visitors per year can view near-real-time earthquake locations and ground motions. An evaluation of displays at the American Museum of Natural History in New York City (AMNH) and the Smithsonian Institution National Museum of Natural History in Washington, DC (NMNH) was conducted in the summer of 2004 to assess the display's ability to increase the public's understanding of seismology and to determine how the displays might be improved. The evaluation involved tracking and timing museum visitors to see what attracted them and what held their attention. The tracking and timing was conducted within a single gallery in both museums. Visitors were also interviewed in order to learn what they liked and disliked about the display, and to assess what they learned about seismology.

The results show that the IRIS/USGS display was the top attraction in both the AMNH and NMNH galleries (in terms of the percentage of visitors that stopped at the exhibit). It was also first at both galleries for cumulative visitor stop time (the sum of the time spent by all visitors) and in the total number of visitors counted in front of the display during random sweeps of the gallery.

In both galleries, visitors were attracted to the display most often by the map on a large plasma monitor that shows the last 2 weeks of seismicity with alternating views of the of the world and the continental US. Smaller numbers of visitors were attracted by the triple-drum recorder. When asked what they liked about the display, the greatest number of visitors (31\% at each museum) replied that they liked that it is real-time/up to date. Visitors also liked the map of recent earthquakes, the list of earthquakes on the small monitor and the triple drum. A large majority of the visitors were interested to know that similar information is available on-line. When asked what they found most interesting or surprising, the frequency of earthquakes was listed most often at both the AMNH (49\%) and NMNH (54\%). While the majority of visitors understood that the triple-drums display real-time information, they were less clear about what was being presented, with only 38\% (NMNH) and 16\% (AMNH) understanding that each drum can record earthquakes from all over the world. Small additions of contextual information could greatly increase visitor understanding of this part of the exhibit.

The evaluation shows that the general public is interested in presentations of real-time earthquake activity that combine state-of-the-art plasma monitors and traditional mechanical displays. Interview responses show that the displays are successfully conveying the message of an active planet that is continually in motion.

LAND STREAMER AIDED DIVING WAVE TOMOGRAPHY AND THREE-DIMENSIONAL SEISMIC REFLECTION SURVEYS

Marvin A. Speece, Trevor M. Dolena, Curtis A. Link, Carlyle R. Miller • Montana Tech, University of Montana

We used land streamers to rapidly collect both two-dimensional and three-dimensional shallow seismic data. Our land streamers consist of a main cable with a central stress member surrounded by insulated conductors. Twenty-four gimbaled geophones are connected to the streamers at fixed take-out lengths of 1 m. The streamers use vertical component type SM-7 gimbaled geophones manufactured by Input/Output Inc. The geophone elements have a natural frequency of 30 Hz and are enclosed in oil-filled cylindrical metal casings. The streamers allow us to quickly collect first break data that are then used to construct diving wave tomograms. These velocity tomograms were used to evaluate archaeological sites and look for tunnels. To test our system, we collected seismic data at a site at Saqqarra, Egypt, near Djozer's Step Pyramid where we anticipated strong, lateral variation of seismic velocities due to the presence of subsurface archaeological features. Here we obtained velocity images of what we suspect is a large manmade feature in the subsurface. Furthermore, we successfully imaged a vertical mineshaft in Butte, Montana, using this same technique. In addition, we built a system to collect three-dimensional seismic data by using a vehicle to tow four parallel land streamers. We tested this system near Belt, Montana, using the reflection method to help locate abandoned subsurface coalmines. For this survey, our receiver, receiver line, source, and source line spacings were all 1 m. In total, we covered a surface area of 100 m by 34 m and achieved a nominal fold of 24. Typical combined advance and occupation times for each station were less than 30 seconds using a crew of three people. A stack clearly shows horizontal layering of the local geology.

THREE DIMENSINAL RAY TRACING FOR ANISOTROPIC INNER CORE

Xiaodong Song • University of Illinois at Urbana-Champaign

Seismological studies have generally suggest that the Earth's inner core is anisotropic and the anisotropic structure change significantly both laterally and with depth. Previouse body-wave studies of the inner core have relied on 1-D ray tracing or waveform modeling, which do not account fully the 3D anisotropic structure. Here we adopt a pseudo-bending ray (PBR) tracing method in spherical coordinates(Koketsu and Sekine,1998) for seismic rays that traverse the inner core(PKP-DF phase). The method iteratively perurbs each segment of the ray through 3D(but isotropic) earth structure so that its travel time is minimum. Our rays satisfy Snell's Law in spherical coordinates across seismic discontinuities. Our implementation includes a flexible scheme in calculating the velocity gradient needed to perturb the ray. A large volume is included in calculating the velocity gradient initially to find the global minimum. But a small volume sourounding the ray is used eventually to obtain the precise local velocity gradient that is sampled by the ray.

Tests show that our implementation is very stable, reliable, and fast. We have traced the rays for over 3000 event-station pairs that we have differential PKP travel-time measurements using both the PBR method and a shooting method for a 1D model (AK135). The travel-time difference from the two methods is generally within 0.05 s with a few up to 0.07 s and the largest path difference is within 24 km.

We will implement the PBR method to invert for 3D anisotropic structure of the inner core using differential PKP times. Because the ray direction in the inner core does not change much(within 10 degrees even with a strong velocity gradient in the inner core), the 3D anisotropic structure of the inner core can be approximated to the first order as 3D heterogeneous (but isotropic) structure for a given ray, assuming the inner core anisotropy is axisymetric.

LITHOSPHERIC STRUCTURE OF THE ARABIAN PENINSULA FROM JOINT INVERSION OF TELESEISMIC RECEIVER FUNCTIONS AND SURFACE WAVES

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With a goal of improving structural estimates of the Eurasian lithosphere, Lawrence Livermore National Laboratory (LLNL) has collaborative projects with a number of institutions in the Middle East. LLNL deployed broadband instruments in Jordan (HITJC1, RUWJC1) and the UAE (MEZE, HALE). The data from Kuwait and Saudi Arabia are from national seismic networks. This has given us a unique opportunity to study Earth's structure below these regions. Traditionally, travel time or waveform seismic tomography is used to reveal fine details of Earth's structure. One of the widely used types of measurements to study lithospheric Earth's structure is surface-wave group velocity dispersion,from which 3-D variations in seismic velocities could be obtained. Pasyanos et al. (2001) studied tens of thousands of paths in Eurasia and Africa, and achieved an excellent coveragein the Middle East. Surface-wave group velocity dispersion can reveal important information about average velocity structure of well-sampled regions. However, it has been shown that when combined with teleseismic receiver function data, a greater level of detail can be obtained about velocity contrasts. In this study we use a combination of grid search and iterative inversion scheme to fit jointly the surface wave dispersion (from 7 to 100 seconds for Rayleigh and 20 to 70 seconds for Love waves) and the receiver functions for the broadband stations installed on the Arabian Peninsula. For the grid search we use a database of pre-calculated theoretical receiver functions and dispersion curves, which allows us to significantly reduce the computing time and investigate wide range of structural models. We initially fit receiver functions and shorter periods of the observed dispersion curves with the structure within the crust and immediately under the crust. We then use an additional grid search to characterize the lithospheric lid and low velocity zone in the upper mantle, fitting longer periods of the dispersion curves. Results for several stations located in the Arabian Shield confirm crust thinning near the Red Sea and thickening towards the Arabian interior, which is consistent with previous studies. However our results indicate the presence of anisotropy in the lithospheric upper mantle, even further away from the Red Sea than previously reported. Without invoking anisotropy, it is not possible to jointly explain the observed receiver functions and surface wave dispersion curves.

