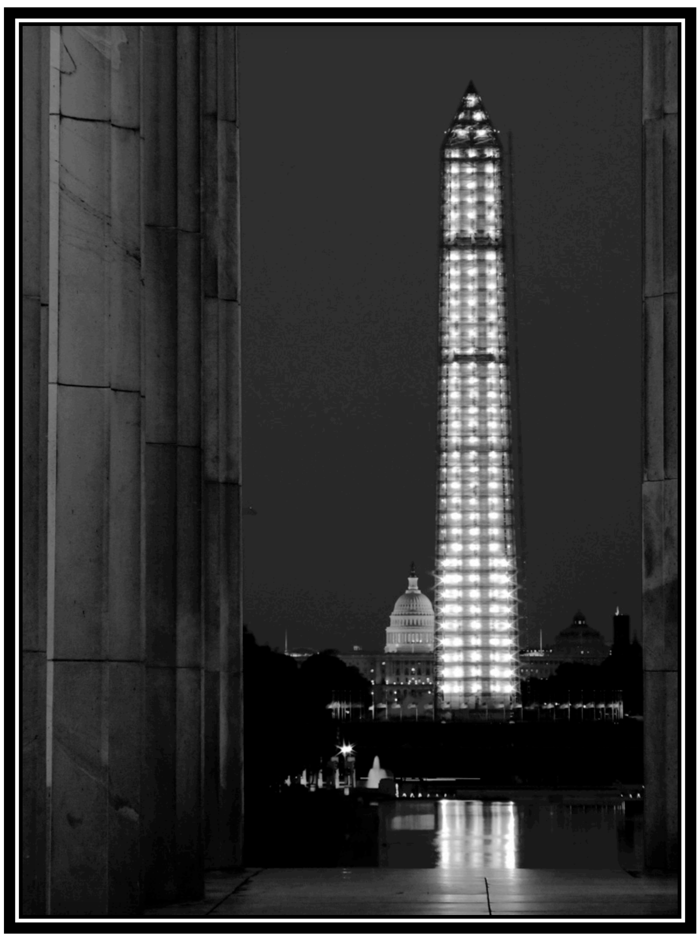
88th Annual Meeting of the Eastern Section of the Seismological Society of America

October 23-26th, 2016
Reston, VA



Acknowledgements

The work of many people made this meeting possible and we are grateful for their contributions. These people include:

Field Trip Leaders: J. Wright Horton, Jr., Steven Schindler, Terrence Paret

Banquet Guest Speaker: Terrence Paret

Abstract Submission and Registration: Bo Orloff, Sissy Stone, Nan Broadbent, SSA main office

Budget and planning: Charles Scharnberger from the Eastern Section of SSA

Graphic Design and Webmaster: Bo Orloff

Jesuit Seismological Society Award Committee.

Past meeting organizers, especially Steven Jaume, Chris Cramer, and Maurice Lamontagne.

Many thanks to all the session chairs!

Thomas Pratt, Oliver Boyd, and Christine Goulet
Planning Committee Chairs

Many thanks to our generous sponsors:

General Information

Meeting Theme:
The 2016 Eastern Section meeting is titled "From the Mantle to the Surface" and is a joint meeting with the Pacific Earthquake Engineering Research (PEER) Center's Next Generation Attenuation-East (NGA-East) project. It will include a combination of geophysical studies being carried out using the USArray and other ground-motion data in the eastern United States. Special sessions include crust and mantle studies utilizing USArray, studies of central and eastern U.S. faults, seismicity and ground motions, and the Next Generation Attenuation Project for Central and Eastern North America—NGA-East.

NGA-East Special Session (Wednesday 8:30-12:00):
The Next Generation Attenuation project for Central and Eastern North America (CENA), NGA-East, is a major multi-disciplinary project coordinated by the PEER. The project was co-sponsored by the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI) and the U.S. Geological Survey (USGS). The GMC model consists of a set of ground motion models (GMMs) for median and standard deviation of ground motions and their associated weights, combined into logic-trees for use in probabilistic seismic hazard analyses (PSHA). An overview of the project is presented, followed by highlights on its various products.

USGS Earthquake Hazards Program: *Review of Central and Eastern U.S. Earthquake Hazards Research Priorities and Funding Opportunities* (Wednesday 1:00-3:00)
The USGS wants to take the opportunity of the Eastern Section SSA meeting and gathering of the CEUS earthquake-hazards community to:

- discuss recent CEUS research funded by USGS
- garner input regarding future CEUS research priorities
- inform the community about research opportunities

This special session will be led by Robert Williams, Central & Eastern U.S. Coordinator of the USGS Earthquake Hazards Program.

"Geology and earthquake engineering, Washington, DC" Field Trip:
The field trip is on Sunday. If you have registered, ***please meet in the hotel lobby at 8:15 AM****, the bus will leave at 8:30 AM sharp. Lunch will be provided and we will return to the hotel between 5 and 5:30 PM.*

This field trip will introduce participants to the geology beneath Washington, DC, will discuss the influence of the geology on ground amplification, and will discuss the damage from the 2011 Mineral, VA, earthquake and the repairs made to two iconic buildings. The first half of the field trip is to understand the influence of the shallow geology on ground shaking in Washington, DC, and particularly during the 2011 earthquake. We will visit the Great Falls of the Potomac to see the crystalline bedrock and discuss the tectonics of the area. We next will stop in Rock Creek Park to see the shallow deposits that overlie the bedrock, and see a Quaternary fault exposed within the city. Discussion there will include summaries of recent studies of the ground amplification caused by the thin cover of Atlantic Coastal Plain strata deposits overlying bedrock. The second half of the field trip will be to visit the Washington Monument and the National Cathedral, both of which were damaged significantly during the 2011 earthquake and have undergone or are undergoing extensive repairs. At these buildings we will discuss the causes of the damage, and the repairs of these iconic structures.

Information for Speakers:
Oral Presentations will be 13 minutes long with 2 minutes for questions. Please make note of the session and time for your presentation. Equipment for PowerPoint presentations will be available. The most efficient way to load your presentation on the computer is to bring a USB stick with your PowerPoint file and load it on the meeting PC during a break before your session.

Information for Poster Presentations:
Tape (blue painters' tape) for the hanging of posters, up to approximately 4 ft wide by 3 ft high, will be made available. Please be near your posters during the Monday afternoon session and during parts of the coffee breaks.

Information for Session Chairs:
There will be a microphone at the lectern. Thirteen minutes should be allotted for the presentation with 2 minutes available for questions and changeovers. Because of the number of talks and the schedule it is imperative to keep all speakers on time. However, it is also important to stimulate discussion on each presentation if there are no immediate audience questions after talks that finish on time. Please be prepared to use your watch or cell phone timer to keep the speakers on time.

Meeting Website:
The full program, including the abstracts, is available at the meeting website:
http://www.seismosoc.org/meetings/ssa2016/es/

SRL Abstracts:
Abstracts for meetings of the Eastern Section, SSA will also published in Seismological Research Letters (SRL). For more information see the SSA website at www.seismosoc.org.

Meeting Venue:

About Reston, VA:
Reston, Virginia, is located 18 miles west of Washington, DC's National mall, and 6 miles east of Dulles Airport. It is a city of about 60,000 people and home to the USGS National Center as well as many businesses. The meeting hotel is located about 0.7 miles from the shops and restaurants of Reston Town Center, and about 1 mile from the DC Metro station with service to downtown Washington, to Reagan National Airport, and to surrounding areas.

Hotel:
Sheraton Reston Hotel
11810 Sunrise Valley Drive
Reston, VA 20191
Reservations: 800-325-3535 ("Eastern Seismological Society of America")

Travel Information to and from Dulles Airport:
Sheraton Reston Hotel is located just minutes from Dulles International Airport, which is served by numerous airlines as well as a free hotel shuttle. Upon arrival at Dulles, phone the hotel at 703-620-9000, proceed to curb 2H outside baggage claim, and look for the Sheraton Reston Hotel Shuttle. When returning to the airport, inform the front desk, which will call the shuttle. Note that due to airport shuttle restrictions you will be dropped off at the arrivals entrance and you will need to proceed upstairs to check in; the hotel advises adding 15 minutes to your departure schedule to accommodate this requirement.

Contacts:
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Program

Student presentations are denoted with ** before the title; presenter name is in **bold**

Sunday, October 23

8:30 AM Field trip: meet at 8:15 AM in lobby of the Sheraton hotel – return between 5:00 and 5:30 PM
6:00 PM Registration opens - at Icebreaker location
6:30 PM Icebreaker, Merlot Room, Cosmopolitan Restaurant, Sheraton Reston Hotel

Monday, October 24

7:30-8:30 Buffet Breakfast and registration

8:30-9:00 Welcome and Announcements (Pratt, Boyd, Goulet)

Session 1: Overview (Chair: Pratt)

9:00	CONTROL OF THE LITHOSPHERIC MANTLE ON EASTERN NORTH AMERICAN PASSIVE MARGIN EVOLUTION BIRYOL, ***Cemal B.***, *WAGNER, Lara S., FISCHER, Karen M., and HAWMAN, R.*
9:30	STRUCTURE AND DYNAMICS OF THE MID-ATLANTIC APPALACHIANS: PRELIMINARY RESULTS FROM THE MAGIC EXPERIMENT, ***LONG, Maureen D***., *BENOIT, Margaret H., KIRBY, Eric, ARAGON, Juan, MILLER, Scott, and LIU, Shangxin.*
10:00	MINERAL, VIRGINIA, 2011 AND CHARLESTON, SOUTH CAROLINA, 1886: SIMILAR AFTERSHOCK SEQUENCES AND THE DOMINANT ROLE OF COULOMB STRESS TRANSFER, ***CHAPMAN, M.C.***, *WU, Qimin, BEALE, Jacob N., and HARDY, Anna C.*

10:30-11:00 Break and Posters

Session 2: Eastern U.S. Overview
(Chairs: Cramer and Pontrelli)

