Eastern Section of the Seismological Society of America

2009 Meeting

Palisades, New York
October 4-8, 2009

Hosted by Lamont-Doherty Earth Observatory

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Campus Map

From Westchester
Take I-287 west across the Tappan Zee Bridge. Take the first exit after the bridge (Exit 10 Nyack). Proceed South on Rte. 9W for a distance of approximately 5 miles. Lamont-Doherty will be on your left.

From New York City & Long Island
Take the upper level of the George Washington Bridge to the first exit (Palisades Interstate Parkway). Proceed north on the parkway for a distance of approximately 10 miles to Exit 4 (Rte. 9W). At the end of the exit ramp at the stop light, turn left onto Rte. 9W North and proceed north for a distance of approximately 200 yards. Lamont-Doherty will be on your right.

From Upstate New York and Northern New Jersey
Via the New York State Thruway Southbound:
Take the Thruway South to Exit 13 (Palisades Interstate Parkway South). Proceed on the Parkway south for a distance of approximately 10 miles to Exit 4 (Rte. 9W). At the end of the exit ramp, turn right onto 9W North. Proceed on 9W for a distance of approximately 1 mile. Lamont-Doherty will be on your right.
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Via Route I-80 and points West:
Take Rte. 80 East (remain in local lanes) to the Palisades Interstate Parkway exit just before the George Washington Bridge. Follow signs to the Palisades Interstate Parkway. Proceed north on the Parkway for a distance of approximately 10 miles to Exit 4 (Rte. 9W). At the end of the exit ramp at the stop light, turn left onto Rte. 9W North and proceed north for a distance of approximately 200 yards. Lamont-Doherty will be on your right.

Via Route I-95 and points South:
Take Rte. 95 North to Rte. I-80 East (remain in local lanes) to the Palisades Interstate Parkway exit just before the George Washington Bridge. Follow signs to the Palisades Interstate Parkway. Proceed north on the Parkway for a distance of approximately 10 miles to Exit 4 (Rt. 9W). At the end of the exit ramp at the stop light, turn left onto Rt. 9W North and proceed north for a distance of approximately 200 yards. Lamont-Doherty will be on your right.
Instrument Museum

Programs, Ice Breaker

Lunch, Poster Session, Coffee Breaks and Banquet
Field Trip (Led by Dr. Leonardo Seeber, LDEO)

A field trip is being planned for Sunday, October 4, 2009, to see geologic structures associated with earthquakes in the Greater New York City region. We will visit the Ramapo fault, which is associated with a linear zone of seismicity and has been discussed as a possible source of damaging earthquakes. We will also visit a branch of the 125th Street fault that crosses northern Manhattan and offsets the Mesozoic Palisades sill. This fault is a member of a family of NW-striking faults, which are associated with most of the larger earthquakes in the area. We will visit the Hudson Gorge near the Ramapo fault and the nuclear power plant at Indian Point.

Starts at 9:00 am in front of GeoScience building at Lamont Campus

09:00 am    Gather at Lamont Campus, GeoScience building
09:00-10:00 Lamont to Manhattan, 125th Street
10:00-11:00 Walk around 125th Street Fault on Manhattan
11:00-12:00 Manhattan to Anthony’s Nose via Dobbs Ferry fault (north of Peekskill)
12:00-13:00 Walk around Anthony’s Nose and Lunch
13:00-13:30 Travel to Wappingers Falls (north of Beacon)
13:30-14:30 Walk around Wappingers Falls
14:30-15:00 Travel to Suffern, NY
15:00-16:00 Walk around Suffern looking around Ramapo fault
16:00-17:00 Return to Lamont Campus
17:00-19:30 Icebreaker and meeting registration at Monell building
Special Sessions

Velocity Structure of the Crust and Upper Mantle in Eastern North America
Oral Session - Monday PM, October 5

The Transportable Array (TA) component of USArray has recently begun to make its way into Eastern North America, and can be expected to provide improvements in imaging capability of at least the magnitude currently demonstrated in the western U.S. Ongoing and new experiments in Canada are also expected to contribute substantially to our knowledge of the velocity structure east of the Rockies. We invite contributions on current knowledge of the structure of the crust and upper mantle beneath Eastern North America, derived from active source studies, passive-source and noise tomography, and other geophysical methods.

Conveners

- Meredith Nettles - nettles@ldeo.columbia.edu
  Lamont-Doherty Earth Observatory and Dept. of Earth & Environmental Sciences, Columbia University

Ground Motion Scaling and Attenuation Relations in Eastern North America
Oral Session - Tuesday AM, October 6

The lack of large earthquakes in the Central and Eastern United States hobbles the development of ground motion relations for these infrequent events. Recordings of moderate earthquakes at regional distances are characteristically used to estimate near-field ground motions for large earthquakes, but require attenuation relations and source scaling relations specific to the CEUS and Eastern Canada. For this session, we invite papers on all aspects of the problem of predicting ground motion from large earthquakes in the CEUS and Eastern Canada.

Conveners

- John Boatwright - Boatwright@usgs.gov
  U.S. Geological Survey, Menlo Park, CA 94025
Presenter Information

Oral presentations will be in the Monell Auditorium. For the exact time and room of any presentation, please check the meeting program.

You will have access to a laptop with LCD projector, wireless remote, and a laser pointer.

Please bring your presentation to the meeting on a flash drive or CD to load on the in-room laptops. There will be the following Audio/Visual Equipment:

- Microsoft Windows PC laptop with PowerPoint and Acrobat Reader

You will not be able to use your own laptop for your presentation. You may load your presentation on one of the conference laptops before the first session (8:30-9:00), during the coffee break, or during lunch preceding your presentation. A technician will assist with the loading.

Please remember that you are allocated 20 minutes total. This includes time for you to be introduced, give your presentation, answer any questions, and do any wrap-up. Therefore, plan your actual presentation for no more than 15 minutes. We have a tight schedule, and it is important that each presenter stay within the time limit.

Poster Information

Your poster boards will be in the Lamont Hall. The poster area will open at 8:30 AM, 30 minutes before the sessions begin each day. Please hang your posters before 9:30 AM the day of your session if possible. Your poster will need to be taken down by 5:30 PM the day of your session.

When you get to the meeting, you will be asked to post a notice at your poster as to what specific time(s) you will be at the poster site.

The poster board usable space is 3 ft 9 inches high x 6 ft wide. We will provide push pins.
EASTERN SECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA
THE 81ST ANNUAL MEETING, 2009

Monday 5 October

9:00-9:10 WELCOME/OPENING REMARKS  (Host: Won-Young Kim, LDEO)

9:10 – 9:50 SPECIAL SESSION:  Velocity Structure of the Crust and Upper Mantle in Eastern North America

9:10 a.m. GAHERTY, James, B., LEVIN, Vadim. and DALTON, Colleen
A THREE-DIMENSIONAL MODEL OF CRUSTAL STRUCTURE IN THE CENTRAL AND EASTERN US DERIVED FROM RECEIVER FUNCTIONS AND BROADBAND AMBIENT-NOISE SURFACE WAVES

9:30 a.m. FOSTER, Anna, EKSTRÖM, Göran, HJORLEIFSDOTTIR, Vala
SURFACE-WAVE PHASE-VELOCITY MODELS AND ARRIVAL ANGLE VARIATIONS ESTIMATED FROM USARRAY DATA

9:50 – 11:30 GENERAL SESSION

9:50 a.m. HOUGH, Susan E.
(YET) ANOTHER NEW LOOK AT THE 1811-1812 NEW MADRID EARTHQUAKES: TAKING THE “I” OUT OF INTENSITY ANALYSIS

10:10 a.m. CRAMER, Chris
EARTHQUAKE RECURRENCE VARIABILITY: LIMITATIONS OF FEW INTERVALS

10:30 a.m. COFFEE BREAK

10:50 a.m. TAVAKOLI, Behrooz, PEZESHK, Shahram, COX, Randel T.
A NEW 3D CONCEPTUAL MODEL OF FAULTING TO EXPLAIN SEISMICITY OF THE NEW MADRID SEISMIC ZONE

11:10 a.m. STEVENSON, Donald and TALWANI, P.
RE-EVALUATION OF HISTORICAL SEISMICITY IN SOUTH CAROLINA PRIOR TO 1886

11:30-12:00 EASTERN SECTION OF SSA ANNUAL BUSINESS MEETING

12:00 p.m. LUNCH

1:00 – 3:00 GENERAL SESSION

1:00 p.m. CHAPMAN, M.C. and BEALE, J.N.
RESULTS OF REPROCESSING SEISMIC REFLECTION DATA COLLECTED NEAR SUMMERVILLE, SOUTH CAROLINA

1:20 p.m. SCHARNBERGER, Charles K., DELANO, Helen, JONES, Jeri,
THE 2008-2009 DILLSBURG, PA, EARTHQUAKE SWARM: GEOLOGIC SETTING

1:40 p.m. KIM, Won-Young and GOLD, Mitchell
THE 2008-2009 DILLSBURG, PA, EARTHQUAKE SWARM: SOURCE CHARACTERISTICS

2:00 p.m. EBEL, John E.
ANALYSIS OF AFTERSHOCK AND FOreshock ACTIVITY IN STABLE CONTINENTAL REGIONS: IMPLICATIONS FOR AFTershock FORECASTING AND THE HAZARD OF STRONG EARTHQUAKES
2:20 p.m.  EATON, David W., VASUDEVAN, Kris
DO MAGNETIC LINEAMENTS PROVIDE A USEFUL PROXY FOR SEISMOGENIC STRUCTURES IN SCRS?