DISCOVERY OF STRONG UPPER MANTLE REFLECTORS FROM BACK-SCATTERING OF NEAR-PODAL PKPPKP WAVES USING DATA ACQUIRED FROM IRIS

Hrvoje Tkalcic, Megan P. Flanagan • Lawrence Livermore National Laboratory

Vernon Cormier • University of Connecticut

PKPPKP waves travel from a hypocenter through Earth's core, reflect from the free surface and travel back through the core to a recording station on the surface. Precursors to PKPPKP waves were reported first by Gutenberg (e.g. Gutenberg, 1960) as small-amplitude arrivals on seismograms. Most prominent of these arrivals were first explained by Adams (1968) and Engdahl and Flinn (1969). They were interpreted as PKPPKP waves that did not reach the opposite Earth's surface but were reflected underside from unknown discontinuities in the upper mantle. Since then, many other examples of similar observations of PKPPKP precursors were reported, indicating that the upper mantle was not uniformly smooth, but quite heterogeneous medium. As the amount of evidence was growing, 410- and 660-km discontinuities were gradually accepted as global features of Earth's interior. However, a scattering hypothesis (e.g. work by Cleary, 1981) threw a considerable doubt on underside reflection hypothesis and established a powerful alternative explanation for many observations. Thus, PKPPKP precursors corresponding to inconsistently observed, less-prominent features at, for instance 220 km and other depths in the mantle, were often disputed. A common denominator of these early observations, however, was that they were assembled at epicentral distances of about 50-70 degrees, corresponding to maximum in the expected amplitudes due to PKP triplication.

Here, we report unprecedented observations at near-podal epicentral distances of very clear and energetic PKPPKP precursor arrivals. This is a result of a systematic and thorough search over waveforms available through the IRIS acquisition system, for both individual and array records (Tkalcic and Flanagan, 2004). For an event located in the southearn Alaska, about 7 degrees away from ILAR network, the main and precursor arrivals of energy at 0.2-1.0 Hz are visible at all ILAR stations. For the same event, at 1.0-1.5 Hz, the energy of the main phase is below noise level, but sharp onsets of the precursors are persitent. We interpret these precursors as back scattering from upper mantle reflectors. The earliest individual packet of energy corresponds to the underside reflection from about 220 km depth, and the latest one corresponds to the reflection from about 150 km depth in the mantle. Forward-scattered PKPPKP waves at such short epicentral distances would in fact produce postcursor arrivals to PKPPKP. We explain high-energy content of the precursor versus the main arrivals by a difference in attenuation experienced by additional two legs that the main PKPPKP phase spends in the antipodal lithosphere.

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MANTLE TRANSITION ZONE BENEATH TIBET: CONSTRAINTS FROM PROFILES OF TRIPLICATE SEISMIC WAVEFORMS

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Tibet, the world's largest and highest plateau, is a key for understanding how the entire continental lithosphere responds to active collision. Many studies in the past 30 years focused on the intriguing double-thickness of Tibetan crust. However, equally important is the role of mantle lithosphere during continent collision, as density differences in the mantle ultimately drives tectonism. Nearly all tectonic models of Tibet invoke removal and sinking of the mantle lithosphere (of either India or Eurasia), including processes such as delamination, subduction, or convective instability. Dense, removed mantle lithosphere would have continued its descent and probably rests somewhere near the transition zone of the mantle where significant increases in density occur across major seismic discontinuities near depths of 410 and 660 km.

We construct a sequence of seismic profiles that sample the mantle beneath Tibet by combining broadband data from several permanent and temporary seismic arrays. Over apertures of more than 1,000 km, the profiles comprise of triplicate waveforms that are particularly sensitive to anomalies near the mantle transition zone from depths 250 to 700 km. We determine seismic properties using absolute and relative timing of arrivals, and amplitudes of triplicate waveforms. Our preliminary results for central Tibet show several important features of P-wave speeds (Vp): 1) The gradient is low in the deep part of the upper mantle; 2) The 410-km discontinuity is sizable (3.5-4.5% contrast in VP), and 3) A surprisingly small contrast in Vp across the 660-km discontinuity (3.0-4.2%), with moderately high gradient in the transition zone and some reduction in VP in the uppermost lower mantle.

EARTHSCOPE: A NATIONAL UNDERTAKING OF UNPRECEDENTED SCALE AND SCIENTIFIC AMBITION

Gregory E. van der Vink • EarthScope

In solid Earth science, EarthScope is an unprecedented undertaking, both in its interdisciplinary approach to Geoscience and in its scope. With approximately $200 million in funding from the National Science Foundation's MREFC account, EarthScope will develop a comprehensive systems approach to understanding the tectonics of the North American continent at all scales ñ from the active nucleation zone of earthquakes, to individual faults and volcanoes, to the deformation along the plate boundary, and to the structure of the continent. Once complete, EarthScope is anticipated by NSF to be operating for an additional 15 years.

The North American continent is an ideal location for EarthScope, as no place else offers such an accessible set of active geological processes. Available for observation is the full spectrum of plate boundary processes, ranging from plate convergence in the subduction zones of Cascadia and the Aleutians, to transform faulting along the San Andreas Fault, and intraplate extension of the Basin and Range. EarthScope is collecting data sets that will allow us to study the transition from plate-scale tectonic interactions to small-scale system level processes, and how they interact. EarthScope is ideally suited to link traditional near-surface geology with deeper structure.

North America also provides a 3.5 billion year record of plate evolution and the assembly and break-up of a supercontinent, a process that occurred twice over the past 1.5 billion years. The resulting linear orogenic belts associated with supercontinent development reflect opening geometry transform faults, incorporation of island arcs and stray continental blocks in the ephemeral oceans, and the geometry of closing cratons.

