S44A-02 1545h INVITED

Advances in global and regional tomography using the GSN

M. Nettles[1] (nettles@eps.harvard.edu)

A. M. Dziewoński[1] (dziewons@eps.harvard.edu)

[1]Dept. of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138, United States

The development of the Global Seismographic Network (GSN) has been critical for advances in seismic tomographic imaging of the Earth's interior. Tomographic models need no longer rely on travel-time data alone nor on hand-digitized records from a few large earthquakes. The high-quality digital data recorded by the GSN allow information to be extracted from the whole waveforms of thousands of seismograms, making waveform tomography of the entire mantle possible. Similarly, measurements of surface-wave phase delays can now be obtained in a routine fashion, allowing for dramatic increases in the resolution of upper-mantle velocity structure. Recently, the high quality and abundance of GSN data have begun to make robust global analyses of anisotropic structure possible as well. We determine a three-dimensional, radially anisotropic, shear-wave velocity model of the upper mantle under North America that constrains velocity variations on a length scale of a few hundred kilometers. Our dataset consists of approximately two million surface-wave phase-delay measurements ($35 \leq T \leq 150$ s) from stations of the GSN, combined with a supplementary dataset from stations of the United States and Canadian national seismographic networks and selected IRIS PASSCAL stations. We also include a smaller dataset of long-period phase-velocity measurements ($200 \leq T \leq 350$ s) made at GSN stations. The global nature of our GSN dataset allows us to determine a hybrid, global-regional velocity model, eliminating some of the artifacts that resulted from reduced ray coverage in and around North America in previous models. The correspondence between major geological features and those imaged in our mantle model is generally good, with a rapid transition from fast to slow velocities at the western edge of the North American craton and a distinct thinning of the fast-velocity region under the Appalachian mountains. We also image intriguing variations in anisotropy, with amplitudes of radial anisotropy reaching 4–6% at a depth of about 170 km under the Basin and Range province. The importance of the GSN dataset to our results highlights the potential benefits of the increase in GSN-quality seismic stations within North America that is planned as a part of the Earthscope/USArray project.

S44A-03 1605h INVITED

Measuring Anisotropy in the Oceanic Upper Mantle from Splitting in SS Waveforms

Fenglin Niu[1] (713-348-4122; niu@rice.edu)

Paul G. Silver[2] (silver@dtm.ciw.edu)

Mark D. Behn[2] (behn@dtm.ciw.edu)

[1]Department of Earth Science, Rice University, 6100 Main Street, Houston, TX 77005, United States

[2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015, United States

The anisotropic properties of the upper mantle beneath a seismic station are most directly estimated from the splitting in core phases, such as SKS. This approach has been very successful in constraining the anisotropy beneath continents, by exploiting the high density of continental stations available. The relatively small number of oceanic stations makes it more difficult to extract the anisotropic properties of the oceanic upper mantle from splitting. It has nevertheless been shown (Behn et al. 2004) that these ocean-station measurements are directly related to asthenospheric flow and can be used to estimate the subasthenospheric flow velocity field in the oceanic upper mantle. Motivated by the high value of oceanic splitting measurements, we have begun a project to map oceanic mantle anisotropy using shear-wave splitting in the phase SS, whose bounce points provide excellent global coverage of the ocean basins. In order to isolate the anisotropy at the bounce point, however, it is necessary to first account for two influences: (i) Moho reverberations at the bounce point, and (ii) anisotropy beneath the source and receiver. Measurement of splitting in synthetic SS waveforms for a model with an oceanic Moho gives rise to an apparent splitting in SS (transverse leading radial) with a delay time as long as 10s. This apparent splitting is produced by several arrivals that include the precursory reflection at the Moho, followed by several later Moho reverberations. The reflection series, when filtered to the low-frequency band of observed SS waveforms (∼20 s), provides an explanation for large observed apparent SS delay times, such as those measured by Wolfe and Silver (1998). If we assume that the crustal structure at the bounce point is known (a good assumption given the simplicity of the oceanic crust), it is possible compute a Moho reverberation operator, and use it to correct the observed seismograms through deconvolution. Regarding source-side and receiver-side splitting contributions, we can remove the source-side contribution by limiting ourselves to deep-focus events that are below the olivine stability field. We can account for receiver-side splitting either by using splitting estimates based on SKS or by limiting ourselves to stations with negligible receiver-side splitting. As a test of the methodology, we have analyzed SS waveforms for a deep-focus Tonga earthquake, recorded by the 54-station Kaapvaal Seismic Array, with bounce points located in the southern part of the Indian Ocean. Our preliminary analysis shows that the fast polarization direction from the SS splitting analysis is consistent with the mantle flow field inferred from the SKS measurements at nearby island stations, suggesting that this is a promising method for constraining mantle anisotropy beneath the ocean basins.