2:40 p.m.  WALDHAUSER, Felix
REAL-TIME DOUBLE-DIFFERENCE SEISMIC MONITORING

3:00-3:30  POSTER SESSION

MILLER, Meghan S., EATON, David W.
IMAGES OF LITHOSPHERIC STRUCTURE BENEATH CANADA USING S-WAVE RECEIVER FUNCTIONS

BENOIT, Margaret H., LONG, Maureen D.
THE TEENA EXPERIMENT: A PILOT PROJECT TO STUDY THE STRUCTURE AND DYNAMICS OF THE EASTERN US CONTINENTAL MARGIN

BUSBY, Robert W., WOODWARD, Robert, SIMPSON, David, HAFNER, Katrin
EARTHTSCOPES TRANSPORTABLE ARRAY; CURRENT PROGRESS AND FUTURE PLANS

SCHAFF, David P., WALDHAUSER, F.
BROAD-SCALE APPLICABILITY OF CORRELATION DETECTORS TO CHINA AND PARKFIELD, CALIFORNIA, SEISMICITY

HUANG, Paul Y., NYLAND, David, MEDBERY, Alec, WHITMORE, Paul, KNIGHT, William
TSUNAMI HAZARD MONITORING ON THE U.S. ATLANTIC COAST

MA xiaojing, DENG zhihui, CHEN meihua, YANG zuzhuan, GAO xiangelin,
ON THERMAL INFRARED ANOMALIES BEFORE EARTHQUAKES FROM THE RELATIONSHIP BETWEEN SATELLITE INFRARED BRIGHTNESS TEMPERATURE AND TERRESTRIAL HEAT FLOW

3:30 p.m.  COFFEE BREAK

4:00 – 5:20  GENERAL SESSION

4:00 p.m.  TALWANI, Pradeep, MALHOTRA, Vivek
DISCOVERY OF PREHISTORIC RUINS NEAR ALLAH BUND IN KUTCH, INDIA.

4:20 p.m.  ZHIHUI, Deng, MEIHUA, Chen, YAN Yan, ZHUZHUAN, Yang, JINLING Tao, JINHUA, Zu
SOME EXAMPLES OF POSSIBLE EARTHQUAKE ANOMALIES OF REMOTE SENSING INFORMATION IN CHINA

4:40 p.m.  YACOUB, Nazieh
DOMAIN ANALYSIS MODELS FOR REFINING SEISMIC SOURCE PARAMETERS

5:00 p.m.  ZARIFI, Zoya and HAVSKOV, Jens
SEISMICITY AND THERMAL STRUCTURE OF SUBDUCTED SLABS IN THE NORTHEAST OF COLOMBIA AND WESTERN VENEZUELA

5:20 – 5:40  TOUR OF EARTHQUAKE INSTRUMENT MUSEUM
(led by John Armbruster and other staff at LDEO)

6:30-9:30  BANQUET (LAMONT HALL)
Jesuit Seismological Association Award
Recipient of JSA Award: Dr. Maurice Lamontagne, Natural Resources Canada
Paul G. Richards (Guest speaker), 60 years of Seismology at Lamont
Tuesday 6 October

9:00 – 11:30  SPECIAL SESSION:  *Eastern North America Ground Motion Scaling and Attenuation Relations*

9:00 a.m.  EBEL, John E
A STRATEGY FOR SITING STRONG-MOTION INSTRUMENTATION IN THE CENTRAL AND EASTERN U.S.

9:20 a.m.  CRAMER, Chris, KUTLIROFF, Jerome, and DANGKUA, Donny
NEXT GENERATION ATTENUATION (NGA) EAST GROUND MOTION DATABASE: ISSUES AND INITIAL EFFORT

9:40 a.m.  BOATWRIGHT, John, and SEEKINS, Linda C.
A SPECTRAL ANALYSIS FOR ATTENUATION AND SOURCE PARAMETERS OF FOUR MODERATE EARTHQUAKES IN NORTHEASTERN NORTH AMERICA

10:00 a.m.  LANGSTON, Charles A.
UPWARD CONTINUATION OF SURFACE WAVES AND NAKAMURAS H/V TECHNIQUE

10:20 a.m.  **COFFEE BREAK**

10:50 a.m.  BRUNE, James N
PRECARIOUSLY BALANCED ROCK CONSTRAINTS ON EARTHQUAKE SOURCE AND ATTENUATION IN CALIFORNIA AND NEVADA: COMPARISONS WITH EASTERN NORTH AMERICA

11:10 a.m.  BAISE, Laurie G., KAKLAMANOS, James
LESSONS LEARNED FOR GROUND MOTION PREDICTION EQUATION DEVELOPMENT FROM NGA WEST

11:30 – 12:00  POSTER SESSION

- ZANDIEH, Arash and PEZESHK, Shahram
GEOMETRICAL SPREADING AND QUALITY FACTOR FUNCTIONAL FORM FOR NEW MADRID SEISMIC ZONE

- EBEL, John E., SMITH, Dina M.
A TEST OF THE PALEOSEISMICITY MODEL IN THE EPICENTRAL AREA OF THE 1727 NEWBURY, MASSACHUSETTS EARTHQUAKE

- DRYSDALE, J. A., HAYEK, S, ADAMS, J., PEÇI, V., WOODGOLD, C.
SEISMIC ACTIVITY IN NORTHERN ONTARIO: AN ONGOING STUDY

- REVETTA, Frank A
CORRELATION OF EARTHQUAKE EPICENTERS WITH GRAVITY ANOMALIES IN NEW YORK STATE

- VASUDEVAN, Kris, EATON, David W., DAVIDSEN, Jrn
INTRAPLATE SEISMICITY IN CANADA: A GRAPH THEORETIC APPROACH TO PHYSICAL STRUCTURE AND INTERPRETATION

12:00 p.m.  **LUNCH**

1:00 p.m.  Student Paper Awards

1:10 –1:30  **TOUR OF EARTHQUAKE INSTRUMENT MUSEUM**
(led by John Armbruster and other staff at LDEO)

1:30 p.m.  **MEETING ADJOURNS**
ABSTRACTS

(LISTED ALPHABETICALLY BY FIRST AUTHOR)

LESSONS LEARNED FOR GROUND MOTION PREDICTION EQUATION DEVELOPMENT FROM NGA WEST

BAISE, Laurie G., Tufts University, Medford, MA 02155, USA, LAURIE.BAISE@TUFTS.EDU; KAKLAMANOS, James, Tufts University, Medford, MA 02155, USA, JAMES.KAKLAMANOS@TUFTS.EDU

Recent earthquake ground motion prediction relations, such as those developed from the Next Generation Attenuation (NGA) West project in 2008, have established a new baseline for the estimation of ground motion parameters such as peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (Sa) for active tectonic shallow crustal regions. Current efforts are underway to develop a similar set of equations for NGA East that would pertain to the Central and Eastern parts of North America. We perform statistical goodness-of-fit analyses to quantitatively compare the predictive abilities of the recent models NGA West models. The prediction accuracy of the models is compared using several testing subsets of the master database used to develop the NGA models. Using these subsets, we compare the predictive capabilities of the models for soil and rock sites for both mainshocks and aftershocks. Somewhat surprisingly, the simpler NGA models perform better than the models of greater complexity when tested on the most comprehensive subsets. By comparing the predictor variables and performance of different models, we discuss the sources of uncertainty in the estimates of ground motion parameters and offer recommendations for model development. The decisions that model developers make during the selection of their regression datasets, such as the inclusion of aftershocks and determination of distance cutoffs, can greatly affect the models predictive capabilities. As the results of this study suggest, increased model complexity does not necessarily lead to increased prediction accuracy. This paper attempts to present a model validation framework to assess prediction accuracy of ground motion prediction relations and aid in their future development.