From a data collection perspective, EarthScope is being implemented through the parallel construction of multiple observational systems. A four-kilometer deep observatory (SAFOD) bored directly into the San Andreas fault at Parkfield is providing the first opportunity to observe and monitor directly the conditions under which earthquakes occur and to collect fault rocks and fluids form the earthquake zone for laboratory study. A network of continuously recording GPS receivers, borehole strainmeters, and borehole seismic stations (PBO) is being installed along the western plate boundary. A network of seismographic stations and magnetotelluric instruments (USArray) is being deployed to migrate across the United States, eventually occupying 2,000 sites over the next ten years. Additional seismic and geodetic instrumentation are available to individual PIs for high-resolution imaging in areas of special geologic interest. A key task for EarthScope is to provide seamless, single-point access to all EarthScope data so that the community may develop higher order data products, tools, visualizations systems, and portals.

Fulfilling the scientific promise identified by the Nation Science Board requires not only the construction of EarthScope, but also a comprehensive plan for its long-term operation that will continue to include a high level of management oversight and accountability. At the request of NSF, EarthScope developed a detailed Operations and Maintenance Proposal with an exhaustive budget analysis that projects costs through 2011. The proposal, which is openly available on the EarthScope website or directly from the EarthScope Office, is undergoing a rigorous vetting process that includes the scientific community, NSF internal review, an independent cost review, and, finally, approval by the National Science Board.

The long-term funding requirements for EarthScope operations and maintenance are modest in terms of the overall capitalizations costs (approximately 20%/year), but are significant in terms of the R&RA Account of divisions with small budgets such as EAR. Certainly, EarthScope can not achieve its goals if funding for its operation comes at the expense of the scientific and educational communities that it is intended to serve. At the same time, identifying additional funding within NSF's current budget environment will require decisions at the uppermost levels of the Foundation.

EarthScope is committed to working with NSF through every part of this process: refining costs and management procedures through extensive reviews; maintaining transparency in schedules, costs, and progress; inviting continued community input and review; and working to identify possible methods for funding structures. Through this process and the continued support of the Geoscience community, we expect to secure sustainable funding for EarthScope, and to help set a positive precedent for the support of large facilities and the scientific and educational activities associated with them. EarthScope will be a positive model for the balance between individual research grants and the community data collection enterprises necessary to support the next generation of scientists, educators, and students.

EDUCATION AND OUTREACH OPPORTUNITIES AT WAUBONSEE COMMUNITY COLLEGE, A NEW IRIS EDUCATIONAL AFFILIATE

David H. Voorhees • Waubonsee Community College

As a new member of IRIS, Waubonsee Community College (WCC) will be able to significantly enhance its earthquake and seismologic education and outreach activities. WCC is a two-year public community college southwest of Chicago, IL serving residents in 5 counties in northeast Illinois that is experiencing tremendous growth and expansion. The enrollment in the earth science classes at WCC has seen an increase of 320% since 1991. We are now starting a major expansion of our three campuses to meet the rapidly increasing enrollment with the construction of a 55,000 square foot science building, which will house the Earth Science, Geology, Geography, Astronomy, Chemistry and Biology departments. It is anticipated that the first classes will be held in the new building in the Fall 2006 semester. The presence of the AS-1 seismograph in the main hallway of our new science building can very effectively increase the understanding of seismology to the diverse Waubonsee students and community using ëteachable moments', such as the recent Andaman Island (26 Dec 2004, M9.0) and Ottawa, IL (28 June 2004, M4.2) events. As an IRIS EA, WCC will become a place to which students and the community can refer when similar significant seismic events occur in the future, both globally and locally. Clear and accurate communication of the significance of these events are important, given our proximity to, and perceived danger from, the New Madrid Seismic Zone, which is approximately 550 km to the south of Waubonsee.

Additionally, the incorporation of real-time seismic data into classroom and lab exercises, using a guided-inquiry approach, will improve the quality of earth and geoscience education at WCC. The use of real time data acquired ëlocally' will be significantly more meaningful and have a greater impact than the use of canned and static exercises now available in laboratory manuals or the internet (i.e., www.sciencecourseware.com/VirtualEarthquake/). Exposure and active engagement in the scientific method by the wide range of our students, mostly non-science majors, can potentially initiate an interest great enough to pursue further or graduate-level study in the earth sciences or seismology. Active engagement in the scientific method will improve the background of pre-service middle and high school earth science teachers as part of our planned Associates of Arts in Teaching of Secondary Science, which is critical to successfully influence the integrity of science education and foster future earth scientists.

Finally, Waubonsee maintains an active non-credit program, which reached 3,600 residents in 2004, through which IRIS based programs could be scheduled. Examples might include seminars given by seismologists from neighboring Member Institutions, such as Northern Illinois University, or other IRIS personnel. Finally, as an IRIS EA, Waubonsee will be able to provide a resource for seismological and earth science education to surrounding K-12 schools and teachers.

TOWARD THE RAPID IMAGING OF LARGE EARTHQUAKE RUPTURE ZONES

Kris Walker, Peter Shearer, Paul Earle, Miaki Ishii • University of California, San Diego

One bottleneck in estimating ground shaking associated with large global earthquakes is the determination of the rupture zone geometry and length. Outlining the locations of the first several hours of aftershocks is currently perhaps the fastest and most robust method to constrain ruptures in sparsely instrumented regions. However, the first few hours after a major earthquake are critical for assessing tsunami risk and mobilizing emergency response teams. To more quickly provide estimates of rupture extent, we introduce a direct reverse-time migration technique that back projects to the source the first arriving P-wave energy recorded by the global GSN network. We account for 3D velocity structure and polarity flips by cross-correlating the initial P wave using a time-varying amplitude normalization. This aligns the waveforms on the first arrival, which we assume only originates from the hypocenter. We test this method on three large earthquakes: M_w 7.8 14 November 2001, Kokoxili, Tibet; M_w 7.8 3 November 2002, Denali; and M_w 8.7 28 March 2005, Sumatra. Our method unambiguously illuminates the surface projection of the rupture zone. In addition, the spatial distribution of seismic moment, source-time function, and rupture propagation direction estimated from other methods are roughly comparable to those we estimate from our images.

Our most recent images of the Sumatra 8.7 earthquake suggest that the rupture is bilateral, but mostly propagates toward the southeast where the seismic radiation reaches a maximum beneath the island of Nias. Images obtained using the broadband GSN network are similar to those generated with the short-period Japanese HiNet network. Guided by the distribution of aftershocks, our images suggest a rupture area of 65,000-85,000 km2, which is generally consistent with a M_w 8.7 earthquake. Assuming a simple amplitude to moment scaling relationship, we convert our spatial distribution of back projected energy into slip. Although this slip distribution predicts a region of positive static Coulomb failure stress change at 15 km depth that correlates with the majority of aftershocks located in the region, this relationship is not well established since the distribution of seismic moment along the fault depends on several factors and the aftershock depths we have been using are not accurately determined.