S44A-04 1625h

Signal Beyond Noise at Ocean Island Stations: Evidence for Magmatic Underplating in GSN Data.

Garrett Leahy[1] (203 432 9809; garrett.leahy@yale.edu)
Jeffrey Park[1] (jeffrey.park@yale.edu)

Vadim Levin[2] (vadim@ldeo.columbia.edu)

[1]Yale Univ., Dept. of Geology and Geophysics, New Haven, CT 06520-8109, United States

[2]Rutgers Univ., Dept. of Geological Sciences, 610 Taylor Road, Piscataway, NJ 08854-8066, United States

Data from GSN observatories on ocean islands can help constrain the structure of the oceanic lithosphere beneath them, if properly analyzed. Specifically, we have discovered that, despite the well-known high-noise characteristics of ocean-island teleseismic earthquake data, we can estimate body-wave receiver functions at frequencies up to 5 Hz that show remarkable consistency among different gathers in back-azimuth and epicentral distance. These receiver functions suggest that vertical profiles of such seismic properties as the shear wavespeed, Poisson's ratio and elastic anisotropy may be developed on the basis of multi-year data sets of global seismicity. A trial analysis of data sets from selected islands in the Pacific proves the feasibility of such investigations, and shows a broad consistency of findings with those of previously conducted ship-borne seismic surveys. There is strong evidence for crustal underplating beneath midplate volcanic islands. The seismic characteristics of the underplated material may offer insight into hotspot processes, magmatic partitioning, and hotspot buoyancy flux.

S44A-05 1640h

The Future of the Very Broadband Seismic Sensor

Shane F Ingate[1] (202-682-2220; shane@iris.edu); Jon Berger[2] (jberger@ucsd.edu); John Collins[3] (jcollins@whoi.edu); William Farrell[4] (farrell@gefion.gso.saic.com); Jim Fowler[1] (jim@iris.edu); Pres Herrington[5] (pbherri@sandia.gov); Charles R Hutt[6] (hutt@asl.cr.usgs.gov); Barbara Romanowicz[7]; Selwyn Sacks[8] (sacks@dtm.ciw.edu); Frank Vernon[2,9]; Erhard Wielandt[10] (ew@geophys.uni-stuttgart.de)

[1]IRIS, 1200 New York Ave, NW, Washington, DC 20005, United States

[2]SIO/UCSD, University of California, San Diego 9500 Gilman Drive, La Jolla, CA 92093, United States

[3]Woods Hole Oceanographic Institution, MS 24 Clark South, 360 Woods Hole Road, Woods Hole, MA 02543, United States

[4]SAIC, Campus Pt Drive, La Jolla, CA, United States

[5]Sandia National Laboratories, PO Box 5800, Albuquerque, NM 87185, United States

[6]ASL/USGS, P.O. Box 82010, Albuquerque, NM 87198, United States

[7]University Of California, Berkeley, 215 McCone Hall, Berkeley, CA 94720, United States

[8]Carnegie Institution Of Washington, 5241 Broad Branch Road NW R-164, Washington, DC 20015, United States

[9]SIO/UCSD, 9500 Gilman Drive, La Jolla, CA 92093, United States

[10]Universität Stuttgart, Richard-Wagner-Str 44, Stuttgart 70184, Germany

Few fundamental advances have been made in seismometers since the introduction of the broadband feedback systems nearly 1/4 century ago. In the intervening period, academic (and to a lesser extent industrial) research and developments on seismographic instrumentation has declined. Today, adequate sensors to meet the scientific requirements are in short supply. This is particularly true of the GSN; the cornerstone of GSN instrumentation is the STS-1 seismometer, which is no longer in production. Further, the pool of trained scientists working on seismographic instrumentation has dwindled to near zero. A 2.5 day workshop was held in Tahoe in March, 2004. Over 40 participants from government, universities, and corporate sectors participated in a mixture of oral, poster and discussion sessions. Through this workshop, the geoscience community interacted with research and development groups involved in sensor technology, material sciences and nanotechnology to assess emerging technologies that have applications in inertial sensors. A goal of this workshop was to consider whether and how such advances might be applied to the design and manufacture of a new-generation, ultra-quiet, mHz - 20 Hz seismic sensors. Key items included an examination of partnerships and technology transfer, new and innovative designs, testing standards and testing facilities, funding strategies and an educational perspective including new University programs. One product of this workshop is the formulation of a plan to revitalize research and development of techniques in broadband seismometry and related seismographic instrumentation.