THE TEENA EXPERIMENT: A PILOT PROJECT TO STUDY THE STRUCTURE AND DYNAMICS OF THE EASTERN US CONTINENTAL MARGIN

BENOIT, Margaret H., Department of Physics, The College of New Jersey, Ewing, NJ, 08628; LONG, Maureen D., Department of Geology and Geophysics, Yale University, New Haven, CT, 06520

During the summer of 2009, a quasi-linear transect of 9 broadband seismic stations was deployed from Knotts Island, North Carolina across Virginia and West Virginia to Marietta, Ohio, comprising the TEENA (Test Experiment for Eastern North America) array. Very little is known about the detailed seismic structure of the crust and mantle beneath this region, and while several models for mantle dynamics beneath the eastern
US passive continental margin have been proposed, the paucity of available seismic data has made it difficult to discriminate among them. The TEENA array traverses several physiographic provinces, including the Atlantic coastal plain, Appalachian Piedmont, Blue Ridge Mountains, Appalachian Valley and Ridge, and Appalachian Plateau. Data recorded from this array will be used to examine variations in crust and mantle structure across these different provinces and will help elucidate how the lithosphere of this region has evolved throughout its complex tectonic history. We also expect to obtain constraints on upper mantle seismic anisotropy beneath the region which will place constraints on mantle dynamics beneath the passive continental margin. Constraints on the structure and dynamics of the crust and mantle gleaned from TEENA and similar pilot projects will be useful in guiding future seismic studies in the Appalachian geologic province of eastern North America, particularly as the Transportable Array and Flexible Array components of the Earthscope USArray move east.

A SPECTRAL ANALYSIS FOR ATTENUATION AND SOURCE PARAMETERS OF FOUR MODERATE EARTHQUAKES IN NORTHEASTERN NORTH AMERICA

BOATWRIGHT, John, and SEEKINS, Linda C., U.S. Geological Survey, Menlo Park, CA, 94025, USA

We analyze broadband spectra of S+Lg+surface waves recorded out to 600 km from four moderate (4 < M < 5) earthquakes in Quebec, New York, and Maine: the 1997 Cap Rouge, 2002 Au Sable Forks, 2005 Riviere du Loup, and 2006 Bar Harbor earthquakes. We combine the spectra of the horizontal component seismograms. We restrict the analysis to hard-rock (Vs > 1500 m/s) and soft-rock (Vs > 700 m/s) sites, avoiding resonant sedimentary sites so that we can model site amplification using 1D impedance functions (Boore and Joyner, 1997). We use r_o = 50 km instead of 100 km for the crossover distance in the Street et al. (1975) geometrical spreading: this distance fits the corrected long-period source spectra at 0.1 Hz to the moment tensor estimates. This simple correction scheme allows us to regress for Q directly as a function of frequency: the source spectral shape is unconstrained. Fitting a Q_0 f^q function from 0.2 to 25 Hz yields Q = 410 f^0.5, for a group velocity of 3.5 km/s. This attenuation is somewhat stronger than the Lg attenuation of 650 f^0.36 found by Erickson et al. (2004) and much stronger than the attenuation 944 f^0.32 found by Atkinson (2004). We fit Brune spectral shapes to the corrected source spectra by matching the low-frequency (0.1 Hz) displacement and high-frequency (from 5 to 20 Hz) acceleration spectral levels. The source spectrum for the M 4.0 Bar Harbor earthquake fits the Brune spectrum from 0.1 to 10 Hz while the source spectra for the three larger earthquakes fall below the Brune spectra from 0.2 to 5 Hz by as much as a factor of 3. The Brune stress drops for the four earthquakes range from 14 to 260 bars, and correlate strongly with hypocentral depth. The M 4.0 Bar Harbor earthquake, at 2 km depth, has the weakest stress drop, and the M 4.4 Cap Rouge earthquake, at 22 km depth, has the strongest.
PRECARIOUSLY BALANCED ROCK CONSTRAINTS ON EARTHQUAKE SOURCE AND ATTENUATION IN CALIFORNIA AND NEVADA: COMPARISONS WITH EASTERN NORTH AMERICA

BRUNE, James N Nevada Seismological Laboratory University of Nevada, Reno, Neno, Nevada, 89557 USA

Precariously balanced rocks (PBRs) in arid regions of southern California and Nevada have been exposed to many large nearby earthquakes over thousands of years, and thus can provide a strong statistical constraint on earthquake source excitation and ground motion attenuation. Some areas exhibit strong attenuation of ground motion typical of extensionally faulted high heat flow regions (e.g., Salton Trough, CA). On the other hand some areas show very low attenuation similar to that of the Eastern U.S. (e.g., the Peninsular Ranges of Baja California -Southern California). PBRs suggest that near-source ground motion is low near short faults in rigid basement and near trans-tensional sections of faults, and, conversely, higher near long straight sections of faults (possibly due to directivity). The Baja California M6.8 earthquake in a solid granite batholith had very low near-source ground motion but anomalously high ground motions at large distances in S. California (similar to some cases in eastern North America). Smaller earthquakes confirm the low attenuation. The low attenuation correlates with a relatively uniform, un-faulted continental crust with low heat flow, similar to the crust in eastern North America. We compare the data with ground motion attenuation curves for both western and eastern North America, and discuss implications for earthquake hazard.

EARTHSORIES TRANSPORTABLE ARRAY; CURRENT PROGRESS AND FUTURE PLANS

BUSBY, Robert W., WOODWARD, Robert, SIMPSON, David, HAFNER, Katrin IRIS, Washington DC 20005

The Transportable Array (TA) element of Earthscope/ US Array is a large deployment of 400 high quality broadband seismographs. The construction of this array began in September 2003 and the full deployment is now continuously rolling from west to east across the continental US, requiring the installation (and removal) of approximately 18 stations each month for a ten year period. New stations have been installed in 2009 in a north-south swath extending from North Dakota to Texas. Stations were removed in from Arizona northward to western Montana. We provide updates to equipment additions made to the TA, and plans for future activities. Equipment improvements include power regulation for sensors and the addition of data channels recording temperature and barometric pressure. Additional data channels are available that could be used for auxiliary sensors such as infrasound. On-site data recording hardware has been improved to reduce the time required before the final and complete archival data are released. The network up-time has averaged greater that 95%. The final data archiving for a TA station, which includes full quality control and fills in any remaining data gaps, takes place a few months after the station has been removed. New
equipment and procedures shorten this time, so that complete, updated archival data are available within a few months after real-time acquisition. The TA now produces a narrative archival report for each station called a Station Digest. This report summarizes the details about the equipment, station performance and service history and is available as a Data Product from the IRIS Data Management Center. We discuss plans to deploy TA stations into the southeastern Canadian provinces of Ontario and Quebec, in cooperation with the Geological Survey of Canada and Canadian researchers in the Great Lakes region, beginning in 2011. The TA deployment is also leaving behind legacy stations, as a number of TA stations remain operational under the Station Adoption program, and numerous seismic vaults have been transferred to other institutions for further studies. The Transportable Array is operated by the IRIS Consortium, and is part of the EarthScope Program sponsored by the National Science Foundation.

**NEXT GENERATION ATTENUATION (NGA) EAST GROUND MOTION DATABASE: ISSUES AND INITIAL EFFORT**

CRAMER, Chris, KUTLIROFF, Jerome, and DANGKUA, Donny, Center for Earthquake Research and Information, University of Memphis, Memphis, TN 38152-3050, ccramer@memphis.edu

The U.S. Nuclear Regulatory Commission has funded our initial effort of developing an eastern North America database of ground motions, which has focused on collecting data for M > 4 earthquakes in the CEUS and southeast Canada, mostly since January 1, 2000. We selected 24 events with moment magnitudes of M 4.0 and greater between 25N and 55N latitude and 65W and 100W longitude. In addition we have added data from the 2008 M5.2 Mt. Carmel, Illinois earthquake and three M4 aftershocks. Waveforms and ancillary information were downloaded from the IRIS data center (USGS ANSS and Lamont Doherty Cooperative Network) and the Canadian national data center (CNDC). Additional data for some events were obtained from the Center for Earthquake Research and Information, St. Louis University, Virginia Institute of Technology, and Weston Observatory. Available source and site information has also been collected for these events and recordings. Collected broadband and accelerometer records have been instrument corrected and bandpass filtered based on event and pre-event spectral signal-to-noise. Additional quality control efforts include examining waveforms and looking for amplitude-distance outliers for each event to identify poles/zeros file and instrument problems. Initial comparisons to current ENA ground motion attenuation relations suggest good correspondence with site-condition corrected observations from the 2005 M5.0 Riviere du Loup and 2008 M5.2 Mt. Carmel earthquakes, particularly at distances less than 100 km. However, alternative magnitude determinations for the same event can vary by 0.2 magnitude units, which can affect attenuation interpretations and comparisons significantly. Issues to be addressed for NGA East include proper assigning of event magnitude, need for more observations less than 100 km, need for stable continental region observations for M>6, examination for radiation/source effects, and limited availability of station Vs data.
EARTHQUAKE RECURRENCE VARIABILITY: LIMITATIONS OF FEW INTERVALS