11:00	EARTHSCOPE USARRAY: A LOOK BACK AT THE MOST EPIC EXPERIMENT, ***BUSBY, Robert W.***, *ADERHOLD, Kasey, FRASETTO, Andy, SUMY, Danielle, and WOODWARD, Robert.*
11:15	LEVERAGING EARTHSCOPE USARRAY WITH THE CENTRAL AND EASTERN UNITED STATES SEISMIC NETWORK, ***SUMY, Danielle F.***, *BUSBY, Robert W., FRASSETTO, Andrew M., ADERHOLD, Kasey, SUMY, Danielle F., and WOODWARD, Robert L., and BRUDZINSKI, Michael R.*
11:30	THE VARIATION OF LG ATTENUATION IN NORTHEASTERN NORTH AMERICA, ***BOATWRIGHT, John.***
11:45	RE-EVALUATION OF SEISMIC HAZARDS AT THE CENTRAL AND EASTERN UNITED STATES NUCLEAR POWER PLANT SITES, ***HEESZEL, David S.***, *MUNSON, Clifford G., and AKE, Jon P.*
12:00	COMPARISON OF STRESS DROPS FOR TECTONIC AND INDUCED EARTHQUAKES IN NORTH AMERICA, ***BOYD, Oliver S.***, *MCNAMARA, Daniel E., HARTZELL, Stephen, and CHOY, George.*
12:15	DISCUSSION

12:30-1:30 Lunch

Session 3: Eastern U.S. Seismicity I
(Chairs: Wu and Boatwright)

1:30	A HIGH-RESOLUTION STRESS MAP OF THE CEUS FROM MOMENT TENSOR INVERSIONS, ***LEVANDOWSKI, Will***, *BRIGGS, Rich, GOLD, Ryan, and BOYD, Oliver S.*
1:45	A SEARCH FOR RECENT EARTHQUAKES OFFSHORE OF NORTHEASTERN NORTH AMERICA, ***EBEL, John E.***, *and BORJA, Marina Silva.*
2:00	** EVALUATING MCADAM, NEW BRUNSWICK EARTHQUAKE SWARMS: AN ANALYSIS USING DOUBLE DIFFERENCE RELATIVE LOCATION, ***PONTRELLI, Marshall A***., *and EBEL, John E.*
2:15	WAVEFORM ANALYSIS OF THE 2015-2016 MCADAM, NEW BRUNSWICK EARTHQUAKE SEQUENCE ***PULLI, Jay J.***
2:30	TESTING THE FEASIBILITY OF USING GROUND PENETRATING RADAR TO IMAGE ATLANTIC COASTAL PLAIN STRATA AND SHALLOW DEFORMATION IN THE AREA OF CHARLESTON, SC, ***COUNTS, Ronald***, *and PRATT, Thomas.*
2:45	ESTIMATING STABLE CONSISTENT SEISMIC MAGNITUDES, ***VEITH, Karl F.***
3:00	DISCUSSION

3:15-4:15 Poster Session

Session 4: Induced Seismicity I
(Chairs: Peng and Levandowski)

4:15	ARRAY DESIGNS FOR THE IRIS WAVEFIELDS DEMONSTRATION EXPERIMENT, OKLAHOMA, ***LANGSTON, Charles A.***, *SWEET, Justin, ANDERSON, Kent, and WOODWARD, Robert.*
4:30	** STRESS DROP AND SOURCE SCALING OF RECENT EARTHQUAKE SEQUENCES ACROSS THE UNITED STATES, ***WU, Qimin***, *and CHAPMAN, Martin C.*
4:45	INTENSITY CORRELATIONS WITH REGIONAL Q, STRESS DROP, AND INDUCED AND NATURAL SEISMICITY IN THE CENTRAL US, ***CRAMER, Chris H.***
5:00	** SPATIOTEMPORAL ANALYSIS OF INJECTION-INDUCED EARTHQUAKES IN OKLAHOMA AND SURROUNDING AREAS, ***CHAMBLESS, Hannah E.***, *and KAFKA, Alan L.*

6:30-8:30 Banquet Dinner – Merlot Room, Cosmopolitan Restaurant

JESUIT SEISMOLOGICAL ASSOCIATION AWARD
BANQUET PRESENTATION: "ASSESSING AND ADDRESSING RISK IN REGIONS OF RELATIVELY LOW SEISMIC HAZARD", ***Terrence Paret - Wiss, Janney, Elstner Associates, Inc.***

Tuesday, October 25

7:30-8:30 Buffet Breakfast and registration	
	Session 5: Eastern U.S. Seismicity II **(Chairs: Jaume and Haji-Soltani)**
8:30	NEW VELOCITY MODELS AND HYPOCENTER LOCATIONS FOR THE NEW MADRID SEISMIC ZONE, ***POWELL, Christine A.***, *LANGSTON, Charles A., WITHERS, and Mitchell M.*
8:45	** SEISMICITY-HYDROLOGY RELATIONSHIPS IN THE EASTERN TENNESSEE SEISMIC ZONE, ***CAMERON, Cortney,*** *BRANDMAYR, Enrico,and VLAHOVIC, Gordana.*
9:00	STATE OF KNOWLEDGE OF EASTERN TENNESSEE SEISMIC ZONE PALEOSEISMOLOGY, *COX, Randel T.*, ***HATCHER, Robert D****. Jr., COUNTS, Ronald, WARRELL, Kathleen F., GLASBRENNER, Jacob C., GAMBLE, Eric, VAUGHN, James F., and OBERMEIER, Stephen F.*
9:15	USING LIDAR TO SEARCH FOR NEOTECTONIC FEATURES IN THE CENTRAL VIRGINIA SEISMIC ZONE FOLLOWING THE 2011 MINERAL, VA. M5.8 EARTHQUAKE, ***BURTON, W.C.***, *CARTER, M.W., HARRISON, R.W., WITT, A.C., and PAZZAGLIA, F.J.*
9:30	SYSTEMATIC INVESTIGATION OF THE AFTERSHOCK SEQUENCE OF THE 2011 MW5.8 VIRGINIA EARTHQUAKE, *MENG, Xiaofeng,* ***PENG, Zhigang****, and YANG Hongfeng.*
9:45	STUDYING THE INFLUENCE OF ROCK UNITS AND JOINTS ON SHALLOW AFTERSHOCKS OF THE 2011 MINERAL, VIRGINIA, EARTHQUAKE, ***HORTON, J. Wright Jr.***, *CARTER, Mark W., CHAPMAN, Martin C., WU, Qimin, SHAH, Anjana K., and WITT, Anne C.*
10:00	SEISMIC AND HYDROACOUSTIC ANALYSIS OF THE JUNE/JULY 2016 UNDERWATER EXPLOSIONS OFF THE EAST COAST OF FLORIDA, **PULLI, Jay J.**, and HEANEY, Kevin D.
10:15	DISCUSSION
10:30-11:00 Break and Posters	
	Session 6: Induced Seismicity II **(Chairs: Ebel and Cameron)**
11:00	BRUNE STRESS PARAMETER ESTIMATES FOR THE 2016 M5.6 PAWNEE AND OTHER OKLAHOMA EARTHQUAKES, ***CRAMER, Chris H.***
11:15	OKLAHOMA EXPERIENCES IT'S LARGEST EARTHQUAKE DESPITE WASTEWATER INJECTION REDUCTION MITIGATION EFFORTS, ***McNAMARA, D.E.***, *YECK, W.L., HAYES, G.P., RUBINSTEIN, J.L., WILSON, D.,EARLE, P.S., and BENZ, H.M.*
11:30	PRELIMINARY GROUND SHAKING AND DAMAGE OVERVIEW FROM THE M5.8 EARTHQUAKE NEAR PAWNEE, OKLAHOMA, ***WILLIAMS, Robert A.***, *BENNETT, Scott, and WALD, David J.*
11:45	IMPROVING CORRELATION ALGORITHMS TO BETTER CHARACTERIZE AND INTERPRET INDUCED SEISMICITY, ***BRUDZINSKI, Michael R.***, *SKOUMAL, Robert J., and CURRIE, Brian S.*
12:00	RE-EVALUATION OF THE HYPOCENTRAL DEPTH OF THE 2008 MW7.9 WENCHUAN EARTHQUAKE AND ITS IMPLICATION FOR RESERVOIR TRIGGERED SEISMICITY, ***PENG, Zhigang***, *SU, Jingrong, LIU, Xiaoyan, RUAN Xiang, ZHANG, Chenyuan, YAO Dongdong, and HUANG Haiying.*
12:15	A ONE-YEAR SEISMIC HAZARD FORECAST FROM INDUCED AND NATURAL EARTHQUAKES, ***MUELLER, Charles S.***, *PETERSEN, Mark D., MOSCHETTI, Morgan P., HOOVER, Susan M., ELLSWORTH, William L.,MICHAEL, Andrew J., RUBINSTEIN, Justin L., McGARR, Arthur F., and RUKSTALES, Kenneth, S.*
12:30-1:30 Lunch	
	Session 7: Site Response and Hazard Mapping I **(Chairs: Mueller and Chambless)**
1:30	SITE EFFECTS IN STRONG-IMPEDANCE ENVIRONMENTS AND THE IMPORTANCE OF F0: LESSONS LEARNED IN BOSTON, MASSACHUSETTS, *BAISE, Laurie G.,* ***KAKLAMANOS, James****, and EBEL, John E.*
1:45	CHARACTERIZING THE LIQUEFACTION POTENTIAL OF PLEISTOCENE DEPOSITS NEAR CHARLESTON, SOUTH CAROLINA, ***ANDRUS, Ronald D.***, *BWAMBALE, Barnabas, GATHRO, Joshua, LAVINE, Norman S., and CRAMER, Chris H.*
2:00	COMMUNITY VELOCITY MODEL FOR THE CHARLESTON AREA EARTHQUAKE HAZARDS MAPPING PROJECT (CAEHMP): DATA COLLECTION, INTEGRATION AND INITIAL RESULTS, ***JAUME, Steven C.***, *LEVINE, Norman S., BRAUD, Alexander, and HOWARD, Timothy.*
2:15	ESTIMATING SITE EFFECT IN THE CENTRAL U.S. FROM DEEP BOREHOLE AND SURFACE RECORDINGS OF AMBIENT NOISE AND EARTHQUAKE AND BLAST SHEAR WAVES, ***CARPENTER, N. Seth***, *WANG, Zhenming, RONG, Mianshui, and WOOLERY, Edward W.*
2:30	SEISMIC AND LIQUEFACTION HAZARD MAPPING AND EARLY EARTHQUAKE WARNING IN WEST TENNESSEE, ***CRAMER, Chris H.***, *VAN ARSDALE, Roy, ARELLANO, David, PEZESHK, Shahram, and HORTON, Steve.*
2:45	DISCUSSION
3:00-3:30 Break and Posters	
	Session 7: Site Response and Hazard Mapping II **(Chairs: Boyd and Al Noman)**
3:30	SITE RESPONSE STUDY OF THE SEVERELY DAMAGED REGION OF MASHIKI TOWN FROM THE 2016 KUMAMOTO EARTHQUAKES, ***MORI, James***, *YAMADA, Masumi, SAKAUE, Hiromu, YAMADA, Masayuki, HADA, Koji, FUJINO, Yoshinori, FUKATSU, Sosuke, NISHIHARA, Eiko, OUCHI, Toru, and FUJII, Akio.*
3:45	AMPLIFICATION OF GROUND MOTIONS IN WASHINGTON, DC, BY SHALLOW DEPOSITS, ***PRATT, T.***, *HORTON, W., Jr., HOUGH, S., MUNOZ, J., CHAPMAN, M., OLGUN, G., and BEALE, J.*
4:00	PRELIMINARY SEISMIC HAZARD MAPS WITH THE EFFECT OF LOCAL GEOLOGY FOR WASHINGTON, DC, ***CRAMER, Chris H.***, *TUCKER, Kathy, and CHAPMAN, Martin C.*
4:15	** A STUDY OF VERTICAL TO HORIZONTAL RATIO OF EARTHQUAKE COMPONENTS IN THE GULF COAST REGION, ***HAJI-SOLTANI, Alireza***, *PEZESHK, Shahram, MALEKMOHAMMADI, Mojtaba,* and ZANDIEH, Arash.
4:30	ALTERNATIVE (G-16V2) GROUND MOTION PREDICTION EQUATIONS FOR THE CENTRAL AND EASTERN NORTH AMERICA, ***GRAIZER, Vladimir.***
4:45	PUBLIC BUSINESS MEETING OF THE EASTERN SECTION OF SSA
5:15 Attendees on their own for dinner	