URL: http://www.iris.edu/stations/seisWorkshop.htm

S51A CC: 220 C-E Friday 0830h

Seismic Measurement, Modeling,and Inversion Posters

Presiding: **C J Thomson,** Queen's University**; R Nowack,** Purdue University

S51A-01 0830h POSTER

Gaussian Beam Migration of Scattered Teleseismic Body Waves

Saptarshi Dasgupta[1] (765-494-0272; sapsy@purdue.edu)

Robert Nowack[1] (765-494-5978; nowack@purdue.edu)

[1]Dept. of Earth and Atmos. Sci., 550 Stadium Mall Dr., West Lafayette, IN 47907, United States

We investigate migration using Gaussian beams to image scattered teleseismic waves. In this approach, the surface recorded wavefield is decomposed into Gaussian beams which are back-propagated into the medium and then correlated with the incident wavefield. The Gaussian beam migration approach is very flexible and can easily be modified for the imaging of different directly scattered or surface reflected waves. The use of Gaussian beams allows for a variable velocity background medium, as well as an unequal but sufficiently sampled station spacing. The Gaussian beam centers can then be constructed to be uniformly sampled. For a greater station spacing auto-regressive trace interpolation may be required to avoid aliasing in the migration operator. For the horizontal components, we have used P to S conversions and surface reflected pPs waves for the imaging where a stacked, master vertical trace is used for the deconvolution or cross-correlation. For the vertical components, the surface reflected pPp phase is used for the imaging. The Gaussian beam migration approach is tested with a suture zone model using ray theoretical forward modeling results. Finite difference calculations for a Moho with a step are also used to test the method. For the Cascadia 1993 experiment, seismic data from 31 events have been extracted and processed starting from the original data tapes. The processed data from individual events are then imaged using Gaussian beam migration for crust and upper mantle structure beneath the array.

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S51A-02 0830h POSTER

Toward Improved Methods of Estimating Attenuation, Phase and Group velocity of surface waves observed on Shallow Seismic Records

Mamadou Sanou Diallo[1] (+49 331-977 1823; mamadou@math.uni-potsdam.de); Matthias Holschneider[1] (hols@math.uni-potsdam.de); Michail Kulesh[1] (mkulesh@math.uni-potsdam.de); Frank Scherbaum[2] (fs@geo.uni-potsdam.de); Matthias Ohrnberger[2] (mao@geo.uni-potsdam.de); Erika Lück[2] (elueck@geo.uni-potsdam.de)

[1]University of Potsdam, Applied and Industrial Mathematics, Am Neuen Palais 10, Potsdam 14669, Germany

[2]University of Potsdam, Faculty for Geoscience, Karl-Liebknecht Str. 24-25, Potsdam 14415, Germany

This contribution is concerned with the estimate of attenuation and dispersion characteristics of surface waves observed on a shallow seismic record. The analysis is based on a initial parameterization of the phase and attenuation functions which are then estimated by minimizing a properly defined merit function. To minimize the effect of random noise on the estimates of dispersion and attenuation we use cross-correlations (in Fourier domain) of preselected traces from some region of interest along the survey line. These cross-correlations are then expressed in terms of the parameterized attenuation and phase functions and the auto-correlation of the so-called source trace or reference trace. Cross-corelation that enter the optimization are selected so as to provide an average estimate of both the attenuation function and the phase (group) velocity of the area under investigation. The advantage of the method over the standard two stations method using Fourier technique is that uncertainties related to the phase unwrapping and the estimate of the number of 2π cycle skip in the phase phase are eliminated. However when mutliple modes arrival are observed, its become merely impossible to obtain reliable estimate the dipsersion curves for the different modes using optimization method alone. To circumvent this limitations we using the presented approach in conjunction with the wavelet propagation operator (Kulesh et al., 2003) which allows the application of band pass filtering in $(\omega - t)$ domain, to select a particular mode for the minimization. Also by expressing the cost function in the wavelet domain the optimization can be performed either with respect to the phase, the modulus of the transform or a combination of both. This flexibility in the design of the cost function provides an additional mean of constraining the optimization results. Results from the application of this dispersion and attenuation analysis method are shown for both synthetic and real 2D shallow seismic data sets.