CRAMER, Chris, Center for Earthquake Research and Information, University of Memphis, TN 38152-3050, ccramer@memphis.edu

In developing time dependent seismic hazard estimates for the New Madrid and Charleston seismic zones, the limited number of recurrence interval observations (3 or less) can provide a reasonable estimate of mean recurrence but not an estimate of variability. The approach used in estimating the mean recurrence interval is to fit a lognormal distribution to a Monte Carlo sampling of recurrence interval estimates that include their uncertainty (Cramer et al., 2000; Cramer, 2001). A lognormal distribution is preferred over a normal one because a normal distribution allows lower-tail negative values and a lognormal distribution is limited to positive values. Using 1000 samples based on uncertainty in dating of three earthquake occurrences does not inherently improve the statistics of small numbers in the case of the New Madrid seismic zone and still leads to an underestimate of variability. Another example of underestimation of the lognormal standard deviation (intrinsic sigma) is Nishenko and Buland (1987) who used short sequences (5 or less, except one event in Japan with 9) at several plate boundaries for a worldwide estimate for intrinsic sigma of 0.21. Ellsworth et al., 1999 used longer sequences of recurrence intervals to obtain a distribution of worldwide intrinsic sigma centered at 0.5. Specific examples reinforce the increase in estimated variability with increasing number of recurrence intervals due to better sampling of the distribution tails. For the Parkfield segment, Savage, 1991 gives a value of 0.35 (7 intervals). Cramer et al., 2000 calculates a southern Cascadia value of 0.43 (9 intervals). Petersen et al., 2002 estimate a value of 0.58 for northern Cascadia (6 intervals). And Cramer et al., 2000 estimates an intrinsic sigma of 0.77 for the southern San Andreas (24 intervals). Clearly, when dealing with few intervals for estimating intrinsic sigma, the worldwide result of Ellsworth et al. of 0.5 should be assumed.

SOME EXAMPLES OF POSSIBLE EARTHQUAKE ANOMALIES OF REMOTE SENSING INFORMATION IN CHINA

DENG, Zhihui, CHEN Meihua, YAN Yan, YANG Zhuzhuan, TAO JinLing, ZU Jinhua, Institute of Geology, China Earthquake Administration, Beijing 100029, China

Some Examples of Possible Earthquake Anomalies of Remote Sensing Information in China During the last decades, scientists have made some progress in using remote sensing to find earthquake anomalies. In this paper, some cases are showed in China. 1. 2000 Yaoan earthquake Yaoan Ms 6.5 earthquake occurred on Jan. 15th, 2000 in Yunnan, Southwest China. It was found there is obvious belt-like thermal anomaly along Honghe fault in 20 days before the mainshock. The brightness temperature inside fault belt is about 0-1.5 higher than the outside temperature in the normal period. But the temperature inside fault belt goes 2 higher than that outside the fault belt in most anomalous period. 2. 2001 Kunlunshan earthquake Kunlunshan Ms 8.1 earthquake took place on Nov. 14th, 2001 on Kunlun Mountain, Northwest China. Brightness temperature difference is studied in HohSaiHu segment of eastern Kunlun fault in 2001. The result
shows that the inside temperature is about 2 lower than the outside temperature in the normal period. But half and one month before the earthquake the temperature inside region goes 1 higher than that outside region. It returns to normal after event. 3. 2005 Jiujiang Earthquake On Nov. 26th, 2005, an earthquake (Ms 5.7) occurred near Jiujiang City, Jiangxi, East China. It is found that significant surface latent heat flux (SLHF) anomaly emerged before the event in the epicentral area and its northern area where a lot of lakes are distributed along the faults. 4. 2008 Wenchuan Earthquake Ms 8.0 earthquake occurred in Wenchuan County, Sichuan, Southwest China on May 12th, 2008. Based on MODIS remote sensing data, large-area SLHF is estimated with dual temperature-difference model from April to May in 2008 in Sichuan area. The result shows that one week before the earthquake, especially 2 days before the mainshock, the SLHF is obvious high in the epicenter area and surrounding areas of Longmenshan fault, which is probably the abnormal response before Wenchuan Ms 8.0 earthquake.

**SEISMIC ACTIVITY IN NORTHERN ONTARIO: AN ONGOING STUDY**

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A seismic monitoring program began in 1982 to document earthquake activity in the northern Ontario portion of the Canadian Shield in order to quantify seismic hazard in this region of minor earthquake activity. More than 750 earthquakes were located in the region with Mn magnitudes ranging from 0.5 to 4.3. This detailed monitoring has: i) dropped the location threshold from 3.5 to about 2.0; ii) established the rate of Mw > 4 events as 0.03 per annum; iii) determined the b-value as 1.2; iv) used Rg-phase and a Regional Depth Phase Method to determine earthquake depths for the larger events; v) identified a non-random distribution of events and observed that much of the activity occurs as shallow swarms; and vi) identified areas where the earthquake depths are shallow (<6 km) and where the depths are deep (6-17 km).

**DO MAGNETIC LINEAMENTS PROVIDE A USEFUL PROXY FOR SEISMOGENIC STRUCTURES IN SCRS?**

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In stable continental regions (SCRs), magnetic lineaments are sometimes employed to aid seismic hazard assessment under the assumption that they provide a proxy for locations and distribution of potential seismogenic faults. In this study, we test this assumption in two regions, by comparing observed magnetic lineaments with other published types of data (seismic profiles, geologic maps), along with patterns of seismicity documented in the GSCs online catalog. The first region contains the western Quebec seismic zone and the second is a seismically quiescent region containing the
Great Slave Lake shear zone in the Northwest Territories. In both of these areas, Precambrian bedrock is well exposed and magnetic lineaments correlate with either dike swarms (sets of iron-rich tabular intrusive bodies) or shear zones, which are ancient, deeply eroded fault zones. We locate and characterize magnetic lineaments using skeletonization, a flexible pattern-recognition technique that can be applied to both seismic profiles and magnetic grids. On seismic profiles in western Quebec, large shear zones are often expressed as bands of reflectivity, although dike swarms are typically not discernible due to their near-vertical orientation. In these areas we find that there is no obvious systematic relationship between magnetic lineaments and seismicity. In western Quebec, there is abundant seismicity, but no evidence for correlation with magnetic lineaments. The Great Slave Lake shear zone of the Northwest Territories is an ancient strike-slip fault analogous to the San Andreas fault. It contains well defined lineaments, but none appear to be associated with any observed earthquake activity. Taken together, our results imply that linearity of features on aeromagnetic maps is insufficient evidence, by itself, to justify concerns about elevated seismic risk. This does not imply that basement structures are unimportant for hazard studies in stable continental regions; it merely indicates that more in-depth analysis of crustal structure is needed before definitive conclusions can be reached.

ANALYSIS OF AFTERSHOCK AND FORESHOCK ACTIVITY IN STABLE CONTINENTAL REGIONS: IMPLICATIONS FOR AFTERSHOCK FORECASTING AND THE HAZARD OF STRONG EARTHQUAKES

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The Omori-law aftershock parameters for 13 earthquakes in stable continental regions (SCRs) globally are found to distribute in the same way as those for California aftershock sequences. Of 19 SCR mainshocks with M6.0 since 1968, 8 had their largest aftershock within 5 days of the mainshock and 11 within 30 days of the mainshock. The mean magnitude difference between the mainshock and the largest aftershock of these 19 SCR events is 1.4 ± 0.7 magnitude units, with a range from 0.3 to 3.6 magnitude units. From 1968 to 2003 the rate at which SCR earthquakes of M4.5 worldwide were followed by a comparable or larger earthquake within the next 30 days is 5%. These statistics can be used to produce aftershock forecasts for strong SCR earthquakes and to estimate the chances that an SCR earthquake of M4.5 will be followed by a larger seismic event within the next month. In particular, they can be used as the basis of aftershock forecasts for mainshocks that take place in eastern North America.

A STRATEGY FOR SITING STRONG-MOTION INSTRUMENTATION IN THE CENTRAL AND EASTERN U.S.
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One important question in the Central and Eastern U.S. (CEUS) is where to place a limited number of instruments to collect strong ground-motion data from future earthquakes, especially near-source recordings of strong earthquakes. Given the earthquake rate in the CEUS, a careful strategy must be followed in siting strong-motion instrumentation both to maximize the number of strong-motion recordings that are obtained and to optimize the chances of acquiring near-source ground-motion records for the strongest earthquakes that will take place during the next 1-2 decades. I propose a strategy based on the past earthquake history and the assumption that a similar pattern of earthquakes will follow in the near future. I have constructed maps that show where the strongest ground motions have been most frequently experienced in the central U.S., the northeastern U.S., and the southeastern U.S. during the past century. For each map, the earthquakes with estimated magnitude of 4.5 and greater were selected, and pga maps were computed using the ground-motion attenuation relations of Atkinson and Boore (2006). The areas within the 0.01g pga contours indicate where the strongest ground motions were experienced. In the central U.S., pga0.01g was most frequently experienced in the New Madrid seismic zone and in southeastern Illinois near Indiana. Curiously, the center of Arkansas, north-central Illinois, and north-central Alabama also are places where strong-motion instrumentation might be considered. In the northeastern US multiple of episodes of pga0.01g occurred in northern Maine, central New Hampshire, and the Adirondack Mountains of northeastern New York. Easternmost coastal Maine and western New York each experienced two episodes of shaking with pga0.01g. In the southeastern U.S. the localities where future ground motions with pga0.01g might occur appear to be in eastern Tennessee, central Kentucky, eastern Georgia, and South Carolina near Charleston.