Wednesday, October 26

7:30-8:30 Buffet Breakfast	
	Session 8: NGA-East Summary from the Project Team (Chairs: Bozorgnia and Goulet)
8:30	PEER NGA-EAST OVERVIEW: DEVELOPMENT OF A GROUND MOTION CHARACTERIZATION MODEL AND GROUND MOTION PREDICTION EQUATIONS FOR CENTRAL AND EASTERN NORTH AMERICA, *GOULET, Christine A.,* ***BOZORGNIA, Yousef****, and ABRAHAMSON, Norman A.*
8:50	NGA-EAST DATABASE, ***KISHIDA, Tadahiro****, GOULET, Christine A., ANCHETA, Timothy D., CRAMER, Chris H., DARRAGH, Robert B., SILVA, Walter J., HASHASH, Youssef M. A., HARMON, Joseph, STEWART, Jonathan P., WOODDELL, Katie E., YOUNGS, Robert R., and MAZZONI, Silvia.*
9:10	REVIEW AND EVALUATION OF SEED GROUND-MOTION MODELS USED IN NGA-EAST, ***GRAVES, Robert W.****, AL ATIK, Linda, GOULET, Christine A., ABRAHAMSON, Norman A., YOUNGS, Robert R., and ATKINSON, Gail M.*
9:35	TREATMENT OF EPISTEMIC UNCERTAINTIES FOR MEDIAN MODELS, ***KUEHN, Nicolas M.****, GOULET, Christine A., AL ATIK, Linda, ABRAHAMSON, Norman A., ATKINSON, Gail M., GRAVES, Robert W., YOUNGS, Robert R., BOZORGNIA, Yousef.*
10:15-10:45 Break and Posters	
10:45	ALEATORY VARIABILITY MODEL FOR NGA-EAST, *AL ATIK, Linda,* ***GOULET, Christine A****., ABRAHAMSON, Norman A., YOUNGS, Robert R., GRAVES, Robert W., and ATKINSON, Gail M.*
11:10	USE OF SEISMIC HAZARD CALCULATIONS IN THE NGA EAST SSHAC PROCESS, ***YOUNGS, Robert R.****, GOULET, Christine A., ABRAHAMSON, Norman A., AL ATIK, Linda, ATKINSON, Gail M., GRAVES, Robert W., KUEHN, Nicolas M., and BOZORGNIA, Yousef.*
11:40	TREATMENT OF DEPTH, HANGING WALL EFFECTS AND GULF COAST REGION, *HOLLENBACK, Justin, Darragh, Robert B., SILVA, Walter J., YOUNGS, Robert R.,* ***GOULET, Christine A.****, ABRAHAMSON, Norman A., AL ATIK, Linda, ,ATKINSON, Gail M., and GRAVES, Robert W.*
11:55	LESSONS LEARNED AND FUTURE RESEARCH NEEDS, ***GOULET, Christine A.*** *and BOZORGNIA, Yousef.*
12:10	DISCUSSION
12:30-1:30 Lunch	
	Session 9: USGS Earthquake Hazards Program (Chair: Pratt)
1:30	REVIEW OF CENTRAL AND EASTERN U.S. EARTHQUAKE HAZARDS RESEARCH PRIORITIES AND FUNDING OPPORTUNITIES, ***WILLIAMS, Robert A.***
2:30	DISCUSSION
3:00 Adjourn	

Posters

Monday 3:15-4:00, and during breaks

IMPROVED LG ATTENUATIONS MAPS IN THE CENTRAL U.S.–ROCKY MOUNTAIN TRANSITION ZONE: NEW INSIGHT FROM INDUCED SEISMICITY IN OKLAHOMA AND KANSAS AND THE RATON BASIN *ABDELHAMEID, Danya, **LEVANDOWSKI, Will**, BOYD, Oliver S. and MCNAMARA, Dan.*

** 2016 UPDATE TO CENA EMPIRICAL GMPES AND DEVELOPMENT OF NEW EMPIRICAL GMPES FOR GULF COAST ***AL NOMAN, M. N.*** *and CRAMER, Chris H.*

NOISE PERFORMANCE IMPROVEMENT WITH POSTHOLE SENSOR EMPLACEMENT *BUSBY, R.W., **ADERHOLD, K.**,FRASSETTO, A., SUMY, D., WOODWARD, R.*

EFFICIENTLY DISCRIMINATING BETWEEN LOCAL EARTHQUAKES AND BLASTS USING WAVEFORM CROSS CORRELATION ***CARPENTER, N. Seth****, RODRIGUEZ, Paul, PAVLIS, Gary L., HAMBURGER, Michael W., GILBERT, Hersh, WOOLERY, Edward W. and WANG, Zhenming.*

** NONLINEAR MOMENT TENSOR INVERSION OF THE ENVELOPES AND CUMULATIVE ENERGY OF REGIONAL SEISMIC WAVEFORMS ***DAHAL, Nawa R.*** *and EBEL, John, E.*

** UPDATING THE USGS BOUNDARY BETWEEN THE CENTRAL AND EASTERN UNITED STATES AND WESTERN UNITED STATES REGIONS ***HAJI-SOLTANI, Alireza****, HALLER, Kathleen M. and, MUELLER, Charles S.*

"CAN I SEE YOUR RICHTER SCALE?": THE CHALLENGES OF TEACHING ABOUT MAGNITUDE WITH EDUCATIONAL SEISMOGRAPHS ***KAFKA, Alan L.****, MOULIS, Anastasia M., RASMUSSON-FINK, Kristi, and CHAMBLESS, Hannah E.*

** REPEATING EARTHQUAKE SEQUENCES IN BERNE, NEW YORK, 2009-2015, *KIM, Won-Young, ARMBRUSTER, John G, and **GOLD, Mitchell***

** FREQUENCY DEPENDENT QUALITY FACTOR OF LG WAVES FOR THE CENTRAL UNITED STATES USING CODA NORMALIZATION ***NAZEMI, N.****, PEZESHK, S. and SEDAGHATI, F.*

** NATURAL AND INDUCED SEISMICITY ANALYSED BY USING SMALL APERTURE SEISMIC ARRAY "MIKHNEVO" ***NEPEINA, Kseniia S.***

** INVESTIGATING TIDAL TRIGGERING OF INDUCED SEISMICITY IN OKLAHOMA AND SCHUSTER SPECTRUM IDENTIFIED OUR DATA HAVE CLUSTERS ***PEARSON, Karen M.****, THOMAS, Amanda M.and LEKIC, Vedran.*

** ATTENUATION OF HIGH FREQUENCY BODY WAVES IN THE NEW MADRID SEISMIC ZONE ***SEDAGHATI, F.****, PEZESHK, S., and NAZEMI, N.*

** EXPLORING THE SUITABILITY OF THE QUAKE-CATCHER NETWORK IN THE USGS SHAKEMAP: CASE STUDIES FROM AFTERSHOCKS OF THE 2010-2011 DARFIELD AND CHRISTCHURCH, NEW ZEALAND EARTHQUAKES ***SHAUGHNESSY, Liam J.****, SUMY, Danielle F., COCHRAN, Elizabeth S., NEIGHBORS, Corrie J. and DE GROOT, Robert M.*

** REPEATING AFTERSHOCKS FOLLOWING THE 2013 MW6.6 LUSHAN EARTHQUAKE ***YAO, D.****, PENG, Z., SU, J., LONG, F. and DU, B.*

** EQUIVALENT LINEAR OR FULL NONLINEAR – WHICH METHOD SHOULD BE USED IN PERFORMING SITE-SPECIFIC RESPONSE ANALYSES ***YARAHAMADI, A.*** *and PEZESHK, S.*

** ESTIMATION OF SITE RESPONSE IN CENTRAL EASTERN NORTH AMERICA USING EARTHQUAKE DATA ***YARAHAMADI, A.*** *and PEZESHK, S.*

Abstracts

Abstracts are organized by alphabetical order of the first author's last name.

IMPROVED LG ATTENUATIONS MAPS IN THE CENTRAL U.S.–ROCKY MOUNTAIN TRANSITION ZONE: NEW INSIGHT FROM INDUCED SEISMICITY IN OKLAHOMA AND KANSAS AND THE RATON BASIN

ABDELHAMEID, Danya, The College of William and Mary, Williamsburg, VA, deabdelhameid@email.wm.edu; LEVANDOWSKI, Will, BOYD, Oliver S., and MCNAMARA, Dan, USGS, Golden, CO.