GPS INSTALLATION PROGRESS IN THE SOUTHERN CALIFORNIA REGION OF THE PLATE BOUNDARY OBSERVATORY

Walls, C., Arnitz, E., Bick, S., Lawrence, S., • Plate Boundary Observatory, UNAVCO

One of the roles the Plate Boundary Observatory (PBO), part of the larger NSF-funded EarthScope project, is the rapid deployment of permanent GPS units following large earthquakes to capture postseismic transients and the longer-term viscoelastic-response to an earthquake. Beginning the day of the September 28th, 2004, Parkfield earthquake, the PBO Transform Site Selection Working Group elevated the priority of two pre-planned GPS stations (P539 and P532) that lie to the south of the earthquake epicenter, allowing for reconnaissance and installation procedures to begin ahead of schedule. Reconnaissance for five sites in both the Southern and Northern California offices began the day following the earthquake and two permits were secured within three days of the earthquake. Materials and equipment for construction were brought along with the response team and within 4 days the first monument (P539) was installed.

Of the 875 total PBO GPS stations, 230 proposed sites are distributed throughout the Southern California region. These stations will be installed over the next 4 years in priority areas recommended by the PBO Transform, Extension and Magmatic working groups. Volunteers from the California Spatial Reference Center and others within the survey community have aided in the siting and permitting process. Currently the production status is: 33 stations built (17 short braced monuments, 16 deep drilled braced monuments), 42 permits signed, 63 permits submitted and 98 station reconnaissance reports. To date, Year 1 and 2 production goals have been met.

GEOMETRY AND P- AND S- VELOCITY STRUCTURES OF THE “AFRICAN ANOMALY”

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Seismic evidence shows that the “African anomaly”, a prominent low-velocity anomaly in the lower mantle beneath southern Africa, has a very-low velocity province (VLVP) in the lowermost 200 - 300 km of the Earth’s mantle with rapidly varying geometries and a strong S-velocity reduction gradient from -2% (top) to ñ9% - -12% (bottom). It is now clear that the VLVP is compositionally distinct and can be best explained by partial melting driven by a compositional change produced in the early Earth’s history (Wen, 2001; Wen et. al, 2001). However, the nature of the anomaly in the lower mantle remains unknown and controversial. Here, we investigate its geometry, and both P- and S- velocity perturbations along a specific great arc from the East Pacific Rise to the Japan sea.

The southwestern side of the anomaly is sampled by direct S, ScS, and SKS waves from earthquakes occurring in the South Sandwich islands, Drake Passage, and the East Pacific Rise. Direct S waves from the South Sandwich islands earthquakes exhibit no travel time delay with respect to the preliminary reference Earth model (PREM) from 44 degree to 68 degree across the Kaapvaal array, but they are increasingly delayed from 0 s at 68 degree to about 3 s at 74 degree across the Tanzania array and from 4 s at 75 degree to 8 s at 89 degree across the Kenya array. The ScS residuals have a simple trend increasing from 3 s at 44 degree to 12 s at 74 degree. The SKS waves for earthquakes occurring in the East Pacific Rise show a uniform delay of about 1 - 2 s before 100 degree, steeply increasing to a uniform delay of 6.5 s after 107 degree. These observations indicate that the ìAfrican anomalyî extends about 1300 km above the core-mantle boundary (CMB) with its southwestern edge dipping towards its center and its basal layer near the CMB extends further southwest. The northeastern side of the anomaly is constrained by the direct S and ScS waves from three events in the Hindu Kush region, the SKS waves from an earthquake in the Drake Passage, and the SKS and SKKS waves from an earthquake in the Japan sea. Both S and ScS waves from earthquakes occurring in the Hindu Kush region do not show travel time delays with respect to PREM, placing bounds on the geographic extent of the anomaly on the northeastern side. The SKS residuals of the Drake Passage earthquake shows a decreasing trend from 5 s at 87 degree to about 2 s at 94 degree. The SKKS wave from an earthquake in the Japan sea is only delayed after 140 degree whereas the SKS residuals are about 2.5 ñ 4.5 s between 129 degree and 140 degree. These observations suggest that, on the northeastern side, the anomaly also dips toward its center beneath southern Africa. Therefore, the ìAfrican anomalyî exhibits a ìcusp-likeî geometry in the lower mantle.

The magnitudes of these travel time residuals can be best explained by a shear velocity structure, with average reductions of ñ5% for the basal layer and ñ2% - -3% for the portion in the lower mantle. With the “cusp-like” geometry, the P-wave velocity structure is constrained by the travel time of direct P, PcP and their differentials from the same events. P-wave data provide good sampling coverage for both the basal layer and the portion in the lower mantle. We test a series of P velocity models with uniform S to P velocity perturbation ratios from 1:1 to 7:1. We find that a ratio of 3:1 best explains the P wave data. The geometry and the S to P velocity perturbation ratio of the anomaly indicate that the “African anomaly” in the lower mantle likely, like the VLVP at its base, is compositionally distinct.

MEASUREMENT OF DIFFERENTIAL RUPTURE DURATIONS AS CONSTRAINTS ON SOURCE FINITENESS OF DEEP-FOCUS EARTHQUAKES

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The focal mechanism of an earthquake identifies two possible fault planes, and our goal is to distinguish the true fault plane using observations of source finiteness. Source finiteness is observable on seismograms at different azimuths and distances, for single-event ruptures, as variations in the apparent rupture duration and, for complex ruptures, as differences in the travel-time delay between subevents. For each earthquake, the rupture duration (or travel-time delay) will be shortest in the direction of rupture propagation and longest in the opposite direction. Rather than measuring the actual rupture duration at each station, we use a cross-correlation technique that includes a stretching factor to measure the differential rupture duration between each pair of stations. These differential measurements then allow us to identify the rupture direction, rupture velocity, and fault plane for each earthquake. First we test the method on two synthetic earthquakes, which represent earthquakes composed of one and two events. The method works well for both examples, although attenuation can bias the determined rupture direction for the single-event case. We also narrow the analysis to deep-focus earthquakes because the P-wave arrival is distinct from the depth phases. To validate this method, we analyze three deep-focus earthquakes composed of two subevents: the 23 January 1997 Bolivian earthquake (M_w 7.1, 276 km depth), the 27 October 1994 earthquake south of the Fiji Islands (M_w 6.7, 549 km depth), and the 21 July 1994 Japan Sea earthquake (M_w 7.3, 471 km depth). Each focal mechanism contains a subvertical and a subhorizontal nodal plane. For all three events, our analysis shows that rupture propagated subhorizontally and we can identify the subhorizontal nodal plane as the fault plane. Rupture velocities vary from 0.18 to 0.55 of the local P-wave velocity.