A TEST OF THE PALEOSEISMICITY MODEL IN THE EPICENTRAL AREA OF THE 1727 NEWBURY, MASSACHUSETTS EARTHQUAKE

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In 1727 there was an earthquake in northeastern Massachusetts near the town of Newbury, a shock that was felt throughout coastal New England and as far southwest as Philadelphia. The earthquake caused modified Mercalli intensity (MMI) VII effects in the Newbury area. Currently there are four portable seismographs deployed in the epicentral area of the 1727 Newbury, MA earthquake in order to test the "paleoseismicity model" proposed by Ebel et al. (2000), in which much of the routine seismicity of the central and eastern U.S. (CEUS) is regarded as aftershocks of earthquakes that occurred decades, hundreds, or even a few thousand years ago. A specific statistical test of the paleoseismicity model is being carried out by conducting a survey of small earthquakes in the inferred epicentral area of the 1727 Newbury, MA earthquake. If the paleoseismicity model is correct, this monitoring should yield the detection of about 12 M 0.0 and many smaller microearthquakes per year in the study.
area. The paleoseismicity model suggests that these events should be spatially clustered on the historic fault plane. Thus, just a couple of years of microearthquake monitoring by several portable seismic stations in the Newbury area should yield enough data to verify the paleoseismicity model in a statistically significant way. In turn, this would allow an assessment of whether or not the paleoseismicity model might be more generally applicable in the CEUS. So far, a couple small earthquakes in the Newbury area have been recorded by the portable instruments as well as the New England Seismic Network seismographs. More careful analysis must still be carried out to look for smaller microearthquakes in the data being collected.

**SURFACE-WAVE PHASE-VELOCITY MODELS AND ARRIVAL ANGLE VARIATIONS ESTIMATED FROM USARRAY DATA**

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The USArray Transportable Array provides a continuing source of new data as it makes its way eastward across the United States. We use a two-station method based on ray theory to make phase-anomaly measurements for Love and Rayleigh waves at 25-100 seconds period. These phase measurements are inverted for phase velocity models at discrete periods, providing insight to the structure of the crust and upper mantle down to approximately 150 km. To improve these phase velocity models, we investigate the single-plane wave, great-circle path propagation assumed in our method by making estimates of the arrival angle for seismic waves recorded across the array. We make single-station phase measurements using the method of Ekström, Tromp, and Larson (1997), and use equal-phase contours to visualize the wavefront for a given event. Varying amounts of deviation from the plane-wave assumptions inherent in traditional two-station methods are observed. Using both USArray data and synthetic seismograms calculated from a 3-D Earth model, we estimate the arrival angle at each station using the geometry of these wavefronts and calculate a corrected inter-station phase value to test the effects of the deviations on two-station measurements. In most cases, corrections are small, in agreement with previous studies, and the synthetic arrival angle estimates are consistent with those made from real data. Thus, these corrections do not explain the sometimes large differences in the observed phase of waves propagating in opposite directions along the same inter-station path. To examine the effects of far-field anomalies on propagation, we estimate the average arrival angle for the entire regional array for a single event, fitting an apparent source location to the observed phase measurements. This is done for events around the globe, and yields a best-fit arrival angle that varies with frequency and shows systematic variations with event back azimuth, providing information about the source-to-array path.
A comprehensive understanding of seismic hazard in the Central and Eastern US (CEUS) requires accurate depths and moment tensors of regional earthquakes. Currently estimation of such parameters for CEUS earthquakes is limited to events with \( M > 4 \), in part because smaller events cannot be modeled using available 1D crustal models. We construct new 3D models of crustal structure for the CEUS east of 100°W. These wavespeed models are derived from two types of data: (1) Rayleigh-wave group velocities in the period range 8-30 s between 72 ANSS and other broadband stations in the region, generated through cross-correlation of ground-motion noise (i.e. ambient-noise Green’s functions); and (2) receiver-function measurements beneath approximately the same seismic stations, which provide localized estimates of Moho depth and crustal stratification. We have compiled ambient-noise Green’s functions from one year of data, producing Rayleigh waveforms for over 1000 station-station paths with sufficient signal-to-noise ratio (>5) for group-velocity analysis, and we have generated \( Ps \) receiver functions for over 45 stations. We have constructed a crustal model with \( P \) and \( S \) velocities defined in three layers (sediment, upper crust, and lower crust) on a 0.25x0.25 degree grid, using model Crust 2.0 as a starting model. The group velocities and receiver function (\( P-s \)) travel times are inverted for variations in \( P \)- and \( S \)-velocities and layer boundary depths across the region. This simply parameterized model characterizes lateral variations in crustal structure within the eastern United States in a form that is useful for earthquake source studies. The model and software to manipulate it will be made available through the website for the Lamont Cooperative Seismic Network (LCSN).

MARCH 2009 SWARM NEAR MANSEL ISLAND, NUNAVUT

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On March 21, 2009 a 4.0 Mw earthquake occurred near Mansel Island in northern Hudson Bay. Within the next ten days a swarm of over 100 events ranging in magnitude from 1.0 to 3.9 mN were located. The focal mechanism of the main shock was found to be predominantly thrust faulting with an EW striking plane, and the depth was found to be shallow (less than 5km). This is supported by the strong Rg-phases seen on the waveforms for the main event, as well as most of the aftershocks. Although this region has experienced earthquakes in the past, the normal rate of earthquakes for this small
area has averaged only 1 M > 3.5 every 10 years since 1985. Historically this region has seen swarms and larger events, notably in 1952 when there was a series of five M 4+ events over two days. Given the network at the time, any smaller events were likely not locatable. The network in the region improved significantly with the addition of over 15 POLARIS installations starting in 2006/09. This has dropped the location completeness threshold from ~M3.5 down to ~M2.5.

(YET) ANOTHER NEW LOOK AT THE 1811-1812 NEW MADRID EARTHQUAKES: TAKING THE "I" OUT OF INTENSITY ANALYSIS

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Documented macroseismic effects provide the most direct constraint on magnitudes of the 1811-1812 New Madrid mainshocks and large aftershocks, as well as an important reality check on predicted ground motions from future large events. The first critical step in analysis of macroseismic observations is the assignment of intensity values. The uncertainties associated with these interpretations are occasionally the subject of discussion but are rarely, if ever, explored systematically. The reinterpreted intensity values determined by Hough et al. (2000) for the 1811-1812 New Madrid mainshocks, for example, are systematically lower than values assigned earlier by Nuttli (1973) and Street (1982), leading to lower magnitude estimates. To explore the uncertainties associated with intensity assignments and develop a set of consensus intensities for the four principal New Madrid events, extant archival accounts were made available to four researchers with experience analyzing historical earthquakes. The independent assignments were then averaged, resulting in 84 intensity estimates for the 12/16/1811 mainshock and 45-49 estimates for the 1/23/1812 and 2/7/1812 mainshocks and the "dawn aftershock" on 12/16/1811. The consensus values are generally lower than those assigned by Hough et al. (2000). Using the method of Bakun and Wentworth (1997) with two published attenuation models for the CEUS, intensity magnitude estimates range from $M_L$ 6.5-7.0 for the December mainshock, dawn aftershock, and January mainshock, and $M_L$ 7.3-7.6 for the February mainshock. These results reveal that uncertainties in intensity assignments contribute significantly to uncertainties in magnitude estimates. For the 12/16/1811 mainshock, magnitude estimates based on assignments by individual experts vary over a range of 0.3 units.