It is well established that the attenuation of Lg-phase waves is greater west of the Rocky Mountains than east of the Rocky Mountains. Yet there has been considerably less clarity in mapping the transition in attenuation, as few near-field strong motion observations have been available in the central United States. In the past decade, however, abundant induced earthquakes in Oklahoma, southern Kansas, and the Raton Basin have provided unprecedented coverage. Utilizing Lg-phase waves recorded at regional distances (200-1500 km) at ~400 seismic stations from Oklahoma to central Nevada, we compute the path-averaged apparent Q (the inverse of attenuation), source terms, and local amplification factors at one-octave frequency bands centered on the frequencies 0.75, 1.0, 3.0, 6.0, and 12.0 Hz. Site-amplification correlates better with km-scale topographic relief than local slope on the Great Plains and Gulf Coast, and amplification is generally greater east of the Rocky Mountain Front than west. We do not observe any difference between magnitude–source term scaling for induced events and for natural seismicity, suggesting either that source term is not a proxy for stress drop or that the stress drops of induced events are not lower than for natural events. Subsequently subdividing the study area into the Basin and Range, Colorado Plateau, Rocky Mountains, and Great Plains and quantify average path-averaged Q in each. As in previous work, Q is 50-100% greater in the Plains and Plateau than the Rockies and Basin and Range. Preliminary 2-D tomography delineates a sharp (100-200 km-wide) boundary between adjacent Q-provinces. Our refined Q(f) model supplements the attenuation component of the USGS National Crustal Model and provides improved ground motion characterization in the USGS National Seismic Hazard map, particularly in the central United States in which shaking from induced seismicity is of increasing concern.

ALEATORY VARIABILITY MODEL FOR NGA-EAST

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Recorded ground-motion data from Central and Eastern North America (CENA) were used to analyze the components of ground-motion variability in CENA. Trends of ground-motion variability with parameters such as magnitude, distance, and VS30 were analyzed and compared to trends of ground-motion variability in other regions, particularly the Western United States (WUS) using the NGA-West2 dataset. The CENA dataset is limited in magnitude range to small-to-moderate magnitudes and in frequency content to frequencies between 1 and 10 Hz due to the bandwidth limitations of the recordings. Therefore, standard deviation models developed using the CENA ground-motion data could not be reliably extrapolated to large magnitudes and to frequencies outside of 1 to 10 Hz. As a result, standard deviation models from other regions such as WUS and Japan were used to inform the extrapolation of CENA standard deviations and overcome data limitations. Models were developed and evaluated in a logic tree framework for the between-event standard deviation (τ), single station within-event standard deviation (φSS), and site-to-site variability (φS2S). In turn, these models were combined to develop single-station sigma (σSS) and ergodic sigma models for CENA.

2016 UPDATE TO CENA EMPIRICAL GMPES AND DEVELOPMENT OF NEW EMPIRICAL GMPES FOR GULF COAST

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We have updated our 2015 central and eastern North America (CENA) empirical ground motion prediction equations (GMPEs) (Al Noman and Cramer, 2015). For our 2016 GMPEs we have removed the ground motions based on intensity observations due to their lack of reliability for intensities above MMI VI as pointed out by Ogweno and Cramer (2016) and included ground motion observations at rupture distances less than 60 km from the 2010 M7.1 Darfield, New Zealand earthquake. We have retained the limited 2001 M7.6 Bhuj, India and 1976 M6.8 Gazli, USSR ground motion observations used in our 2015 GMPE regressions. The updated GMPEs agree reasonably with other ENA GMPEs and provide smaller uncertainties than our previous 2015 GMPEs. We also developed an empirical GMPE for the Gulf Coast region using the NGA east database, USArray data, and close-in records (less than 60 km in rupture distance) from the 2010 M7.1 Darfield, New Zealand earthquake. The developed GMPE is based on the observed CEUS/Gulf Coast Q boundary locations (Cramer and Al Noman,

2016) and ground motions from raypaths entirely within the Gulf Coast region. Our Gulf Coast GMPEs tend to compare well with the other previously published GMPEs, but predict lower ground motions at distances less than 100 km and shows higher attenuation beyond 500 km.

CHARACTERIZING THE LIQUEFACTION POTENTIAL OF PLEISTOCENE DEPOSITS NEAR CHARLESTON, SOUTH CAROLINA

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The purpose of this presentation is to summarize selected results of ongoing work, supported by the United States Geological Survey, to characterize the liquefaction potential of Pleistocene deposits near Charleston, South Carolina. Moderate to severe surface manifestations of liquefaction occurred in some Pleistocene deposits while little to no manifestations occurred in others during the 31 August 1886 Charleston earthquake (M∼7.0). We are characterizing liquefaction potential using seismic cone penetration test (SCPT) data from the fieldwork of several investigators. One major advantage of the SCPT is that both small-strain shear wave velocity and large-strain penetration resistance are measured at the same location. Ratios of measured shear wave velocity to estimated shear wave velocity based on penetration resistance (MEVR) within the sand facies of the 200,000-year-old Ten Mill Hill beds increase from an average value of 1.1 in liquefied areas near the seismic source zone to an average value of 1.4 at a distance of 30 km from the source zone. An MEVR of 1.1 corresponds to a deposit age of 120 years, which is in good agreement with the average time between the 1886 earthquake and the date of SCPT measurements. Because most current liquefaction potential assessment procedures are derived from measurements made in relatively young deposits, a deposit resistance correction based on MEVR is used in our liquefaction potential analysis. The initial results indicate good agreement between the computed liquefaction potential index values and the observed field behavior for the surficial beach sand deposits. For the surficial clayey deposits, the agreement is not as good, likely because of the more complex depositional environment associated with marsh and fluvial sediments. Without the deposit resistance correction, liquefaction potential is extremely over predicted for the deposits which experienced little to no surface manifestations of liquefaction.

SITE EFFECTS IN STRONG-IMPEDANCE ENVIRONMENTS AND THE IMPORTANCE OF F0: LESSONS LEARNED IN BOSTON, MASSACHUSETTS

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In environments with strong impedance contrasts, soil amplification can be significant. Ground motions recorded at the surface and at depth in bedrock during the 2011 Mineral earthquake at a soil site in Boston, Massachusetts, exhibited an amplification ratio of 10 at the fundamental site period (0.7 s). The vertical seismometer array at Northeastern University consists of 51 m of sediments (VS ∼ 200-400 m/s) overlying hard bedrock (VS ∼ 2000 m/s). To test whether these amplifications persist for design-level ground motions, we performed a series of site-specific ground response studies for typical sites with varying bedrock depth in Boston. The results show that when bedrock depth is near 30 m, the mean short-period and intermediate-period NEHRP site coefficients (Fa and Fv, respectively) are consistent with the results of the site-specific ground response study. However, if bedrock depths are less than 30 m, the NEHRP Fa significantly underpredicts the soil amplification, and the NEHRP Fv significantly overpredicts the soil amplification. For bedrock depths greater than 30 m, the NEHRP Fa and Fv both underpredict the soil amplification. We conclude that modifications to NEHRP site coefficients are needed for strong-impedance environments. Because the soil response in strong-impedance environments is driven by bedrock depth, microtremor studies can be used to identify the fundamental site frequency, f0. By combining local information on soil profiles and soil velocities in Boston, f0 can be used to adequately predict soil amplification in Boston.

CONTROL OF THE LITHOSPHERIC MANTLE ON EASTERN NORTH AMERICAN PASSIVE MARGIN EVOLUTION

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The present tectonic configuration of the southeastern United States is a product of earlier episodes of arc accretion, continental collision and breakup. Following the rifting and break-up of Pangea, this region became a passive margin, some 1500 km away from the closest active plate margin. However, there is ongoing tectonism across the area with multiple zones of seismicity, rejuvenation of the Appalachians of North Carolina, Virginia, and Pennsylvania, and Mesozoic-Cenozoic intraplate volcanism. The factors governing the varying geological stability and the modern-day state of stress in this passive margin setting remain enigmatic. Two factors often regarded as major contributors are plate strength and preexisting inherited structures. Recent improvements in broadband seismic data coverage in the region associated with the South Eastern Suture of the Appalachian Margin Experiment and EarthScope Transportable Array make it possible to obtain detailed information on the structure of the lithosphere in the region. Our new tomographic images beneath the region reveal large-scale structural variations in the upper mantle. We observe fast seismic velocity patterns that can be interpreted as ongoing lithospheric foundering. We also observe an agreement between the locations of these upper mantle anomalies and the location of major zones of tectonism, volcanism and seismicity, providing a viable explanation for modern-day activity in this plate interior setting long after it became a passive margin. Based on distinct variations in the geometry and thickness of the lithospheric mantle and foundered lithosphere, we propose that piecemeal delamination has occurred beneath the region throughout the Cenozoic, removing a significant amount of reworked mantle lithosphere. Ongoing lithospheric foundering beneath the eastern margin of stable North America explains significant variations in thickness of lithospheric mantle and variations in geological stability across the region.

THE VARIATION OF LG ATTENUATION IN NORTHEASTERN NORTH AMERICA

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Lg dominates seismograms at distances 50 to 500 km from earthquakes in North America. The Lg phase develops as a superposition of S-waves that are critically reflected within the crust. Beyond 500 km, crustal attenuation reduces Lg relative to Sn, which is refracted through the uppermost mantle. Unfortunately, this simple attenuation model has not produced a consensus Lg attenuation model: 30 years of analyses have yielded estimates ranging from Q = 410f0.5 to 900f0.2. We estimate the attenuation from a broadband (0.04 to 30 Hz) analysis of Fourier spectra of S+Lg+surface wave groups from 102 small and moderate (2.0 ≤ M ≤ 5.8) earthquakes, using both vertical and horizontal components of Canadian and American seismographs on rock at distances from 5 to 625 km. Specifying the average site-response spectra for hard and soft-rock sites allows the record spectra to be decomposed into source and propagation spectra. The geometrical spreading is assumed to be r-1 out to 50 km and r-1/2 beyond 50 km; the attenuation estimates depend only slightly on the near-source geometric spreading. We exclude recordings of small (M < 3.4) earthquakes beyond 300 km and use low-frequency cutoffs for fitting the attenuation. The attenuation observed for earthquakes in eastern Quebec and New England corroborates Boatwright and Seekins' (2011) result Q = 410f0.5. Recordings of earthquakes in the Western Quebec Seismic Zone obtain exhibit Q = 412f0.5 to the east and south, and Q = 580f0.46 to the west and north. The boundary between the areas with different attenuation approximately follows the boundary between the Appalachian and Grenville Provinces. For some earthquakes located outside the Appalachian region, such as the 2000 M4.6 Kipawa earthquake, Sn is relatively weak and we can fit recorded spectra out to 900 km using the attenuation and Lg travel times in the different regions.