WEB-BASED, REAL-TIME DATA FOR MUSEUMS AND VISITOR CENTERS

Russ Welti, John Taber • IRIS Consortium

Rick Aster • New Mexico Tech

The Museum Lite display is a newly developed, simple to implement, and low cost way to provide high-quality, real-time seismology and other information to a wide audience. It can be easily customized for regional and local audiences in numerous ways. The project evolved out of the online Seismic Monitor and the successful IRIS/USGS large-scale earthquake displays in use in major museums around the US. The museum display is too expensive and takes too much maintenance to be practical for small museums, schools, visitor centers, etc. The Seismic Monitor allows for interactive or preset use for such venues, and its capabilities are very flexible.

Museum Lite provides a customizable set of web pages that can be viewed either via an interactive touch screen or an automatically cycling display. An individual venue will be able to select from a menu that currently includes:

1 maps of current seismicity at various scales (global, regional, local) with touch-screen capability to get information on individual earthquakes,

2 online helicorder displays of nearby seismic (e.g., USArray) stations,

3 static maps of long-term seismicity and seismic hazard,

4 other local information or graphics as desired by the client.

These choices will be expanded to include a range of EarthScope data products.

The full museum display requires a dedicated staff and costly hardware. A number of good web sites exist supplying a variety of pertinent information, but none are customizable and as easy to use (Museum Lite requires only a networked computer running a browser). There is a high level of interest in an engaging real-time dynamic seismology display. For example, the recent evaluation of the IRIS museum display carried out by the IRIS E&O program highlighted broad public fascination with real-time earthquake monitoring information.

Versions of Museum Lite have been installed so far at the Sunset Crater Volcano National Monument Visitor's Center and the Bruce Museum in Greenwich CT (as part of a Women in Science exhibit that features Inge Lehman). A short-term exhibit was also developed for the Pacific Science Center in Seattle. Museum Lite has the potential to provide significant education and outreach for EarthScope because it can be easily customized for each region. For example, it can be offered to communities before USArray deployments to promote Earthscope, then can highlight data from instruments once they are installed, and can remain after USArray departs to show how data from each region is part of the continental scale experiment.

REGIONAL VARIATIONS OF SEISMIC ANISOTROPY IN THE TOP 80 KM OF THE EARTH'S INNER CORE

Lianxing Wen, Wen-Che Yu • State University of New York, Stony Brook

Seismic anisotropic velocity structure plays an important role in understanding the geodynamics and mineral physics in the Earth's inner core. Previous seismic studies using the PKiKP-PKIKP phase pairs have suggested that no evidence for the presence of anisotropy in velocity in the top 80 km of the inner core. However, the sampling coverage of the PKiKP-PKIKP phase pairs in previous studies was limited, especially along the polar paths. Here we expand our PKiKP-PKIKP dataset by collecting a vast number of PKiKP-PKIKP differential travel times and waveforms sampling the top 80 km of the inner core globally and along various sampling directions. Our data are selected from the Global Seismographic Network for the time period of 1990-1998 and many regional seismic networks: Broadband Andean Joint Experiment (BANJO), Seismic Exploration Deep Andean (SEDA), Brazilian Lithosphere Seismic Project (BLSP), FREESIA, Canadian National Seismic Network (CNCN), Kazakhstan, Krygyz, Oceanographic Hemisphere Project (OHP), and a temporary seismic experiment in Antarctica. Our seismic observations show that there is indeed no evidence for the difference in PKiKP-PKIKP differential travel time between the polar and equatorial paths in most regions of the inner core and suggest no anisotropy in velocity in the top 80 km of the inner core in most regions. Our expanded PKiKP-PKIKP phases, however, reveal a localized region in the western hemisphere beneath Africa, where a clear polar-equatorial difference in differential travel time is observed, with those PKIKP phases propagating along the polar paths arriving about 0.7 ñ 1.2 s earlier than those traveling along the equatorial paths. This polar-equatorial difference can be explained by a localized anisotropy in velocity in the top 80 km of the inner core, with the velocity in the polar paths being about 1.3%-1.8% higher than that along the equatorial paths. The absence of anisotropy in velocity in most regions and the presence of anisotropy in a localized region in the top of the inner core may shed light on the dynamics of the inner core and possible mechanisms on the inner core formation.

TIME-DEPENDENT PROBABILISTIC SEISMIC HAZARD MAPS FOR ALASKA

Rob Wesson, Oliver Boyd, Chuck Bufe, Chuck Mueller, Art Frankel, Mark Petersen • U.S. Geological Survey

We are currently revising the probabilistic seismic hazard maps of Alaska and the Aleutians. In addition to preparing time-independent hazard maps, we are also preparing experimental maps including time-dependent earthquake probability estimates. We are investigating various methods to implement time-dependent probability density functions including log-normal and Brownian Passage Time. These methods depend on knowing the time of the last earthquake, knowledge of the earthquake recurrence interval and its variability, and the assumption that the last earthquake reset the slip deficit. We are actively investigating the applicability of these assumptions to the Alaska/Aleutian region as well as the sensitivity to default assumptions. We are also investigating the significance of both elastic and viscoelastic stress transfer on source and target faults as a means for influencing the time-dependent probabilities. We find that time-dependent probabilities can lead to significant reductions in probability on some faults while increasing others by more than a factor of two. This can dramatically change the resulting seismic hazard maps relative to time-independent seismic hazard maps. Elastic stress transfer can have a large but relatively short lived effect on the probabilities while time-dependent phenomena such as post-seismic afterslip and viscoelastic deformation can have larger and more long-lasting effect on earthquake probabilities.

IRIS SABBATICAL IN SEISMOLOGY: A COLLABORATION TO ASSESS DIFFUSE PLATE BOUNDARY CHARACTERISTICS

Laura Reiser Wetzel • Eckerd College

Cliff Frohlich • University of Texas

Sabbaticals in Seismology is a new IRIS Education and Outreach initiative to promote high-quality geophysics instruction and research opportunities for undergraduates. The program supports collaborative geophysical research efforts involving faculty at IRIS member institutions and Educational Affiliates.

As the inaugural participants of Sabbaticals in Seismology, we have collaborated on research, designed and implemented projects for undergraduates, and proposed plans for future joint studies. Unlike a traditional sabbatical whereby a faculty member spends an extended period of time at a host institution, collaboration involved five short visits by Wetzel to the University of Texas Institute for Geophysics. One Eckerd College undergraduate is working with us for the summer of 2005. She will submit an abstract and attend the fall American Geophysical Union annual meeting. The Sabbaticals in Seismology program provided travel funds while Eckerd College paid for Wetzel's salary during the sabbatical and the student's summer stipend. IRIS Education and Outreach staff introduced us; we had not met prior to the start of the sabbatical in January of 2005.