M. Kulesh, M. Holschneider, M. S. Diallo, Q. Xie and F. Scherbaum, Modeling of Wave Dispersion Using Wavelet Transfrom (Submitted to Pure and Applied Geophysics).

S51A-03 0830h POSTER

Industry-Grade Seismic Processing System for Controlled- (and Passive-) Source Research in Seismology

Glenn Chubak[1] (glenn@sasktoon.com)

Igor Morozov[1] (igor.morozov@usask.ca)

[1]University of Saskatchewan, 114 Science Place, Saskatoon, SK S7N5E2, Canada

Open-source seismic processing provides flexibility, functionality and value that are not found in commercial packages. A seismic processing system called SIA, initially developed at the University of Wyoming and continued at the University of Saskatchewan, represents one of the most extensive efforts to integrate the flexibility of academic seismic data analysis with polish and performance of a commercial processor. At present, SIA offers capabilities for nearly complete reflection processing, combined with built-in support for multicomponent, variable-format seismic data, extensive database capabilities, input/output in several data formats accepted in exploration and earthquake seismology (e.g., SEG-Y, SEG-2, Seismic UNIX, PASSCAL-SEGY, GSE3.0, SAC), original inversion codes (e.g., 2-D and 3-D reflection and receiver function migration, genetic algorithms and artificial neural networks), software and documentation maintenance, and interfaces to popular packages such as Datascope, GMT, rayinvr, reflectivity, and Seismic UNIX. Recently, we included in the system a modern graphical user interface (GUI) based on the open-source, platform-independent QT technology by TrollTech. The interface organizes project data while hiding the system structure from the user and generally resembles that of ProMAX (by Landmark Graphics). Nearly 200 tools are arranged into packages (e.g., reflection, travel-time, earthquake data processing, or graphics), and processing flows are constructed by dragging these tools and dropping them in the flows. Multiple processing flows may be opened simultaneously allowing the user to edit and execute concurrent jobs. Context-sensitive help can be accessed through the interface, in addition to the full HTML documentation automatically generated by the system. Context-dependent color highlighting is used to improve readability of the parameters. Processing jobs are submitted through the Parallel Virtual Machine (PVM) which allows multiple processes to be initiated and controlled from a single interface. Jobs may be executed either locally or on a single or multiple remote systems in a heterogeneous computing environment. The GUI includes tools for run-time control of both local and remote processes.. The GUI also includes provisions for cluster scheduling, allowing processes to be executed on Beowulf clusters. Depending on their design, individual tools or flows can be parallelized using either PVM or MPI (Message Passing Interface). With the decentralized processing concept implemented in SIA, grid computing and seamless data exchange could become a reality without any effort from the users. In passive-source work, which is quickly adopting reflection processing techniques, this industry-style processing could provide sophisticated, inexpensive, and high performance approaches to data retrieval and access to hundreds of signal enhancement tools developed in reflection seismics.

URL: http://www.usask.ca/~igm852/sia

S51A-04 0830h POSTER

The Axisymmetric Spectral Element Method for Elastic Wave Propagation

Tarje Nissen-Meyer[1] (609-258-1504; tarje@princeton.edu)

Alexandre Fournier[1,2] (fournier@ipgp.jussieu.fr)

F. A. Dahlen[1] (fad@princeton.edu)

[1]Department of Geosciences, Princeton University, Guyot Hall, Princeton, NJ 08540, United States

[2]Laboratoire de Dynamique des Systèmes Géologiques, Institut de Physique du Globe de Paris, 4, place Jussieu, Paris Cedex 05, Paris 75252, France

Considering finite frequency effects in the propagation of seismic waves has recently received notable attention due to their refining character in tomographic images of the Earth. The Fréchet sensitivity kernels used in these inversions are calculated using ray theory and can therefore not account for e.g. D"-diffracted phases. With the lowermost mantle being well sampled by those arrivals, it is however desirable to include these phases in tomographic studies. Our objective is to compute exact sensitivity kernels for the full wavefield based on seismic forward modeling to allow for inversion of any seismic phase. Exact kernels require the response to the full moment tensor and forces throughout the model space. Here, we introduce the axisymmetric spectral element method for elastic wave propagation which is well suited to eventually calculate those kernels. The axisymmetric approach takes advantage of the fact that kernels are computed upon a spherically symmetric Earth model. Axial singularities are removed by introducing a weighted quadrature rule while retaining a diagonal mass matrix. In this reduced dimension formulation, all moment tensor elements and single forces can be included and respectively represent different 2D problems to be solved separately. The simulations on a 2D mesh then allow for high resolution. We demonstrate the efficiency and high accuracy of this method by validation against normal mode solutions and constrain crucial numerical parameters. The parallelized algorithm can at this point handle monopole sources (diagonal moment tensor elements or a vertical force) in a homogeneous or two-layered solid sphere.