COMPARISON OF STRESS DROPS FOR TECTONIC AND INDUCED EARTHQUAKES IN NORTH AMERICA

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We estimate stress drops for tectonic and induced earthquakes in and near the conterminous United States using the method of spectral ratios. The ratio of acceleration spectra between collocated earthquakes recorded at a given station removes the effects of path and recording site and yields source parameters including corner frequency for and the ratio of seismic moment between the two earthquakes. We determine stress drop from these parameters for 1121 earthquakes greater than ~M3 in 60 earthquake clusters where each event in the cluster acts as an empirical Green's function for the others. We find that the average Brune stress drop for the few eastern United States (EUS) tectonic mainshocks studied (2.6–34 MPa) is about three times greater than that of tectonic mainshocks in the western United States (WUS, 1.0–7.7 MPa) and six times greater than stress drops of potentially induced mainshocks in the central United States (CUS, 0.2–4.1 MPa). EUS events tend to be deeper thrusting events, whereas WUS events tend to be shallower but have a wide range of focal mechanisms.

CUS events tend to be shallow with strike-slip to normal faulting mechanisms. With the possible exception of CUS aftershocks, we find that differences in stress drop among all events can be accounted for, within one standard deviation of significance, by differences in the shear failure stress as outlined by Mohr-Coulomb theory. The shear failure stress is a function of vertical stress (or depth), the fault style (normal, strike-slip, or reverse), and coefficient of friction (estimated here to be on average 0.68). After accounting for faulting style and depth dependence, we find that average Brune stress drop is about 3% of the failure stress. These results suggest that high frequency shaking hazard (> ~1 Hz) from shallow induced events and aftershocks is reduced to some extent by lower stress drop. However, the shallow hypocenters will increase hazard within several kilometers of the source.

IMPROVING CORRELATION ALGORITHMS TO BETTER CHARACTERIZE AND INTERPRET INDUCED SEISMICITY

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Correlation algorithms have proven useful for identifying repetitive microearthquake sequences buried in vast passive seismic datasets. Multi-station waveform template matching has been used in characterizing seismicity potentially induced by hydraulic fracturing or wastewater disposal. A swarm of many events with similar waveforms, presumably driven by localized fluid injection, can be used as criteria to help discern induced seismicity from naturally occurring seismicity. Swarm detection with template matching applied to a regional network can be done in near real-time without the requirement of local seismic deployments or industry data (e.g., injection volumes/pressures or stimulation reports), although this additional data can be utilized if available to further build support for either an induced or natural origin. An advantage of this technique is that the cross correlations are ideally suited to perform advanced source location and magnitude estimation to better characterize the seismicity. In Ohio, 9 recent swarms have been correlated temporally and spatially with either hydraulic fracturing or wastewater injection, while nearly 20 less repetitive earthquakes were not and appear to be natural. A lack of evidence for any induced seismicity in neighboring Pennsylvania despite an order of magnitude more unconventional wells suggests that geology plays a key role in whether seismicity is induced. We identify the proximity of the basement to the injection depth as a key factor, suggesting basement involvement is needed in the Appalachian Basin to generate M>2 seismicity. In other areas of prevalent induced seismicity, we developed a new algorithm for detection of repetitive sequences that employs agglomerative clustering to discern signals from multiple source regions. The repetitive signal detector does not require a pre-existing cataloged template event, which helps to detect smaller M<2 sequences that typically precede larger M>2 induced seismicity.

USING LIDAR TO SEARCH FOR NEOTECTONIC FEATURES IN THE CENTRAL VIRGINIA SEISMIC ZONE FOLLOWING THE 2011 MINERAL, VA. M5.8 EARTHQUAKE

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The August 23, 2011 Mw5.8 Mineral, Virginia earthquake prompted a renewed focus by geoscientists on the extent and cause of neotectonism in the central Virginia seismic zone. New one-meter resolution, bare-earth Lidar-derived digital elevation models have been acquired for a 1300 km2 area surrounding the epicenter of the Mineral earthquake, and these elevation models are being analyzed for landforms of possible neotectonic origin. Although no fault scarps have been recognized in the Lidar-derived hillshade raster or other derivative imagery, a topographic lineament has been identified along the approximate surface projection of the ~N30E-trending, SE-dipping subsurface causative fault of the Mineral earthquake. The lineament correlates closely with the NE-striking contact between early Paleozoic granodiorite and volcaniclastic phyllite and schist. Features exposed by trenching across this contact at Roundabout Farm show Cenozoic brittle reactivation of an older fault zone containing Paleozoic ductile and Mesozoic semi-ductile shear fabric. In an area NE of the mainshock epicenter along the regional bedrock strike trend, an undulating ground surface at Carter Farm that was possibly formed by ground shaking has been tentatively correlated with features on the Lidar imagery. Regionally, Lidar lineament analysis reveals a NNW trend previously unrecognized in field mapping that is parallel to the strike of shallow aftershock nodal planes. Lidar is also being used to delineate Quaternary terrace deposits along the South Anna River and other regional drainage systems in the epicentral area; downstream correlation of these terraces through mapping and age dating suggests neotectonic warping of terrace levels that could be used to estimate rates of Quaternary uplift.

EARTHSCOPE USARRAY: A LOOK BACK AT THE MOST EPIC EXPERIMENT

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The rolling deployment of nearly 2,000 broadband seismic stations across the entire contiguous United States as part EarthScope's USArray Transportable Array (TA) was named by Popular Science as "The #1 Most Epic Experiment in the Universe." More than 30 Tb of high-quality seismic data were archived, fueling a library of student theses, dissertations, and a steadily increasing stack of publications and presentations. With the conclusion of the Lower 48 portion of the TA, we look back on the performance of stations across the continent through metrics like station uptime and noise power spectra to characterize overall network performance. Such review provides insights into the efficacy of installation and operational methodologies, and natural effects such as geographic and seasonal variability in station performance. The last TA station I60A was removed on September 27, 2015 from Shoreham, Vermont, but the legacy lives on through the 158 transitioned stations currently operating in the Central and Eastern US Seismic Network (CEUSN). The capabilities of the CEUSN may be improved through the use of a new posthole sensor emplacement technique that has been developed and perfected in the Alaska Transportable Array deployment. The USArray continues to redefine what is possible in seismic experiments and has built a solid foundation for the Alaska Transportable Array (currently underway), the Subduction Zone Observatory (in early planning stages), and future continent-scale projects.

NOISE PERFORMANCE IMPROVEMENT WITH POSTHOLE SENSOR EMPLACEMENT

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The EarthScope Transportable Array (TA) deployment currently underway in Alaska and Western Canada utilizes a specially designed, highly portable and lightweight drill to emplace Nanometrics Trillium-120PH and Streckeisen STS-5A broadband seismometers in steel cased, 2.7 meter deep postholes. Construction and installation procedures have been streamlined, and an autonomous seismic station can be up and running in a single work day with a three person crew. In ideal conditions when the posthole is drilled into bedrock or intact permafrost and the sensor is emplaced below the active layer, noise levels of the Alaska TA temporary stations approach the performance of permanent, benchmark Global Seismic Network (GSN) stations. Performance is enhanced most notably at long periods (greater than 70 seconds) on the horizontal components. Here we will compare the noise performance of Alaska TA, Alaska Earthquake Center (AEC), GSN, and CEUSN stations through power spectral density analysis using the IRIS DMC MUSTANG data quality metric web service. The Alaska TA emplacement procedure has the potential to dramatically improve the quality of regional networks like the Central and Eastern United States Seismic Network (CEUSN) and can be a relatively low-cost alternative to the traditional vault style emplacement widely used in the Lower 48.

SEISMICITY-HYDROLOGY RELATIONSHIPS IN THE EASTERN TENNESSEE SEISMIC ZONE

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Causes of seismicity in the eastern Tennessee seismic zone (ETSZ), the second most active intraplate seismic zone in the U.S.A., remain unclear. Hydroseismicity posits that intraplate seismic events result from surface-driven pore-fluid pressure transients triggering failure in pre-stressed crust. Alternative explanations to hydrology-seismicity correlations invoke crustal loading. Seismic strain (the square root of energy) in the ETSZ was evaluated for periodicity and relationships with river discharge using 1,580 seismic events from 1977 to 2015, located within the 55,430 km^2 watershed of a Tennessee River streamgage near Chattanooga. Initial findings differ from many other seismic zones, where discharge correlates positively with seismicity. In the ETSZ, interpolated strain and discharge residuals anti-correlate ($r = -0.61$). Cross-correlation shows discharge leading strain by ~1 year ($r = -0.65$) and lagging strain by ~8 years ($r = 0.75$). Geodetic data from 2008 to 2015 show crustal displacement lagging residual discharge by ~1 year ($r = -0.71$) and residual energy by 0 days ($r = 0.74$). Autocorrelation shows strong annual and weak decadal periodicities in both strain and discharge. Average monthly strain and discharge residuals anti-correlate at $r = -0.65$, and a monthly preference was found for seismic energy release ($\chi^2 = 43.3$, $p < 0.01$), although not for occurrence of seismic events ($\chi^2 = 17.5$, $p = 0.10$), suggesting interaction with the pronounced seasonal hydrologic cycle. The shared decadal cycle between seismicity and discharge could result from the interaction of seismic and hydrologic cycles or from coincidental temporal overlap of separate physical cycles. The decrease in seismicity as discharge and subsidence increase implies crustal loading rather than pore-fluid pressure transients as a control on seismicity. The ETSZ may differ from other seismic zones with respect to hydroseismicity due to its deep hypocenters and compartmentalized surface aquifers.