The projects we have developed thus far require earthquake catalogs that are freely available and software for a Unix workstation. All research, therefore, is accessible for undergraduate use in small class assignments or extensive independent projects. Students who are involved in such activities will be better prepared for graduate school and more likely to pursue careers in earth science. Faculty who participate in future Sabbaticals in Seismology will have an opportunity for professional development to inform their teaching and improve their research skills.

In one collaborative project, we are investigating diffuse plate boundary seismicity and triple junction stability. A diffuse plate boundary is a broad zone of deformation between two rigid plates that move independently. In contrast to traditional narrow plate boundaries, diffuse plate boundaries are hundreds to thousands of kilometers wide. For example, diffuse plate boundaries exist between the North American and South American plates, the Nubian and Somalian plates, the Indian and Australian plates, and the Eurasian and North American plates.

In each of these cases, the velocities across the boundary are slow (less than 4 cm/yr) because the pole of rotation for the plate pair is located within or near the diffuse plate boundary. This geometry causes extension on one side and compression on the other side of the pole. Earthquake distributions and focal mechanisms confirm this observation.

Stability of diffuse triple junctions can be assessed by modifying the velocity vector diagram method of McKenzie and Morgan (Nature, 1969). At first glance, the problem of creating velocity vector diagrams for diffuse triple junctions where one diffuse and two narrow plate boundaries meet appears straightforward. For each pair of plates, one draws a vector representing their relative velocity. Then, one constructs a stability line representing all possible vector motions that remain along the plate boundary. If the stability lines for the three plate boundaries meet at a single point, then the triple junction is stable.

At many diffuse plate boundaries, however, the edge of the plate is not clearly defined by a spreading center, trench, or transform; rather, the ongoing deformation is distributed over a broad zone. As a result, a considerable range of vectors will represent motions that remain in this zone. On a velocity vector diagram the stability line becomes a broad zone rather than a single line. At triple junctions with one diffuse boundary, this ìstability zoneî typically encompasses the stability lines of the remaining two plate boundaries where they intersect. This indicates that these triple junctions are stable for a wide range of plate boundary orientations.

EXPLORING ANTARCTICA WITH BROADBAND SEISMOLOGY

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Andrew Nyblade, Sridhar Anandakrishnan, Tim Watson • Penn State University

The geological structure and history of the vast interior region of Antarctica is essentially unknown. Unlike the other continental regions, geological mapping, sampling, and analysis are impossible, and even the basic outline of the tectonic evolution and uplift history of this continent are unconstrained. Yet Antarctica occupies a unique place in Earth's history as both the locus of the initial glaciation as the early Cenozoic climate changed and as the repository, in large ice sheets, of a significant portion of the Earth's water. Broadband seismology represents an efficient ìremote sensingî method for mapping the lithospheric structure of Antarctica and placing constraints on the geologic history of the continent.

The 2000-2003 TAMSEIS PASSCAL experiment demonstrates some of the potential for broadband seismology in Antarctica. This experiment deployed 44 broadband seismic stations extending from the Ross Sea (RS) to the East Antarctic Plateau in order to investigate the lithospheric structure beneath the Trans-Antarctic Mountains (TAM) and East Antarctica (EA). The experiment consisted of three components: 1) A 1400 km linear array of 17 seismic stations extending from the central regions of the East Antarctic craton to the TAM 2) an intersecting 400 km dense linear array of 16 stations extending from the coast across the TAM in the Dry Valleys region. 3) 11 stations in coastal regions within 300 km of Ross Island. Stations were installed using helicopter and twin otter aircraft operating out of McMurdo station and a remote field camp.

Combined receiver function and Rayleigh wave phase velocity inversion, as well as P and S wave tomography constrain models for the development of the TAM. The crustal thickness increases rapidly from 20 ± 2 km in the Ross Sea to 40 ± 2 km beneath the TAM, achieving the maximum thickness immediately beneath the TAM crest. Farther inland, the crust of EA is uniformly 35 ± 3 km thick over a lateral distance greater than 1300 km. The phase velocities and body wave tomography indicate high velocity cratonic upper mantle beneath EA, low velocity beneath WA, and a transition beneath the TAM crest. These results are in agreement with models suggesting that warm buoyant Ross Sea upper mantle extends beneath the edge of the TAM, inducing flexural uplift of the mountains. Both Rayleigh wave phase velocities and SKS splitting results show a large uniform region of azimuthal anisotropy within the uppermost mantle of EA, with fast axes oriented about N55E. The shallow depth of the anisotropy indicated by the surface waves suggest it results from remnant upper mantle lattice preferred orientation from past deformational episodes, rather than the current upper mantle flow pattern. The mapping of upper mantle anisotropic directions offers a possible method for delineating geologic terrains in ice covered East Antarctica.

Antarctic observations from even a short deployment can provide important data for global seismology studies due to the unique geographical location and low seismic noise levels. For example, TAMSEIS observed two near-antipodal Arctic Ridge earthquakes (M_w 5.1-5.2), which uniquely sampled the inner core with a north-south traveling PKPdf phases at distances between 169∞ to 176∞. PKPdf-ab anomalies range from -3.9 to -6.4 s and show a stronger correlation with df anomalies rather than ab anomalies, suggesting that the signal largely accumulated along the df path. The PKPdf-ab anomalies show a decrease in magnitude at distances of 174∞-176∞, consistent with other recent results showing an innermost inner core with different anisotropic characteristics than the rest of the inner core.

C-GPS AT REMOTE ANTARCTIC SITES: TAMDEF NETWORK EXPERIENCE.

Mike Willis, Terry Wilson • Ohio State University

Graeme Blick • Land Information New Zealand

Larry Hothem • U.S. Geological Survey

The TransAntrarctic Mountains DEFormation project (TAMDEF), which is run by Ohio State University in collaboration with the US Geological Survey and Land Information New Zealand, has installed six continuously running remote GPS (CGPS) stations on bedrock around Victoria Land in Antarctica.

The station design philosophy has been to use off-the-shelf, low power components, many of which have been tried and tested by Antarctic support contractors for communications applications. Our receivers are 40 channel JNS OEM boards that are set to automatically return to logging after any power failures.

The Cape Roberts site was deployed during November of 2000. The site is powered by four 40W solar panels that feed twelve 86 AmpHr batteries through a reliable charge controller. We used several styles of antennae over the first year, and this shows up as jumps within the vertical of the time series. Since 2001, an Ashtech Dorne Margolin choke ring with a SCIGN short radome has been used. This set-up has become the standard for our five other stations. We have collected over 1000 days of continuous data from Cape Roberts, the only major interruption being caused by extreme amounts of drifting snow smothering the solar panels, some five feet off the ground during the austral winter of 2003.