S51A-05 0830h POSTER

Inversion of Forward Scattered Teleseismic Body Waves: Why we have to go to 2D elastic media

Chengliang Fan[1] ((812)8551008; cfan@indiana.edu); Gary L. Pavlis[1] (pavlis@indiana.edu); Arthur B. Weglein[2] (aweglein@central.uh.edu); Haiyan Zhang[2] (hzhang5@uh.edu); Bogdan Nita[2] (bnita@uh.edu); Simon A Shaw[3] (shawsa@earthlink.net)

[1]Indiana University,Bloomington, 1001 E. 10th Street, Bloomington, IN 47405, United States

[2]University of Houston, 617 Science and Research Building 1, Houston, TX 77204, United States

[3]BP, 200 Westlake Park Boulevard, Houston, TX 77079, United States

We described how the inverse scattering series method can be used for the nonlinear inversion of earth properties using forward scattered teleseismic body waves. This is a general series expansion method based on perturbation theory. We derived the first order terms of the inverse scattering series for plane waves in a constant reference medium. For the first order perturbations of bulk modulus, shear modulus, and density (κ_1, μ_1, and ρ_1, respectively), they are dependent on the type of media. That is, 1) for 1D acoustic constant density media, only the summation of κ_1 can be obtained; 2) in 1D elastic media, for P-P scattering mode, ρ_1 and κ_1 are always combined together and not separable. μ_1 can not be inverted. Similarly, for S-S scattering mode, κ_1 can not be inverted, and μ_1 and ρ_1 can not be separated. However, for either P-S or S-P scattering, μ_1 and ρ_1 can be inverted explicitly and κ_1 can not be determined; 3) with 2D elastic media, for P-P scattering mode, all three type of first order perturbations can be inverted uniquely. For P-S, S-S, and S-P scattering modes, only μ_1 and ρ_1 can be inverted. Thus, if we want to invert the three parameters from the forward scattered teleseismic waves by using inverse scattering theory, the algorithms must be expected to accommodate either 2D or 3D elastic media.

S51A-06 0830h POSTER

Azimuthal Variation in *P*, *S*, and *Rg* Waves from Single-Fired Explosions in a Coal Mine in Arizona

Heather J. Hooper[1] (1-781-860-0124; heather@westongeophysical.com)

Mark Leidig[2] (1-713-515-9363; mleidig@westongeophysical.com)

Jessie L. Bonner[3] (1-936-632-4226; bonner@westongeophysical.com)

[1]Weston Geophysical Corporation, 57 Bedford Street Suite 102, Lexington, MA 02420, United States

[2]Weston Geophysical Corporation, 3919 Essex Lane #232, Houston, TX 77027, United States

[3]Weston Geophysical Corporation, 4000 South Medford Suite 10W, Lufkin, TX 75904, United States

In September, 2003, a series of single-fired chemical explosions were detonated in a coal mine in the Black Mesa coal basin in northern Arizona. These explosions were part of the Source Phenomenology Experiment, which aims to quantify the differences between contained single-fired chemical and delay-fired mining explosions in mines located in different lithologic and tectonic regimes. As part of this study, we are quantifying the azimuthal variation of *P*, *S*, and *Rg* waves produced by the explosions. This will allow us to determine the source physics that govern energy partitioning between regional seismic phases, and to examine the effects of source depth, yield, and confinement on the source functions of these explosions.

The single-fired tests consisted of 8 explosions with different yields, depths of burial, and levels of confinement. Data were recorded on several networks of sensors with different frequency and distance ranges, including a local network of 130 single-component vertical seismic stations. This network included one fully enclosed ring of sensors between 1.5 and 5.5 km from the sources, which forms the focus of our study. We use an Empirical Green's Function (EGF) method to remove the attenuation, path and station effects from the data, using the smallest, most well-contained shot as the EGF. We then compare the amplitudes of the various phases from station to station, and from shot to shot. Preliminary results show that the method works well, and that yield, source depth, and containment (particularly for shots detonated close to a free face) have a quantifiable effect on the azimuthal variation of the amplitudes of different phases. We will demonstrate that these parameters, as well as secondary effects such as spall and free-face interactions, affect energy partitioning among seismic phases, and that these effects vary with azimuth from the source.