

## S43A-02 1350h INVITED

## Discovering earthquakes and other phenomena with the GSN

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With more than 100 well-distributed stations, the Global Seismographic Network (GSN) provides a continuous record of broadband ground motion of the Earth's surface. Data from many GSN stations are routinely used for traditional high-frequency detection and location of earthquakes, but research using GSN data has until recently been focused almost exclusively on the analysis of seismograms from known events for the determination of detailed earthquake characteristics or Earth structure. The potential for signal monitoring and event discovery using the broadband signals of the GSN is only now starting to be realized. Over the last two years, we have developed a technique to use the GSN as a global, steerable array to search for localized sources of intermediate-period (40–150 s) Rayleigh waves. We use a method of surface-wave cross correlation and stacking to search for seismic events using archived and near-real-time data from the GSN. Given a test location, seismograms are corrected for propagation effects to each station in the network. The envelopes of the resulting waveforms are stacked and cross correlated with a model wavelet to determine a detection. Maximizing the cross correlation as a function of latitude and longitude leads to the determination of an origin time and location. The method detects nearly all standard earthquakes with magnitudes greater than 5. In addition, we regularly find 10–15 M=5 events each month that are not listed in standard earthquake catalogs (PDE, ISC, REB). Among these unassociated events, we have identified a new class of seismic events that involve the sudden sliding motion of glaciers. These events appear to have a characteristic duration of tens of seconds, and we infer that they involve the displacement of several cubic kilometers of ice by several meters. During a period of 10 years, we have found more than 100 M=5 glacial earthquakes on Greenland. We have also found approximately 10 events of this type in Antarctica and Alaska. Many other unassociated events await analysis and interpretation. Results from our real-time search for seismic events can be found on our web site, [www.seismology.harvard.edu](http://www.seismology.harvard.edu).

## S43A-03 1410h INVITED

## Identification of the fault planes of deep earthquakes from analysis of source finiteness

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One of the basic issues regarding the physical mechanism for deep earthquakes is the extent to which they occur on pre-existing faults: Do deep earthquakes reactivate faults that formed in the oceanic plate prior to subduction? A previous study of the Tonga subduction zone (Jiao et al, 2000) compared nodal plane distributions between outer-rise events to events as deep as 450 km depth, and found them to be very similar. While this comparison provides some support for the pre-existing fault hypothesis, a more stringent test of the hypothesis is available by identifying the actual rupture planes of these events. We are developing the methodology to perform such a test based on the detection of source finiteness. First, we examine rupture directivity with long-period *P* waves. For earthquakes with primarily unilateral rupture, the pulse width will vary depending on the angle between the rupture direction and the takeoff vector to the station. For 66 large, globally-distributed earthquakes recorded by the GSN between 1993 and 2000, we estimate variations in pulse width over the focal sphere from differences in frequency content at different stations. We use these pulse-width estimates to determine the best-fitting rupture direction and to identify which nodal plane of the Harvard CMT solution is most consistent with this rupture direction. In about 40% of the cases, one of the two nodal planes produces a much better fit to the data and can be identified as the true fault plane. Our second approach to studying source finiteness is to identify and locate subevents using broadband *P* waveforms. This allows us to detect source finiteness even

for events that are not characterized by unilateral rupture, and to analyze a larger catalog of smaller, shallower events. We seek to apply these two approaches, augmented by the observation of aftershocks, to determine the distribution of rupture-plane orientations of deep- and outer-rise seismicity for the Tonga subduction zone.

## S43A-04 1430h

## The Global Seismographic Network and the Earth's Inner Core

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The Global Seismographic Network (GSN) has been providing high-quality open-access broad-band seismic data to the scientific community since its establishment in 1986 by the Incorporated Research Institutions for Seismology (IRIS). The accumulation of the GSN data has led to many discoveries of unique features of the Earth's inner core. Among them are the hemisphericity of seismic velocity and attenuation, and the correlation of high velocity with high attenuation in the top of the inner core. In this presentation, we present recent results of the seismic velocity and attenuation structures for the top 400 km of the inner core along the equatorial path using the GSN data. Our datasets consist of differential travel times and waveforms of the PKIKP-PKIKP phases observed at the epicentral distance range of 120°-141° and the PKPbc-PKIKP phases observed at 146°-159°. The observations show these characteristics: (1) both the observed PKIKP-PKIKP and PKPbc-PKIKP differential travel times exhibit a clear "east-west" hemispheric pattern. PKIKP phases arrive about 0.7 second earlier for those sampling the "eastern" hemisphere (40°E-180°E) than those sampling the "western" hemisphere (180°W-40°E); (2) amplitude ratios of the PKIKP/PKIKP phases observed at the distance range of 131°-141° and the PKIKP/PKIPbc phases observed at 146°-151° are in general smaller for the PKIKP phases sampling the eastern hemisphere than those sampling the western hemisphere. At distances larger than 151°, the observed PKIKP/PKIPbc amplitude ratios are indistinguishable between the two hemispheres; (3) PKIKP phases sampling the eastern hemisphere bifurcate at smaller epicentral distances for those sampling the eastern hemisphere. These observations can be explained by two different types of seismic velocity and attenuation models for the two hemispheres of the inner core. For the eastern hemisphere, the velocity model has a *P* velocity increase of 0.748 (km/sec) across the inner core boundary and a flat velocity gradient of 0.0042 (km/sec)/100 km in the top 235 km, followed by a gradual velocity transition of 0.1 (km/sec)/100 km extending from 235 km to 375 km and the PREM velocity gradient in the deeper portion; the attenuation model has an average *Q* value of 250 in the top 300 km followed by an average *Q* value of 600 in the deeper portion. For the western hemisphere, the velocity model has a *P* velocity increase of 0.645 (km/sec) across the inner core boundary and a velocity gradient of 0.049 (km/sec)/100 km in the top 375 km, followed by the PREM value in the deeper portion; the attenuation model has an average *Q* value of 600 in the top 400 km of the inner core. The top portion of the inner core in the eastern hemisphere is anomalous, in having a flat velocity gradient, high velocity and high attenuation. Our models also suggest that the hemispheric variation in seismic velocity possibly extends deeper than 375 km below the inner core boundary. We will discuss possible interpretations and implications of these seismic results.