TSUNDERI HAZARD MONITORING ON THE U.S. ATLANTIC COAST

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The primary operational objectives of a tsunami warning system are: Rapidly locate, size, and characterize major earthquakes, Determine their tsunamigenic potential,
Forecast tsunami impact, and Disseminate the appropriate information. The level of tsunami hazard to the Atlantic Coast of North America is difficult to assess because of the absence of historical tsunami records, and the large uncertainty in the recurrence interval of significant events. Large transoceanic tsunamis may be generated by major earthquakes west of Portugal as well as from the Puerto Rico Subduction Zone. The West Coast and Alaska Tsunami Warning Center (WC/ATWC) seismic detection system includes about 400 stations, many of which are located in the Eastern U.S. The system uses a regional coherent energy associator that automatically detects and locates 97% of global earthquakes magnitude 5.5 and above. In addition, we are also enhancing detection capability through the recent implementation of a neural network trained to differentiate between seismic signals generated by earthquakes and those generated by ambient and coherent noise. Another significant tsunami hazard for this region is local submarine landslides that may cause concentrated damage to nearby communities. Surface and submarine landslides are often difficult to locate due to the emergent nature of the primary wave. However, landslides large enough to generate a dangerous tsunami produce high amplitude surface waves that may be used to determine the source location. A surface wave locator was developed at the WC/ATWC that tracks the peak of the Hilbert transform of the recorded Rayleigh wave packet. A least squares grid search is then performed that yields an optimal solution for both the location and the group velocity at specified frequencies. Seismic arrays and potentially hydrophones may also be used to detect submarine landslides.

THE 2008-2009 DILLSBURG, PA, EARTHQUAKE SWARM: SOURCE CHARACTERISTICS

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Very shallow earthquakes have occurred in the northeastern U.S. which were characterized as having extremely high ground shaking than the size of the earthquakes implied. For example, 2003 Milford, NJ - Upper Black Eddy, PA (M 3.5) and Bar Harbor, ME (M 4.3). Beginning in October 2008 and continuing through the summer of 2009, an intense microearthquake swarm of over 650 felt events have occurred near Dillsburg, York County, Pennsylvania. Because of their shallow depth, the microearthquakes caused booming sounds and noticeable shaking, despite their small magnitudes. However, no significant damage from these earthquakes has been reported. A common feature of the Dillsburg, PA earthquake swarm and the two shallow earthquakes mentioned before is intense shaking around the epicentral area due to their shallow depth as well as perhaps, higher stress drops of these events that give rise to higher ground accelerations. We deployed portable seismographs around the Dillsburg, PA epicentral area for two months in 2008. We analyzed the microearthquake data in an attempt to address a set of questions. The first question is whether intraplate earthquakes are self-similar or whether there is a break down in stress drop scaling relations below a critical magnitude. Constant stress drop is widely accepted as a first order approximation for earthquakes that occur in plate boundaries globally, but a non
constant scaling relationship has been proposed for Eastern North America. A breakdown in stress drop scaling relation implies changes in fault dimension with earthquake size within stable continental settings. The observed break down of self-similarity has been suggested as due to measurements made with severely band limited seismic data. That is, source corner frequencies determined from 40 to 100 samples/s data for earthquakes smaller than about magnitude Mw 3.0. We monitored aftershocks of the Dillsburg earthquake swarm with portable digital seismographs with sample rate between 250 to 500 samples/s to constrain source spectrum corner frequencies of small earthquakes. We analyzed S waves from small earthquakes using Empirical Green’s Function method to minimize local site and path effects. Preliminary results indicate that corner frequencies range from 75 to 180 Hz for small earthquakes in the magnitude (Mw) range 0 to 1.

**UPWARD CONTINUATION OF SURFACE WAVES AND NAKAMURAS H/V TECHNIQUE**

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Nakamuras technique for understanding ambient noise H/V ratios relies on a series of empirical assumptions and simple wave propagation ideas. These include assuming that vertical and horizontal ground motions are equal at depth, that the horizontal component of ground motion becomes amplified but the vertical components do not, and that horizontal ground motion amplification is due to vertically propagating shear waves that constructively interfere in near surface, low velocity layers. Ambient ground motions in the period range of 3-5 sec in the Mississippi embayment have been shown to be primarily composed of fundamental and higher mode surface waves that propagate into the continent from oceanic waves interacting with the continental shelves. These surface waves are horizontally propagating and interact with the thick unconsolidated sediments in a complex way. A plane wave propagator matrix method is developed to create surface wave receiver functions to model observed ambient noise H/V ratios. Use of complex wave slowness for incident plane waves can mimic surface wave geometrical spreading and attenuation and serves to remove artificial singularities in computed H/V ratios. The propagator matrix technique also provides a way of directly propagating the H/V ratio at depth to the surface. In the case of the thick embayment sediments, the placement of the fundamental frequency of the H/V peak is mostly controlled by a robust spectral null in the vertical component motion but that much of the amplification does occur in the horizontal components. However, the amplitude of the spectral peak is not an appropriate measure of shear wave amplification from local earthquakes since it is strongly dependent on the wave slowness. These results are broadly consistent with Nakamuras assumptions but show that, in detail, the wave propagation is much more complex.
ON THERMAL INFRARED ANOMALIES BEFORE EARTHQUAKES FROM THE RELATIONSHIP BETWEEN SATELLITE INFRARED BRIGHTNESS TEMPERATURE AND TERRESTRIAL HEAT FLOW

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Most scholars agree that thermal anomalies on the earth surface would occur before some strong earthquakes. But it is debatable whether thermal anomalies can be observed by satellite remote sensing technology. By analyzing the relationship between thermal infrared brightness temperature and terrestrial heat flow, this thesis tries to discuss the probability on the observation of thermal anomalies before earthquakes using satellite remote sensing technology. If results indicate that rules between the brightness temperature and terrestrial heat flow in different regions are similar on the whole, then we can infer that there are highly significant correlations between them and it is possible to observe the thermal anomalies by satellite remote sensing technology. On the contrary, if results indicate that rules between the brightness temperature and terrestrial heat flow in different regions are very inconsistent, then we can infer that thermal anomalies are not always observed by satellite remote sensing technology. The results are as follows: (1) In most cases, brightness temperature increases with the terrestrial heat flow increasing and the average rate is 0.057/mWm^{-2}. If terrestrial heat flow anomaly resulted from an earthquake is 100 mWm^{-2}, there would be a satellite thermal infrared anomaly about 5.7. (2) The brightness temperature rates of change following terrestrial heat flow are different in different regions. That is to say there are different forms in different regions if satellite thermal infrared anomalies occur before earthquakes. (3) The relationship between brightness temperature and terrestrial heat flow is unclear in some regions and seasons. It may because the brightness temperature data is disturbed by meteorological factors. That implies that the thermal infrared brightness temperature anomalies are very complicated and they even cant be observed sometimes.

IMAGES OF LITHOSPHERIC STRUCTURE BENEATH CANADA USING S-WAVE RECEIVER FUNCTIONS

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S-wave receiver functions are used to image the lithospheric structure along a southwest-northeast transect extending from Vancouver Island, across the Canadian Cordillera, Prairies and Shield to Baffin Island. The images were created using 90 teleseismic events with magnitudes greater than 6.0, in a distance range of 55 > 90 degrees recorded by 10 broadband stations. Receiver functions allow for detection of mantle discontinuities and provide constraints on the depth, sign and amplitude of velocity contrasts. We have chosen to use S receiver functions to image the lithosphere.
because Ps receiver functions often suffer from strong crustal multiple reflections in the range of ~10-25s (depending upon crustal thickness) following the P arrival. The conversions of elastic energy from shear to compressional (Sp) are not affected by multiple contamination, as the Sp phases appear as precursors to S. This allows for clear interpretation of boundaries in the depth range expected for tectonic plates (both subducted and continental). Along the entire transect across Canada the Moho is clearly imaged in the S receiver functions as a positive amplitude feature that increases in depth from 30km beneath Vancouver Island to almost 50 km beneath Baffin Island. In western Canada the images show a shallow lithosphere-asthenosphere boundary (LAB) beneath British Columbia (~85km) transitioning to a deeper LAB (100-150km) beneath the Rocky Mountains. The subducted Juan de Fuca slab can be traced beneath this to depths of ~300km, in basic agreement with previous studies. Beneath central Alberta and farther northeast the LAB becomes increasingly deep and reaches a maximum depth of ~250km beneath eastern Hudson Bay and Baffin Island. The amplitude of the LAB signal is variable throughout the region, perhaps reflecting regional differences in the sharpness of the boundary. In contrast to a number of previous studies in which the LAB beneath cratonic regions has proved difficult to map using SRFs, or the LAB appear to occur at depths that are significantly shallower other types of data, ours yield clear images that agree well with constraints from surface waves, magnetotelluric soundings and heat-flow modelling.

CORRELATION OF EARTHQUAKE EPICENTERS WITH GRAVITY ANOMALIES IN NEW YORK STATE

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Geographic Information System (GIS) technology is used on the undergraduate level as a teaching and research tool. The technology was used to create a map of earthquake epicenters and gravity measurements in New York State and Pennsylvania. The gravity and earthquake data collected by undergraduates at SUNY Potsdam and the Lamont Cooperative Seismic Network were converted to an ARCGIS grid. The gravity data and earthquake epicenter locations are displayed with political and state boundaries to study the relationships between gravity anomalies and earthquake epicenters. The project involves the compilation of 6500 gravity measurements and 370 earthquake epicenters. The compilation of both data sets to compile gravity seismicity maps revealed correlations between gravity anomalies and earthquake epicenters. An east-west trending gravity high north of the Adirondacks in northern New York correlates with a belt of earthquakes of shallow depth. This is the most seismically active area in New York State. The large gravity anomalies and steep gradients indicate the anomalies have a shallow source in an outer brittle layer where the earthquake epicenters are located. In western New York, the earthquakes have a northwest trend, which correlates with a northwest trending gravity high. In southeastern New York, the epicenters lie along a northeast trending gravity gradient. The Scranton gravity high
extending from Albany to Harrisburg has a deep-seated origin with few earthquake epicenters.