Two sites with an identical design to that at Cape Roberts were built at Mount Fleming and Fishtail Point during the 2001-2002 field season. Each of these sites has provided more than 500 days of data since installation, but each has also experienced GPS receiver malfunctions, where the L2 GPS signal has not been recorded. During the 2004-2005 field season we attempted to install communications at each of these sites with assistance from UNAVCO. Both the radio- and Iridium-modem installations involved some changes to the internal configuration of our systems and proved to be problematic.

Three more sites, widely spread across the network, were installed in 2003-2004. Updated versions of the OEM cards were used. Two of these sites, at Westhaven Nunatak and Franklin Island, worked perfectly and over 300 days of continuous data have been obtained at each. The solar panels at the third site on Lonewolf Nunatak were damaged after six months by an extreme wind event, and the site went dormant after 210 days. A new solar panel frame with a lower profile and reduced wind load area was put at the site in 2004-2005.

Our simple designs and well-specified GPS receivers have worked well in the harsh environment of Antarctica. The motions derived from the CGPS are being used to constrain vertical rates of motion across the region and can also be used for multi-disciplinary science applications.

POLENET: POLAR EARTH OBSERVING NETWORK FOR THE INTERNATIONAL POLAR YEAR

T. Wilson, the POLENET Team

The polar regions have unique geodynamic environments where the solid earth, the cryosphere, the oceans, the atmosphere and the global climate system are intimately linked. An IPY programme is being proposed to investigate systems-scale interactions within the polar earth system and polar geodynamics by deploying autonomous remote observatories, on the continents and possibly offshore. The principal components of these observatories will consist of continuous GPS and seismometers, with the potential addition of meteorology packages, geomagnetic observatories, tide gauges (at coastal sites), and bottom pressure gauges (at offshore sites). Remoteness and environmental challenges have resulted in a dearth of observational systems in the polar regions of Earth, which this programme will overcome.

Geodetic studies, including GPS measurements of crustal motion, tide-gauge measurements of relative sea-level change, and gravity measurements of mass change, constitute essential elements in developing an understanding of the stability and mass balance of the cryosphere and of ongoing sea-level change. There is a critical need to understand the contribution to sea-level change due to changes in mass balance of the major ice sheets of the world, most importantly the Antarctic and Greenland ice sheets. Accurate measurement of millimeter-scale vertical and horizontal crustal motions is possible in only 2-5 years if continuous GPS trackers are deployed. Deployment of C-GPS stations in optimal positions with respect to historical and modern ice mass changes, and at sufficiently high spatial resolution, provides robust constraints on ice models, improving our ability to predict sea-level change. Deployment of C-GPS stations across tectonic blocks and boundaries allows crustal motions due to global plate motion and intraplate neotectonic deformation to be measured and velocity fields to be mapped and modeled.

Seismological data from the observatories will provide the first relatively high-resolution data on the Earth beneath the polar seas and ice sheets. Advanced techniques to image the Earth's deep interior, such as seismic tomography, will be used to place constraints on the planet's internal processes. Seismic imaging of the crust and mantle will assess causes for anomalously high elevations in East Antarctica, linked with ice sheet development, will provide information on heat flow and mantle viscosity that are key factors controlling ice sheet dynamics and the Earth's response to ice mass change, and will provide constraints on the magma sources for polar volcanism. The axial vantage points of the poles will allow unprecedented studies of Earth's inner core, contributing to our understanding of the initial differentiation of the Earth, the Earth's thermal history, and the physics and variability of the Earth's magnetic field. Enhanced seismic station coverage will vastly improve the detection level for earthquakes and permit evaluation of seismotectonic activity and associated seismic hazard across the remote high latitudes. POLENET is coordinated with the AntarcticArray seismological initiative to establish a permanent backbone sensor network, a lattice seismic array at South Pole (CRYSTAL), evolving regional array deployments, process-oriented experiments, and active-source seismology.

PRELIMINARY IMAGES OF COLORADO PLATEAU CRUST AND UPPER MANTLE SEISMIC STRUCTURE

Dave Wilson, the RISTRA research group

We present preliminary images of the crust and upper mantle seismic structure beneath a transect extending from the center of the Colorado Plateau northwest into the Great Basin. We use teleseismic data from the ongoing (summer 2004-summer 2006) RISTRA 1.5 experiment which is a northwest extension of the LA RISTRA passive seismic array deployed from July 1999 to May 2001. By combining these two data sets, we create images of the crust and upper mantle seismic structure that show a complete transect of the Colorado Plateau. Preliminary images show crustal thickness that ranges from approximately 45 km thick in the center of the Colorado Plateau to less than 30 km thick in the Great Basin. Ongoing receiver function and body wave tomography work will facilitate a better understanding of lithospheric deformational styles, processes related to late Cenozoic volcanism, mantle convection, and to address the long-standing question of the mechanism supporting the high CP elevation.

PROBABILISTIC MAGMA CHAMBER BASED ON IMPORTANCE REWEIGHTING AND INSAR OBSERVATIONS

Sang-Ho Yun, Andy Hooper, Paul Segall, Howard Zebker • Stanford University

Simulated annealing inversion with boundary element calculations subject to a uniform pressure boundary condition showed promising results for modeling planar crustal deformation sources that do not have symmetry (Yun et al., JVGR in press). We now adopt Bayesian formulation to produce the posterior probability distribution of the opening of a distributed source. In order to achieve unbiased sampling, we use importance reweighting and Gibbs sampling (Brooks and Frazer, 2005). As a result we are able to produce a map of the probability of opening that provides the information of the uncertainty and the resolution of our model parameters. This probability map is useful for estimating the resolving power of geodetic measurements. Using the distributed source model and the probability map, we can solve for detailed geometry of any planar deformation source such as dikes and sills. These sources can be jointly resolved with other type of deformation source models that use a uniform pressure boundary condition.

BOLIVAR: CRUSTAL STRUCTURE ACROSS THE CARIBBEAN-SOUTH AMERICAN PLATE BOUNDARY AT 67.5∞W

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the BOLIVAR study group

The active-seismic component of the multi-disciplinary NSF Continental Dynamics BOLIVAR project (Broadband Ocean and Land Investigations of Venezuela and the Antilles arc Region) was carried out between April-June, 2004. About 6000 km of marine reflection profiles were collected along with 169 Ocean Bottom Seismometer (OBS) deployments along 5 transects, four ~200 km long offshore-onshore refraction profiles, and seismic recordings on several islands in the Leeward Antilles arc. In addition to the active-seismic studies, other workers on this project in the U.S. and Venezuela are involved in geological, geochemical and passive seismological studies. The main goal of this multidisciplinary investigation is to understand the processes of continental crustal growth that have been taking place along this boundary since the late Cretaceous during the oblique collision between the South American plate and the Caribbean plate.