EFFICIENTLY DISCRIMINATING BETWEEN LOCAL EARTHQUAKES AND BLASTS USING WAVEFORM CROSS CORRELATION

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Broadband waveforms from the OIINK (Ozark, Indiana, Illinois, and Kentucky) Flexible Array in the EarthScope project were used to develop routines to efficiently identify infrequent, small earthquakes in an area in which frequent mine blasts occur. The broad approach taken was to first create a database of all seismic events that were detected by the array. Next, false-detections, events detected from outside of the project area, known (i.e. cataloged) local earthquake, and events related to mine blasts were removed from the database. In principle, once these events are removed, the remaining events in the database are unknown, local earthquakes. Vertical-component waveforms from 121 stations for one month while the OIINK array was focused on Kentucky was processed with the Antelope software package to develop an event database. Cross-correlation of waveforms, band-pass filtered in a band where both body waves and surface waves from local events have energy, namely 0.5 to 5.0 Hz, successfully identified repeating mine blasts in this database, and allowed common waveform families to be inspected and efficiently removed. Identification of event families was more successful when events within particular spatial clusters, regions of area on the order of 10^3 km^2, were simultaneously processed. Of the more than 200 events in the one-month database, more than 80 percent were identified as blasts, representing a significant reduction in analysis effort. The remaining events were spurious detections, non-repeating blasts, and local earthquakes. Other techniques for earthquake-blast discrimination have been attempted and will be presented.

ESTIMATING SITE EFFECT IN THE CENTRAL U.S. FROM DEEP BOREHOLE AND SURFACE RECORDINGS OF AMBIENT NOISE AND EARTHQUAKE AND BLAST SHEAR WAVES

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We performed horizontal-to-vertical spectral ratio (HVSR) analyses on ambient noise and S-wave recordings from earthquakes and blasts at broadband stations in the central U.S. HVSRs from each energy source consistently revealed dominant peaks at the fundamental frequency, consistent with the frequency determined from the sediment shear-wave velocity structure and thickness (i.e., base-mode resonance due to the constructive interference of S-waves). However, ambient-noise HVSRs are less sensitive to higher modes, which are apparent in HVSRs determined from the S-waves of local earthquakes and blasts. In addition, the HVSRs of local blasts and earthquakes are very similar, indicating that blasts may provide a viable S-wave source for characterizing velocity structure in regions with low seismicity rates. We also compared HVSRs with spectral ratios (SR) determined from S-waves recorded by two vertical seismic arrays in the Mississippi Embayment in the central U.S. Both arrays penetrate the thick sediment overburden and include sensors within bedrock—a depth of 100m at one site and 587m at the other—allowing the sediment-column S-wave transfer functions to be determined through spectral division of the horizontal-components at the surface by the horizontal-components in the bedrock at each location. The S-wave SRs differ from HVSRs—taking into account the effects of the free surface on the SRs—indicating that HVSRs do not directly estimate the S-wave transfer functions at these sites. However, we confirmed that horizontal-motion SRs are recoverable from the HVSRs when they are corrected for the vertical-motion transfer functions. In particular, dividing surface HVSRs by the ratio of the bedrock HVSR to the vertical-component SR reproduces the transfer functions at these thick-sediment sites.

SPATIOTEMPORAL ANALYSIS OF INJECTION-INDUCED EARTHQUAKES IN OKLAHOMA AND SURROUNDING AREAS

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In 2016, the U.S. Geological Survey published a short-term National Seismic Hazard Map that includes the effects of both natural and human-induced earthquakes (Peterson et al., 2016). Very prominent on that map is the high potential for earthquake hazards in Oklahoma associated with wastewater disposal from oil and gas operations. However, a lack of comprehensive data on geological conditions and injection well pumping makes spatiotemporal assessment of future induced seismicity difficult. The objective of this research is to discern the

extent to which identifiable well and geologic parameters correlate with a higher potential for induced seismicity in Oklahoma and surrounding areas. The study is based on analysis of Gutenberg-Richter (GR) distributions, a grid cell analysis, and a modified version of Cellular Seismology (CS). Here we report on the GR and grid-cell analyses. The GR analysis shows that b-values have increased over time. The grid cell analysis shows no significant correlation between the density of optimally-oriented faults and frequency of earthquakes greater than M3.0, though it did show a significant, albeit moderate, correlation between cumulative wastewater volume and frequency of earthquakes. These results suggest that it will be difficult to identify parameters that clearly correlate with a higher potential for induced seismicity. To explore the possibility of identifying such parameters, future grid cell analyses will investigate the possible correlation between injection pressure, depth of wells, and some combinations of well parameters with earthquake frequency. Modified CS analyses will then be conducted to investigate the extent to which sites with specific parameters are likely to trigger nearby seismicity.

MINERAL, VIRGINIA, 2011 AND CHARLESTON, SOUTH CAROLINA, 1886: SIMILAR AFTERSHOCK SEQUENCES AND THE DOMINANT ROLE OF COULOMB STRESS TRANSFER

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Seismicity in the epicentral area of the 1886 "Charleston" earthquake is similar to the aftershock sequence of the 2011, Mineral, VA, earthquake. In both places, Coulomb stress transfer plays a major role in the generation of aftershocks on minor reverse faults with a range of orientation. In 2011, an 8-station temporary network was deployed in the Summerville, SC area. 134 hypocenters define a south-striking, west-dipping tabular seismogenic zone in the upper 13 km. The majority of the 48 well-constrained focal mechanisms exhibit reverse slip on N to NW trending planes. The data support the hypothesis that the source of the Charleston earthquake was compressional reactivation of a south-striking Mesozoic fault. At Mineral and Summerville hypocenters define tabular seismogenic zones, with the majority of events at shallow depth (1 to 6 km). The two sets of focal mechanisms show similar diversity. For Mineral, more than half exhibit reverse mechanisms with P-axis trends differing by more than 15 degrees from that of the mainshock. The same is true for Summerville, in terms of the difference between focal mechanism B-axis trend and the N186E strike of the seismogenic zone. This suggests that seismicity following the two mainshocks is largely controlled by the spatial geometry of Coulomb stress transfer caused by the respective, mostly-reverse, mainshocks acting on minor faults with diverse orientation. The resulting hypocenter locations define the orientation of both mainshock damage zones. This is certainly the case for the Mineral, Virginia aftershocks. It appears that this is also the case for the on-going seismicity in the epicentral area of the 1886 Charleston earthquake, despite the passage of 130 years since the mainshock. Finally, the role of Coulomb stress triggering is obvious for the shallowest shocks in the Mineral sequence, which occur of a specific set of N-NW trending reverse faults parallel to a prominent set of Lidar lineaments.

TESTING THE FEASIBILITY OF USING GROUND PENETRATING RADAR TO IMAGE ATLANTIC COASTAL PLAIN STRATA AND SHALLOW DEFORMATION IN THE AREA OF CHARLESTON, SC

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The 1886 Charleston, South Carolina earthquake caused extensive liquefaction and perhaps shallow faulting of the shallow Atlantic Coastal Plain strata, and faults are imaged on seismic reflection profiles in the area. In this study we test ground penetrating radar (GPR) as a tool to examine shallow deformation from the 1886 and previous earthquakes, and specifically the feasibility of collecting long (>10 km) profiles in a reconnaissance mode of operation. We used an unshielded, 25 MHz GPR system to collect continuous transects of coastal plain stratigraphy by towing the system along roadsides at speeds under 5 km/hr. We also towed the system behind a boat on the Ashley River. This mode of operation allowed us to acquire more than 85 km of GPR radargrams in a week, with profiles ranging from 1 to 20 km in length and having a depth of penetration of as much as 40 m. The profiles show a variety of features such as beach ridges, incised channels, and a distinctive, horizontal reflector that is nearly ubiquitous in the region and is interpreted as top of the late Oligocene Cooper Group. The GPR data show that at some sites, the relatively flat Cooper Group reflector is abruptly displaced vertically, with some of the displacements at or near locations where faults were identified on seismic reflection images. Some locations with displaced reflectors occur where there are fluvial anomalies such as straightened channels and surface lineaments visible in aerial photography. One site shows a displaced reflector in the vicinity where a historic photo shows railroad tracks that were bent during the 1886 earthquake, and also coincides with an anomalously straight river segment. Our results show that GPR can successfully image the shallow near-surface and can be used to identify recent deformation and faulting that could provide future trenching targets. Following the success of these surveys, we plan to collect a more extensive set of profiles in the near future.

STATE OF KNOWLEDGE OF EASTERN TENNESSEE SEISMIC ZONE PALEOSEISMOLOGY

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The eastern Tennessee seismic zone (ETSZ) is the second most active and second largest areally in the eastern US after New Madrid, extending from NE AL across TN into SE KY. Despite its activity and size, no historic earthquakes of Mw>4.8 have occurred here. Our goal is to identify the largest paleo-earthquakes, and establish their recurrence interval. We have concentrated on Quaternary river sediments up to 800 ka resting on Paleozoic shale bedrock to eliminate Quaternary karst features formed on carbonate rocks. We have discovered numerous fractures and several 1-2 m-displacement faults filled with red sandy clay that displace bedrock shale and Quaternary river deposits. These faults occur along a >80 km linear trend from Vonore, TN, (057 moderately SE-dipping thrust and 070 steeply SE-dipping normal faults) to near Alcoa, TN, (060 moderately SE-dipping thrust) to Dandridge, TN (050 moderately to near-flat, SE-dipping listric thrust). Most faults occur along an 060 linear trend (parallel to a local trend of maximum seismicity), with one small, steeply dipping group near Tellico Plains, TN (005 steeply W- and E-dipping), located along an almost N-S seismicity alignment. All thrust faults have a NE trend and are top-to-the-NW, oblique to regional bedrock strike; the normal fault may be a part of a local thrust-strike-slip stepover system. The 060 linear fault trend, if part of a common system that produced the surface ruptures, may be connected in either a NE-striking master fault at depth and more widespread red sandy clay-filled fractures, or an array of localized coseismic faults and widespread fractures that developed above an active basement fault. Either option is very likely the product of one or more Mw>7.0 earthquakes; taken separately they would require one or more earthquakes of Mw>6.5 in the ETSZ to produce the observed displacements. Our current data suggest a recurrence interval of <7,500 y; this data set, however, is incomplete.