**BROAD-SCALE APPLICABILITY OF CORRELATION DETECTORS TO CHINA AND PARKFIELD, CALIFORNIA, SEISMICITY**

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We investigate the potential use of correlation detectors on a broad scale to improve seismic monitoring and reduce magnitude detection thresholds. Previous work has indicated from semi-empirical analysis and a case study in Xiuyan, China, that an order of magnitude improvement is possible comparing a correlation detector for similar events with a standard STA/LTA detector. This unit reduction in detection threshold is achieved with acceptably low false alarm rates of about one per day. Semi-similar events due to less than perfect matches arising from location and mechanism differences or source complexities can provide useful detections. Synthetic tests on 78,028 focal mechanisms indicate that statistically significant detections are still triggered for strike, dip, and rake variations as large as 55 degrees. The correlation techniques were then applied on a larger scale to 5,000 events at Parkfield, California, and 19,000 events in and near China. We are attempting to see how broadly applicable correlation methods can be applied to different tectonic settings and for what percentage of the seismicity. 111 million correlations were performed on Lg-waves for the events in China at 363 stations. Final results indicate two thirds of the 19,000 events can be detected by cross-correlation using this relatively sparse regional network. For Parkfield 82% of the events studied can be detected by cross correlation. Correlation detection is able to find additional events beyond what standard processing detects for China (70% increase) and for Parkfield (factor of 10 increase like Gutenberg-Richter predicts). Most event separation distances for events that correlate at Parkfield are less than 1 km. Detection magnitude threshold reduction of about 1 unit holds for large scale application to the 19,000 events in China and 5,000 events in Parkfield with false alarm rates of a few percent.

**THE 2008-2009 DILLSBURG, PA, EARTHQUAKE SWARM: GEOLOGIC SETTING**

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Beginning in early October, 2008, and continuing, so far, through September, 2009, residents of Carroll Township, just southeast of the Borough of Dillsburg in northern York County, Pennsylvania, have felt and reported more than 650 small earthquakes.
The largest intensities have been III on the modified Mercalli scale. This activity is occurring within the Mesozoic Gettysburg Basin, about 3 km. south of the border fault that separates the basin from early Paleozoic carbonate rocks. The earthquakes seem to be originating within and just below an approximately 350 m. thick sheet of York Haven diabase. The Jurassic diabase has intruded the Triassic Gettysburg Formation, which consists of shale, sandstone and limestone fanglomerate. The sedimentary rocks have experienced contact metamorphism and mineralization, predominantly magnetite, from the intrusion. Stress concentration near the contact between the contrasting diabase and metamorphosed sediments may play a role in the current seismicity.

RE-EVALUATION OF HISTORICAL SEISMICITY IN SOUTH CAROLINA PRIOR TO 1886

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The earthquake history of South Carolina spans a period of over three centuries, and is dominated by the catastrophic Charleston earthquake of August 31, 1886. Today, the Summerville Charleston area remains both the most seismically active region, and the most significant seismogenic zone to affect South Carolina and the southeast United States. When considering South Carolina seismicity, the 1886 Charleston earthquake stands out as a logical point of reference. So, as a first step in chronicling the earthquake history of South Carolina we have chosen the roughly 200 year period encompassed by the first permanent European settlement of the State and the 1886 event as the beginning chapter in recorded South Carolina seismic history. Utilizing the current USGS earthquake catalog as the most complete and generally accepted catalog in use today we critically examined and compared its pre-1886 seismicity to that presented in 6 other published catalogs listing pre-1886 South Carolina earthquake data. Our intent was to verify each catalog entry using primary sources of information (original newspaper accounts and diaries) to accurately update and modify the existing catalog. Results of our re-evaluation revealed a few event location inconsistencies, fictitious events, and missed events. Eight, possibly 9, of the 23 pre-1886 events listed in the USGS catalog were found to be fictitious. Most all the fictitious events were attributed to either misprints or transcription errors appearing in secondary and/or tertiary sources, with 4 of the 8 originating from a single author. Two, perhaps 3, additional events not listed were also found. A heretofore unmentioned series of small events occurring in May, 1835 near a long ago abandoned Union County town is one example. What finally emerges from our efforts is a modified list containing 18 pre-1886 South Carolina earthquakes.

DISCOVERY OF PREHISTORIC RUINS NEAR ALLAH BUND IN KUTCH, INDIA.
In the Rig Veda—the most ancient book in India (ca. 2500 BCE) there is mention of three rivers (Indus, Saraswati and Drishadvati) and possibly a fourth (Sutlej), that flowed from the Punjab in the northwest India to the Arabian sea. The tectonism that affected the outer Himalayas, the Aravalli hills, and the Kutch region, led to river capture in Punjab, and tilting to the north and northwest of the region in which these rivers flowed. These resulted in large changes in the courses of these rivers and in the amounts of water that they carried. By the time of the Mahabharata (ca. 900 BCE) the Saraswaati and Drishadvati had dried up, leaving behind tell-tale paleo-channels with ruins of ancient cities of the Indus-valley civilization on their banks. Malik et al. (1999) mapped possible paleo-channels of the deltas of these rivers in the northern reaches of the Rann of Kutch. The currently visible southward extents of these deltas terminate along the E-W Allah Bund, a south-facing fault scarp, about 4 to 6m high and about 90 km long, that was formed by the M 7.8 Kutch earthquake in 1819. While visiting the Allah Bund we discovered prehistoric ruins, with shards of baked clay pottery on the bank of one of the paleo-channel mapped by Malik et al. (1999). We anticipate that the age of a sample shard will help us establish if this was a site occupied at the time of the Indus-Valley civilization, nearly 5,000 years ago, or one established in historical times that followed, and was destroyed by a major earthquake.

**A NEW 3D CONCEPTUAL MODEL OF FAULTING TO EXPLAIN SEISMICITY OF THE NEW MADRID SEISMIC ZONE**

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A conceptual 3D flower structure model of strike-slip faulting is proposed to explain the occurrence of earthquakes in the New Madrid seismic zone (NMSZ) and to illustrate the potential rupture faults for the 1811-1812 earthquake sequences. The proposed model of the NMSZ is based on concepts of material failure under a stress field. Using a conceptual model of a strike-slip subsidiary fault array, we identify tectonic features that are oriented properly relative to regional stresses and classify the regions where stresses might be expected to be amplified. The upper crust in the vicinity of the NMSZ is modeled as a uniform overburden with a horizontal-basal surface, which rests on a horizontal ductile lower crust that is intersected by a vertical, right-lateral strike-slip shear zone. The brittle overburden material is subject to simple shearing stress parallel to the deep-seated lower crustal shear zone combined with an extension in the minimum stress direction or where expansion is caused by vertical uplift. The deep-seated fault movement deforms the overlying upper crust that controls the structural geometry, the modern seismicity, and the large earthquake sequences in NMSZ. The proposed conceptual model of faulting shows that the Bootheel and Big Creek
lineaments, inferred to be two subparallel shear faults rooted in the lower crust, are significant in shaping the geometry of the NMSZ. These series of faults produce a large-scale flower structure in cross section. The results show that some component of the shear strain in the NMSZ left-stepover region between the two shear faults is accommodated by right-lateral slip on the Big Creek fault, rather than on the northeast-trending seismic zone along the axis of the Reelfoot rift. The model gives rise to a predictable pattern of surface deformation that is in good agreement with observed seismicity patterns in the region. We suggest that the conceptual NMSZ model of faulting developed in this study be used as an alternative working model for defining locations of possible earthquake sequences, fault ruptures scenarios, earthquake magnitudes, and hence the future seismic hazard of the area.