We present results from one of the 5 main profiles of the experiment, trending approximately N-S at the longitude of 67.5∞W. The ~600 km long profile extends from latitude 8.5∞N to 14.0∞N, crossing from south to north the fold and thrust belt in Venezuela, the E-W trending Oca-Moron-El Pilar Fault strike slip system, the Bonaire basin, the ABC Ridge, the South Caribbean deformed belt and the southern edge of the Venezuela basin. High-quality multi-channel seismic reflection data were acquired along the ~400 km offshore portion of the profile using the R/V Ewing. The Ewing airgun shots were also recorded by 42 OBS's deployed from the R/V Seward Johnson II. In addition, onshore-offshore data were acquired by recording the airgun shots using Reftek Texans at 329 stations extending from the coast to ~200 km inland. Two land shots were also recorded by the land stations to provide reversed coverage of the onland portion of the profile. Along the same transect wide angle seismic data were recorded by 42 Ocean Bottom Seismometers and by 550 Reftex Texans deployed at 329 sites onshore.

The high-quality offshore marine reflection profile documents the complex evolution of the plate boundary starting from the development of the Caribbean Mountain system and the accretion of the volcanic arc on the South American continental margin, and the opening of the Falcon-Bonaire-Grenada basins (~55 Ma). The south-dipping subduction of the Caribbean plate started at 28 Ma and the Moron-El Pilar dextral strike-slip system developed at about 12 Ma, inverting several Paleogene extensional features on the southern edge of the Bonaire-Grenada basin. In the south we have imaged the Moron Fault, a segment of the continental strike-slip system boundary. The geometry of the sediments in the upper portion of the profile suggests modern deformation along the fault. Compressive structures, likely related to the movement along the Moron fault, are also visible in Paleogene sediments ~40 km north of the fault trace. The Bonaire basin is characterized by Paleogene rift structures buried under 6 km of Cenozoic sediments. The platform of the ABC ridge separates the Bonaire basin to the south from the Los Roques basin to the north. This narrow and relatively deep basin filled with ~6 km of sediments is bounded to the north by compressive features of the Cenozoic accretionary wedge of the Southern Caribbean Deformed Belt. The 75 km wide belt has a typical mÈlange seismic signature with the thrust fault geometry difficult to identify. A bottom simulating reflector (BSR) is traceable along the top of the northern portion of this feature. To the north, the accretionary wedge overrides the basement of the Caribbean plate and the sediments of the Venezuelan basin. The subducting plate is visible 25 km south of the frontal thrust of the accretionary prism. The only deep reflectors that we interpret as Moho along this profile are observed at the base of the subducting plate at 10-11.5 s, defining a normal crustal thickness for the oceanic Caribbean plate of ~6.5 km.

The velocity model for the full length of the ~600-km-long profile was obtained using traveltime inversion of the wide-angle data from the OBS, Reftek Texan and land shot recordings. Both first arrivals and PmP (Moho) reflections were inverted for a smooth velocity field with a sharp Moho. The subducting Caribbean plate is clearly imaged along with the thick sediments of the South Caribbean Deformed Belt. The middle and lower crust beneath the ABC Ridge contains relatively high velocities as compared to beneath the Bonaire Basin and further south onshore. The Moho thins from about 27 km under the ABC Ridge to about 24 km under the Bonaire Basin, and thickens rapidly near the coastline to about 40 km. Perhaps the most interesting feature in the model is a zone of relatively high crustal velocity (~6.5 km/s) about 15 km thick and extending to about 15 km depth beneath the major E-W continental strike-slip system, known locally as the Moron Fault.

PN TOMOGRAPHY OF THE CENTRAL AND EASTERN UNITED STATES

Qie Zhang, Eric Sandvol • University of Missouri, Columbia

Pn is a leaky mode guided wave that propagates primarily within the mantle lithosphere and is often used to explore the velocity and azimuthal anisotropy structure of the lithospheric mantle. To map the Pn velocity structure in the Central and Eastern United States (CEUS), we carefully selected approximately 18,000 Pn travel times from the ISC and NEIC catalogs. We supplemented these phase data with 770 hand picked arrivals from both permanent and temporary stations. Overall we have a high density of ray paths within the active seismic zones in the eastern and southern parts of the CEUS and poorer ray coverage in many of the shield portions of the North American plate. To compensate for the relatively small number of ray paths, we chose a 0.5∫x 0.5∫ cell size for our model parameterization. Then using the method of Hearn (1996), we mapped lateral variations in the mantle lid velocity and azimuthal anisotropy.

We have found that the average Pn velocity in the CEUS is approximately 8.0 km/s. Furthermore, there is first order agreement between our Pn tomography model and the NA00 shear wave velocity model (Goes and Van der Lee, 2002). The high Pn velocities within the North American shield are consistent with the high S-wave velocities measured at the 100 km depth. In contrast, low Pn velocities are found within the Mississippi Embayment (~7.95 km/s) and in the northern Appalachians (~7.9 km/s), which also agrees with the NA00 model. However, we have also observed some interesting small scale differences between our model and the NA00 model. The largest difference is within the southern Appalachians, especially the Eastern Tennessee Seismic Zone (ETSZ), where our model shows a high Pn velocity (~8.1 km/s) in vivid contrast to the low S velocity in the NA00 model. Our results also show relatively low velocities (~7.9 km/s) beneath the Illinois Basin with a much wider area than the shear wave model. We also observe a correlation between the seismicity and the edges of the uppermost mantle LVZ within the CEUS.

We have also inverted for the Pn azimuthal anisotropy variations within the North American continent. In order to investigate the trade-off between lateral velocity variations and azimuthal anisotropy, we employed a variety of different weights. We have found that the fast directions within the portion with the highest ray density of our model appear to be robust. These fast directions appear to parallel the edge of the high velocity anomalies and thick lithosphere underlying the North American craton.

CRUSTAL THICKNESS VARIATION IN THE AEGEAN REGION AND ITS IMPLICATIONS FOR THE EXTENSION OF CONTINENTAL CRUST

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We combined teleseismic waveform data from a temporary seismic network and permanent seismic stations in the Aegean region to determine crustal thickness variation using the H-kappa and CCP stacking methods. The results show a general trend of westward crustal thinning from 36 km in central Anatolia, to 28-30 km in western Turkey, to 25 km in the Aegean Sea. Significant crustal thinning has taken place beneath the Menderes Massif (28 to 30 km) and the Cyladic Massif (25 to 26 km). Outside these metamorphic belts in western Turkey and the Aegean Sea, the crust is 32-34 km thick. Such a long-lived elevated Moho under metamorphic core complexes suggests that the lower crust in the Aegean region is probably an order of magnitude stronger than that in the Basin and Range province, where the Moho is much flatter. Our results indicate that the crustal thinning in the Aegean is not uniform in the N-S extensional direction. The rapidly varying Moho depth across boundaries of the complexes seems to favor high-angle crustal penetrating normal faults during the formation of metamorphic core complex.