BRUNE STRESS PARAMETER ESTIMATES FOR THE 2016 M5.6 PAWNEE AND OTHER OKLAHOMA EARTHQUAKES

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I have estimated Brune (single-corner) stress parameters for several Oklahoma earthquakes, including the 2016 M5.6 Pawnee earthquake. My approach is to estimate corner frequency from the peak of the tangential component of the velocity Fourier spectrum using recordings about 50 km or less from the epicenter. Because Brune stress parameter is for body waves, care has been taken to avoid contaminating spectral peaks from surface waves, nearby-building interactions, and soil resonances. For shallow earthquakes, surface-waves have been observed overlapping P and S waves, including in Oklahoma. So spectral shape fitting has been avoided in this study. Brune stress parameter for an earthquake is estimated from the corner frequency and seismic moment (from moment magnitude). Oklahoma earthquakes (potentially induced) tend to be shallow (less than 10 km and usually ~5 km or less). In general, Brune stress parameter for Oklahoma earthquakes ranges between 5 and 10 MPa, which is typical for the south central US, including the New Madrid seismic zone (natural earthquakes). The 2016 M5.6 Pawnee, 2016 M5.0 Fairview, and 2011 M5.6 Prague earthquakes have estimated Brune stress parameters of 20 MPa, 15 MPa, and 10 MPa, respectively. Thus the recent M5 earthquakes appear to have higher stress parameters than the smaller earthquakes, similar to mainshocks versus aftershocks. I have used Herrmann's regional moment magnitude (M5.55) for the Pawnee earthquake. If the USGS moment magnitude of M5.8 is used, the Brune stress parameter estimate for the Pawnee earthquake becomes 50 MPa, which is high for most CENA earthquakes. For comparison, Atkinson (two-corner) stress parameter estimates should be about twice these Brune stress parameter estimates.

INTENSITY CORRELATIONS WITH REGIONAL Q, STRESS DROP, AND INDUCED AND NATURAL SEISMICITY IN THE CENTRAL US

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Hough (2014) proposed that earthquake intensity data in the central and eastern US (CEUS) is not correlated with regional Q but is correlated with stress drop for potentially induced earthquakes (PIE). We have completed a regional Q study of the Gulf Coast region and to the west and north in Kansas, Oklahoma, and Texas (Cramer and Al Noman, 2016). I have also examined stress drops from PIE and natural earthquakes in central and eastern North America (CENA) (Cramer, 2015, 2016). Atkinson and Boore (2014) estimate an average mid-continent Q for CENA as a Qo of 525 and eta of 0.45. We estimate Gulf Coast regional Q as a Qo of 259 and eta of 0.715 (Cramer and Al Noman, 2016). West and north of the Gulf Coast region we see low 5 Hz Q in central Kansas, central Oklahoma, and northern Texas similar to Gulf Coast 5 Hz Q, but mid-continent Q at 1 Hz. Smaller basins and rifts may be responsible for the Q pattern west of the Gulf Coast region and east of the Rocky Mtns.

The intensity patterns of Hough and Page (2015) for the 1957 M5.7 El Reno, OK and 2011 M5.6 Prague, OK earthquakes show decay with distance patterns that correlate with our regional Q pattern. This is also true for the 2016 M5.6 Pawnee, OK earthquake. This suggests that intensities are strongly correlated with region Q in the central US (CUS). H sough's (2014) differences between moment magnitude and intensity estimated magnitude (Mie) are also strongly correlated with region Q, supporting strong Q/intensity correlation in the CUS. My study of CENA stress drops shows that there is no difference between PIE and shallow natural earthquakes. Regional variations in CENA stress drops are more significant. Based on observations I conclude that intensity observations are strongly correlated with region Q and not correlated with PIE stress drops, the opposite of Hough's (2014) assumptions.

PRELIMINARY SEISMIC HAZARD MAPS WITH THE EFFECT OF LOCAL GEOLOGY FOR WASHINGTON, DC

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We have developed preliminary seismic hazard maps with the effect of local geology for the Washington, DC area. The input ground motion prediction equations, source model, and logic tree for the analysis is taken from the 2014 U.S. Geological Survey national seismic hazard model (Petersen et al., 2014). We have added a preliminary local geology model based on the bedrock elevation map of Darton (1950) and three shear-wave velocity profiles for Piedmont, Fall Line, and Coastal Plain regions (Olgun et al, 2015). We developed reference profiles from the three Olgun et al. profiles that extend to hard rock for site amplification relative to the rock conditions for the ground motion prediction equations. Our preliminary seismic hazard maps include both probabilistic (2% in 50 years) and scenario (M6.0 at Mineral, VA) maps. The local geology in the Washington DC area strongly amplifies higher frequency ground motions (peak ground acceleration, 0.2 s spectral acceleration) in keeping with the three site-specific profiles of Olgun et al. (2015). The soil response is driven by the 10 to 20 m thick low shear-wave velocity (200–300 m/s) top layers of the reference profiles. These low velocity layers are composed of residual soil and/or alluvium. The thicker Cretaceous Potomac Formation sediments, up to 600 m thick in the SE corner of the study area 6 km SE of the SE edge of Washington, DC, have an effect on seismic hazard at 1.0 s and longer periods. The greatest effect on 1.0 s spectral acceleration seismic hazard is from the ~200 m thick sediments near the SE edge of Washington DC. Our preliminary maps have a resolution of 0.01 degree (1 km) and are missing the sub-km scale detailed geology variation in the Washington, DC area. These preliminary maps can serve as a guide to improving the understanding of seismic hazard and risk in the area and stimulate further work on a more detailed local geology model with higher resolution.

SEISMIC AND LIQUEFACTION HAZARD MAPPING AND EARLY EARTHQUAKE WARNING IN WEST TENNESSEE

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The Center for Earthquake Research and Information (CERI) is beginning a five-year earthquake hazard mapping and earthquake early warning study funded under the National Disaster Resilience Competition by the Department of Housing and Urban Development (HUD). The study area of this hazard mapping project comprises four counties adjacent to the Mississippi River in westernmost Tennessee – Dyer, Lauderdale, Lake, and Tipton – and one major population center – Jackson, TN and all of Madison county. This hazard mapping project will extend the urban hazard mapping already done in Shelby Co. to adjacent parts of the state and use the techniques and approaches developed in Shelby Co. The project will include the gathering of available geological and geotechnical well and boring log information to supplement our existing database of subsurface information in the Mississippi embayment. Field geophysical measurements will help fill data gaps in the 3D geological/geotechnical model for these counties. Geophysical techniques will include surface-wave and ambient noise measurements for the soil profile layering and Vs values (mainly uppermost 100 m). Supplemental techniques and novel approaches of developing 3D geological/geotechnical models with limited data on the subsurface conditions will be evaluated as well. Liquefaction probability curves will also be developed to supplement existing curves in Shelby Co and the embayment. During the first year of the project, earthquake early warning (EEW) research will also be conducted. The focus of the EEW research is to determine the feasibility of EEW in western Tennessee and develop a monitoring improvement plan that will facilitate EEW in the central US. The EEW and seismic hazard mapping studies will mainly focus on flood mitigation structures and support facilities, but will also help earthquake planning and mitigation efforts in communities within these counties.

NONLINEAR MOMENT TENSOR INVERSION OF THE ENVELOPES AND CUMULATIVE ENERGY OF REGIONAL SEISMIC WAVEFORMS

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Moment-tensor inversion of seismograms recorded at regional distances is a routine process to determine seismic moment, focal mechanism and depth of moderate and large magnitude earthquakes. We are working to extend the inversion of regional waveforms for the moment tensor to smaller magnitude events which are rich in high frequency content but lacking in observable longer period surface-wave energy. We are developing a nonlinear moment-tensor inversion scheme to invert processed seismic waveforms for smaller seismic events. In the inversion we fit either the envelopes or the cumulative energy curves of the seismograms, both of which preserve some element of the high-frequency part of the signal but still present a relatively simple waveform for the inversion without frequency filtering. The proposed scheme has successfully extracted the desired source information of moderate magnitude regional earthquakes within epicentral distances of 70-400 km in the frequency band of 0.05-0.1 Hz after the seismograms have been processed to their envelopes. We plan to test higher frequency content in the seismograms so that P-wave and S-wave as well as surface-wave energy is incorporated. We also are testing the method using a “cut-and-paste” approach to match separate sections of the envelopes such as the P-wave window, S-wave window, surface-wave window or even seismogram sections with multiple phases. We plan to repeat all of these tests using cumulative energy curve of the seismograms to compare the results with the waveform envelope computations.

A SEARCH FOR RECENT EARTHQUAKES OFFSHORE OF NORTHEASTERN NORTH AMERICA

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An exploratory search of the regional seismic network data from the northeastern U.S. was carried out to look for previously undocumented offshore earthquakes for the time period from 2007 to 2016. From 2013 to 2015 the EarthScope Transportable Array (TA) stations were operating the northeastern U.S. and provided a vastly improved dataset than previously available to search for offshore seismicity. Since October 2015 the one-in-four TA stations that were left in the region continue to provide important data along with the legacy regional seismic network stations for detecting offshore earthquakes. Our search yielded nine new offshore earthquakes between November 2012 and August 2016. Because the events were too far from the seismic network stations for HYPO2000 to compute an effective location, we used a simple location algorithm based on the arrival times of the P and S/Lg waves to locate the events, albeit with an epicentral uncertainty of 20-50 km. Four of our nine new events were located on the North American continental shelf, one new event was on the continental slope, and four new events were in the old oceanic crust. The events on the continental shelf all occurred in areas where there are major submarine channels associated with river drainages from the continent, perhaps indicating that the seismicity is somehow related to the locally high rates of sediment accumulation in these areas. One of the deep ocean events took place at the edge of the Bermuda rise and another was located beneath the New England seamounts, perhaps indicating local stress concentrations beneath these deep ocean topographic features. Our study suggests that the areas offshore of the northeastern U.S. are more seismically active than previously appreciated.

PEER NGA-EAST OVERVIEW: DEVELOPMENT OF A GROUND MOTION CHARACTERIZATION MODEL AND GROUND MOTION PREDICTION EQUATIONS FOR CENTRAL AND EASTERN NORTH AMERICA

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The Next Generation Attenuation project for Central and Eastern North America (CENA), NGA-East, is a major multi-disciplinary project coordinated by the Pacific Earthquake Engineering Research Center (PEER). The project was co-sponsored by the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI) and the U.S. Geological Survey (USGS). NGA-East involved a large number of participating researchers from various organizations in academia, industry and government and was carried-out as a combination of 1) a scientific research project and 2) a model-building component following the NRC Seismic Senior Hazard Analysis Committee (SSHAC) Level 3 process. The science part of the project led to several data products and technical reports while the SSHAC component aggregated the various results into a ground motion characterization (GMC) model. The GMC model consists in a set of ground motion models (GMMs) for median and standard deviation of ground motions and their associated weights, combined into logic-trees for use in probabilistic seismic hazard analyses (PSHA). NGA-East addressed many technical challenges, most of them related to the relatively small number of earthquake recordings available for CENA. To

resolve this shortcoming, the project relied on ground motion simulations to supplement the available data. Other important scientific issues were addressed through research projects on topics such as the regionalization of seismic source, path and attenuation of motions, the treatment of variability and uncertainties and on the evaluation of site effects. Seven working groups were formed to cover the complexity and breadth of topics in the NGA-East project, each focused on a specific technical area. This presentation provides an overview of the NGA-East research program and its key products.