**INTRAPLATE SEISMICITY IN CANADA: A GRAPH THEORETIC APPROACH TO PHYSICAL STRUCTURE AND INTERPRETATION**

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Intraplate seismicity is localized in both thinly and densely populated regions of Ontario, Quebec and Nunavut in Canada. The reasons for the occurrence and periodicity of the intraplate earthquakes are not as well understood as the interplate earthquakes. Here, we propose a graph theoretic approach to extracting information from the physical structure of the network of recurrent seismic events that occur in space and time, and to providing an interpretation on the causality of seismic events. To this end, we have identified five areas for our study as defined by the following ranges of latitude/longitude values: area 1: 45°-48°/74°-80°; area 2: 42°-45°/76°-81°; area 3: 51°-55°/77°-83°; area 4: 45°-57°/80°-98°; and area 5: 56°-70°/65°-95°. In this work, using a recently proposed definition of recurrences based on record breaking processes (Phys. Rev. E 77, 066107, 2008), we have constructed digraphs of the data extracted from the five areas (http://earthquakescanada.nrcan.gc.ca) with attributes drawn from the location of the events, the time of occurrences and the magnitude of the events. For a quantitative insight into the digraphs of the recurring events in space and time, we have examined the probability distributions of space-interval and time-interval recurrences for different magnitudes of earthquakes, the network properties such as the in-degree as well as the out-degree distributions for different magnitudes, and the clustering coefficient. To test for the presence of non-trivial spatiotemporal correlations and causal connections, we have carried out a series of Monte-Carlo simulations by reshuffling the spatial locations of the data without altering the time of occurrences. Here, we present the results of our study, compare them with similar ones obtained for a data set in an active, well-studied interplate region such as southern California, and draw certain conclusions about the physical structure of the intraplate seismicity in Canada.
REAL-TIME DOUBLE-DIFFERENCE SEISMIC MONITORING

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A real-time procedure is presented that uses cross-correlation and double-difference methods to rapidly relocate new seismic events with high precision relative to past events with accurately known locations. Waveforms of new events are automatically cross-correlated with those archived for nearby past events to measure accurate differential phase arrival times. These data, together with delay times computed from arrival time picks, are subsequently inverted for the vector connecting the new event to its neighboring events using the double-difference algorithm. The new seismic monitoring technique is tested with and applied to earthquakes recorded in Northern California, using near-real-time data feeds from the Northern California Seismic Network (NCSN) and the Northern California Earthquake Data Center (NCEDC), and a locally stored copy of the NCSN seismic archive. New events are automatically relocated in near-real-time (tens of seconds) relative to a high-resolution double-difference earthquake catalog for Northern California. Back-testing using past events across Northern California indicates that the real-time solutions are on average within 0.08 km laterally and 0.24 km vertically of the double-difference catalog locations. We show that the precision with which new events are located using this technique will improve with time, helped by the continued increase in density of recorded earthquakes and growth of the digital seismic archives. Real-time double-difference location allows for monitoring spatio-temporal changes in seismogenic properties of active faults with unprecedented resolution and therefore has considerable social and economic impact in the immediate evaluation and mitigation of seismic hazards. The usefulness of the new tools for monitoring seismic activity in Eastern North America is explored.

DOMAIN ANALYSIS MODELS FOR REFINING SEISMIC SOURCE PARAMETERS

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Current state of the art time-domain seismic analysis procedure entails 3 measurements; first break (FB) arrival time, maximum signal amplitude, and its period. Measured FB arrival times are applied to determine sources location parameters, and measured amplitudes and periods are applied to determined sources magnitude. As it stands, analysis procedure is limited in scope to impulsive phases with sharp clear discernible onset arrival times, and preferably high signal to noise ratio, otherwise the analysis is an interpretive art depending on analyst experience. Frequency-domain seismic analysis approach permits in depth look of seismic signals as function of amplitude, frequency, and time, and expands analysis scope to include, impulsive phases with or without discernible FB, emergent phases such as Rayleigh and Love
waves, regional phases, and low SNR. The approach applies Multiple Filter Analysis (MFA); a sliding narrow band Gaussian filters that generates monochromatic complex trace for each band. Modulus of most energy (ME) complex trace envelope among filtered traces is selected and its arrival time, amplitude and period are determined, and then processed to determine sources parameters. Time and frequency domains analyses are evaluated by determining location parameters for 27 nuclear explosions, with known ground truth, via seismic analysis models FB-H68 and ME-H68. Averaged location errors relative to ground truth, is 12 km for model FB-H68, compared to 6 km for model ME-H68, a 50% reduction in location error. Also, determined locations for 19 explosions by model ME-H68 are within the boundaries of their respective 95% coverage region error ellipses, compared to 7 determined by model FB-H68. In addition determined locations by model ME-H68 for 24 explosions are within 10 km from ground truth, compared to 13 determined by model FB-H68. Primitive P-waves ME travel time table, Y98, developed by the author, correlates well with Herrin et al 1968 (H68), in the distance range 5 to 90 degrees, with an average origin time delay of 2 seconds relative to FB arrivals. Location errors and origin time delays for 3 explosions at 3 different nuclear test sites are determined for seismic models, ME-Y98, ME-H68 and FB-H68. Averaged location errors for the 3 explosions are: 2.621.39 km for ME-Y98 model, 4.721.34 km for ME-H68 model, and 7.322.5 km for FB-H68 model. Corresponding averaged origin time delays are: 0.450.23 seconds for model ME-Y98, 3.170.47 seconds for model ME-H68, and 2.170.52 seconds for model FB-H68.

GEOMETRICAL SPREADING AND QUALITY FACTOR FUNCTIONAL FORM FOR NEW MADRID SEISMIC ZONE

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The functional form of geometrical spreading and quality factor functions are investigated for the New Madrid seismic zone (NMSZ) using recorded small and moderate earthquakes. These functions are used to model the path effect in frequency domain during the stochastic modeling. The database used in this study consists of 500 broadband seismograms from 65 events of magnitude Mw 2.5 to 5.2, recorded by the Center for Earthquake Research and Information (CERI) at the University of Memphis. CERIs broadband stations are located on different site conditions within the Mississippi embayment. The hypocentral distances of the seismograms in database vary from 10 to 400 km. The vertical components of the records are processed and used to define the path effect term in frequency range of 0.2 to 30 Hz. A hinged-trilinear geometrical spreading and frequency-dependent quality factor functions are used to describe the path term. The regression analysis using a Genetic Algorithm indicates that at distances less than 70 km the spectral amplitudes decay as 1/R, between 70 and 140 km, spectral amplitudes are approximately constant, and beyond 140 km, the attenuation is described by $R^{0.46}$ which is consistent with the theoretical studies. The quality factor function is obtained to be $Q=750f^{0.34}$ following a regression analysis. The results of this study are compared to those of Atkinson and Mereu (1992) and Atkinson (2004). The
result for geometrical spreading function is compatible with that of Atkinson and Mereu (1992). The path term obtained in this study can be used in the stochastic method to predict ground motions in NMSZ and eastern North America (ENA).

**SEISMICITY AND THERMAL STRUCTURE OF SUBDUCTED SLABS IN THE NORTHEAST OF COLOMBIA AND WESTERN VENEZUELA**

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The local seismicity in Colombia shows low frequency of seismic activity in the north and northeast of the country in comparison with the high frequency of seismicity in the central, south and south eastern of Colombia. The transition between these two distinct area is marked by the location of the smallest and the most active intermediate depth earthquake nest, the so called 'Bucaramanga nest'. In this research, we show that the observed subducted slabs in this region have two different thermal structure. The thermal structure can control the strength and deformation of the material. The high rate of seismicity, in this region is associated with the colder slab in the south. For a strain rate of $10^{-15}\text{S}^{-1}$, suitable for the upper mantle, the depth of brittle-ductile transition zone in the northern slab can vary between 127-139 km. In the southern slab this transition zone laid on depth interval of 156-172 km. The Bucaramanga nest at depths of 150-180 km, with high rate of seismicity can barely be produced as a process of brittle failure in the northern slab. The southern slab must be the host for the Bucaramanga nest, as has been suggested by different observations.

**RESULTS OF REPROCESSING SEISMIC REFLECTION DATA COLLECTED NEAR SUMMERVILLE, SOUTH CAROLINA**

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Reprocessing of seismic reflection data collected near Summerville, South Carolina in the period 1975-1983 reveals an extensive early Mesozoic extensional basin lying between Summerville and Charleston. The basin is delineated by the geometry of basement reflections that image early Mesozoic mafic volcanic rocks, and by positive magnetic and gravity anomalies. Cenozoic compressional reactivation of Mesozoic extensional faulting is imaged in the interior of the basin. The northwestern boundary of the basin is marked by a sharp gradient in the magnetic field. Folding of Cretaceous and Tertiary Atlantic Coastal Plain sediments, diffractions from the basement and truncation of basement reflections is observed at four locations along this magnetic gradient, indicating that the northwestern basin boundary is controlled by faulting. Instrumentally located earthquakes are tightly clustered at the location of the faulting imaged in the interior of the basin, and in proximity to the imaged faulting on the northwestern basin margin. Modeling of the magnetic and gravity data indicates that the upper crust beneath the seismically imaged structural basin is comprised of mafic rocks to a depth of at least 4 km. It appears that the Charleston earthquake occurred due to compressional reactivation of extensional faulting associated with a localized zone of intense early Mesozoic continental rifting.