URL: <http://geophysics.geo.sunysb.edu/wen/>

## S43A-05 1445h

## 3D Whole-Mantle Velocity and Quality Factor

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We present seismic inversions for 3-D whole-mantle velocity and quality factor (*Q*) with the same spatial resolutions in order to better characterize anomalous seismic structures. By analyzing both the elastic and

anelastic properties of a medium, we may better characterize anomalies as chemical, thermal, phase change, or mechanical. Using over 70,000 differential measurements of travel time and attenuation between SS-S, ScS-S, SKS-S, sScS-sS, and sSS-sS, and ScS-SS, as well as over 30,000 absolute *S* arrival time and attenuation measurements, we invert for velocity and quality factor with similar spatial resolutions. These inversions produce a model, VQ3DA, that provides a first look at 3D whole-mantle quality factor as it affects shear body waves on a global scale. Using both radial and tangential measurements, we are able to measure anisotropy for both velocity and quality factor. We characterize regions within the Earth as having anomalous high-*Q* and high-*V*, high-*Q* and low-*V*, low-*Q* and low-*V*, and low-*Q* and high-*V*. We then correlate anisotropy with each of these four categories to explain some possible dynamic processes responsible for or resultant from the anomalies. To first order there is excellent agreement between quality factor and velocity throughout the mantle. Interestingly, there is also a strong agreement between velocity anisotropy and attenuation anisotropy. Subduction zones and spreading ridges are the predominant features observed in the model. Nevertheless, smaller second-order anomalies are also resolvable. The quality factor models agree with upper mantle models inverted from *P*-wave and *PP*-wave attenuation, normal mode, and surface wave attenuation. Similarly, the velocity model agrees well with recent models such as S16U6L8. This study shows that resolvable 3-D quality factor anomalies extend into the lowermost mantle.

URL: <http://epsc.wustl.edu/seismology/jfisher/>

## S44A CC: 516 D Thursday 1530h

## Seismology From Crust to Core: The Science of the Global Seismographic Network II (joint with G, T)

Presiding: L Wen, State University of New York at Stony Brook; J Park, Yale University

## S44A-01 1530h

## The IRIS Data Management Center: Providing Efficient Access to GSN data

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The IRIS Data Management Center (DMC) in Seattle, Washington is the host of the largest seismological database of its kind in the world. The Global Seismic Network (GSN) lies at the center of the DMC holdings. The DMC relies heavily upon a petabyte mass storage system for waveform storage and Oracle for its relational data base infrastructure. During the past several years, emphasis has been placed upon the development and implementation of robust and effective technologies that allow access to the information at the IRIS DMC in a variety of ways. This talk will highlight the general structure of the IRIS DMC and the method we use to manage the gigabytes of information in Oracle as well more than 100 terabytes of time series data we have in our mass storage systems. An overview will be given of the methods through which users can access the information in our relational database systems as well as the mass storage systems in order to conduct their research using GSN and other data. A discussion of three distinctly different approaches will be presented. These include an email-based method, a web-based method as well as a multi-tier distributed computing environment we call the Data Handling Interface (DHI). The DHI is based upon Common Object Request Broker Architecture (CORBA) and provides direct connections between client applications, normally provided by IRIS, and data center servers established at several data centers within the United States. The DHI presently supports the distribution of information about seismic events, information about the seismic stations that record the time series and finally the time series (seismograms) themselves. The system is capable of transmitting seismic waveform data in real time. Waveform data and all associated metadata are available through this interface allowing direct access to information at the DMC within client applications running on a users workstation.

URL: <http://www.iris.edu/>

## S44A-02 1545h INVITED

## Advances in global and regional tomography using the GSN

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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

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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 to 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.

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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

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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

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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.