ALTERNATIVE (G-16V2) GROUND MOTION PREDICTION EQUATIONS FOR THE CENTRAL AND EASTERN NORTH AMERICA

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Introduced is the ground motion prediction equations model for the Central and Eastern North America that represents an alternative more physically justified approach to ground motion attenuation modeling then previous Graizer (2016) G-16 model. The new model has a bilinear slope of ~R-1 within 70 km from the fault with a slope of ~R-0.5 at larger distances corresponding to the geometrical spreading of body and surface waves. The new (G-16v2) model is based in part on the NGA-East database for the horizontal peak ground acceleration and 5%-damped pseudo spectral acceleration (SA) and also on comparisons with the Western U.S. data and ground motion simulations. Based on data, I estimated the average slope of the distance attenuation within the 50-70 km distance from the fault to be ~ -1.0 at most of the frequencies supporting regular geometrical spreading of body waves. Multiple inversions are performed to estimate apparent (combined intrinsic and scattering) attenuation of SA amplitudes from the NGA-East database for incorporation into the model. These estimates demonstrate a difference between seismological Q(f) and the above mentioned attenuation factor that I recommend calling Qsa(f). I adjusted previously developed site correction which was based on multiple runs of representative VS30 (time-averaged shear-wave velocity in the upper 30 m) profiles through SHAKE-type equivalent-linear codes. Site amplifications are calculated relative to the hard rock definition used in nuclear industry (VS=2800 m/s). These improvements resulted in a modest reduction in standard deviation in the new G-16v2 relative to the G-16 model. The number of model predictors is limited to a few measurable parameters: moment magnitude M, closest distance to fault rupture plane Rrup, VS30, and apparent attenuation factor Qsa(f). The model is applicable for the stable continental regions and covers the following range: 4.0≤M≤8.5, 0≤Rrup≤1000 km, 450≤VS30≤2800 m/s and frequencies 0.1≤f≤100 Hz.

REVIEW AND EVALUATION OF SEED GROUND-MOTION MODELS USED IN NGA-EAST

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The final NGA-East median ground-motion models (GMMs) were built on a set of 19 seed GMMs. Details of this development process are given in a related presentation (Goulet et al., 2016). Here, we describe how the seed GMMs were selected from an initial set of 30 candidate models, as well as highlight some of the similarities and differences among the seed GMMs. To begin the process, the NGA-East Technical Integration (TI) team evaluated the vintage and redundancy of the candidate models, as well as their applicability to the range of magnitude (M=4-8.2), distance (R=0-1200 km) and frequency (f=0.1 to 50 Hz, plus PGA) required in the final model. This initial screening found 10 of the candidate models (EPRI, 2013) were redundant with more recent versions already included in the set of models being considered. The remaining 20 GMMs come from a set created specifically for the NGA-East project by 11 developer groups using various combinations of empirical, hybrid-empirical, and simulation-based approaches. These GMMs were developed to be applicable to footwall conditions in the mid-continent region and do not include an explicit source depth term. Adjustments for hanging-wall conditions, extension to Gulf Coast and depth scaling are addressed separately. After the initial screening, the TI team utilized visual comparison of response spectra for selected M and R combinations in order to investigate the scaling trends of the various GMMs. This process determined the range of frequencies over which a candidate model could be used as a seed model across the entire range of M and R values. To ensure a practical, efficient and consistent model-building process, the TI team excluded any model that could only be used over a subset of M and R ranges, ensuring a consistent number of seeds at each frequency. Ultimately, 19 GMMs were selected as seed models. Most are used over the entire target bandwidth, although a few are used only for limited frequency ranges.

UPDATING THE USGS BOUNDARY BETWEEN THE CENTRAL AND EASTERN UNITED STATES AND WESTERN UNITED STATES REGIONS

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The purpose of this study is to revisit the boundary between the western United States (WUS) and the central and eastern United States (CEUS) regions, which has been used in deriving the USGS National Seismic Hazard

Models since 1996. The boundary determines the ground-motion models and seismicity-zone rates that are used in the probabilistic seismic hazard analysis. We have adjusted the boundary in the vicinity of the Raton Basin, southern Colorado, in order to make the mapped earthquake locations fall consistently within the CEUS. Other possible adjustments would be based on regional geologic and seismologic criteria. While the boundary approximates the location of Fenneman's Physiographic Province boundaries pretty well, there are several areas where adjustments can be made. Where feasible, the position of the boundary will be tested by assessing focal mechanisms of nearby earthquakes to discriminate between regions of extension (normal faulting) and non-extension (strike-slip or reverse faulting).

A STUDY OF VERTICAL TO HORIZONTAL RATIO OF EARTHQUAKE COMPONENTS IN THE GULF COAST REGION

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A new model is developed for the spectral ratio of vertical to horizontal components of earthquakes (V/H ratio) for the Gulf Coast region. The proposed V/H ratio model has the advantage of considering the earthquake magnitude, source to site distance, style of faulting, and the shear-wave velocity of soil deposits in the upper 30 m of the site (Vs30) for PGA, and a wide range of periods (0.01 to 10.0 s). The model evaluation is based on a comprehensive set of regression analyses of the newly compiled Next Generation Attenuation (NGA-East) database of available Central and Eastern North America (CENA) recordings with the moment magnitude M ≥ 3.4 and the rupture distance RRup < 1000 km. The 50th percentile (or median) pseudo-spectral acceleration (PSA) value computed from the orthogonal horizontal components of ground motions rotated through all possible non-redundant rotation angles, known as the RotD50 (Boore, 2010), is used along with the vertical component to perform regression using the one-stage maximum likelihood method (Joyner and Boore, 1993). The predicted ratios from the proposed model are compared with recently published V/H ratio models and can be used to develop the vertical response spectra for the Gulf Coast sites, which include the Mississippi embayment.

RE-EVALUATION OF SEISMIC HAZARDS AT THE CENTRAL AND EASTERN UNITED STATES NUCLEAR POWER PLANT SITES

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Following the March 11, 2011 Tohoku earthquake, the US Nuclear Regulatory Commission (NRC) and the nuclear energy industry undertook a comprehensive reanalysis of natural hazards at nuclear power plant (NPP) sites in the United States. In particular, the NRC requested that nuclear power plant licensees re-analyze seismic hazards at their sites using current NRC regulations and guidance to determine if the plants could cope with the re-evaluated seismic hazards and submit their assessment results to the NRC. In parallel, the NRC undertook a series of confirmatory analysis for seismic hazards at the currently operating NPP sites. The purpose of NRC's effort was to develop an efficient and effective review process of the licensees' seismic hazard submittals. The licensees submitted all Central and Eastern United States (CEUS) seismic hazard re-assessment results by March 2014. Using risk insights from the confirmatory analyses, the NRC staff reviewed these hazard submittals and documented the reviews in Staff Assessment reports, which were completed by February 2016. In this presentation, we outline the process, including guidance documents, licensees used to conduct the re-analyses and will summarize the resulting seismic hazards at CEUS nuclear power plants. We will present an overview of the seismic source and ground motion models used for NRC staff's confirmatory analyses. In addition, we will describe the approach used to develop NRC staff's site-response analysis for sites in the CEUS. Specifically, we will describe the approaches used for two types of sites: one with limited information about the subsurface structure and one with well-constrained information. We will discuss how differences in subsurface model uncertainty affected the approach NRC staff used to calculate the site responses and the resulting effects this uncertainty had on the overall seismic hazard results.

STUDYING THE INFLUENCE OF ROCK UNITS AND JOINTS ON SHALLOW AFTERSHOCKS OF THE 2011 MINERAL, VIRGINIA, EARTHQUAKE

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Geologic field studies and recent seismological observations are combined to investigate the influence of geologic structures on distal aftershock clusters triggered by the Mw 5.8 Mineral, Virginia, earthquake of 2011. 1,666 well located hypocenters elucidate previously identified shallow aftershock clusters near Fredericks Hall (FHC), north of Cuckoo (CKC), and NW of the mainshock (NWC). Modeling shows that these outlying aftershocks are in areas of positive static Coulomb stress change <20 km from the mainshock. Most focal mechanisms of aftershocks >6 km deep have reverse slip and NE-striking nodal planes, whereas a majority of those <4 km deep have reverse slip and N to NW striking nodal planes, suggesting a possible change in stress field with depth. Aftershock hypocenters in the FHC deepen northeastward along and beneath a NE-striking, steeply SE-dipping belt of biotite metagranitoid and adjacent amphibolitic metadiorite-metagabbro, but the majority of nodal planes strike N to NW, oblique to gneissic foliation, and dip either NE or SW. A NNW-trending diabase dike may locally perturb the stress field where it intersects the metagranitoid. Hypocenters in the CKC are near and beneath a NE-striking, steeply SE-dipping contact between the Quantico Fm. (mainly schists) and Chopawamsic Fm. (mainly gneissic metavolcanic rocks) on the SE limb of the NE-plunging Columbia-Quantico syncline; the aftershock nodal planes strike N to NW, oblique to the regional trend, and dip NE or SW. Joint orientations were measured at exposures in and near the aftershock clusters for comparisons with nodal planes to test the hypothesis that some earthquakes occurred on preexisting joints. Common joint sets are moderately to steeply dipping and parallel to NE-striking foliation, orthogonal to foliation, or strike NNW, and are parallel to topographic lineaments identified on LiDAR imagery. Sheeting joints dipping <25° are also common. Initial results indicate that most N to NW striking joints dip >60°, while those dipping ≤60° NE or SW coexist and vary locally in relative abundance; those dipping NE are more abundant around Sherman Lake in the FHC, and those dipping SW are more abundant in the CKC. The shallow outlying aftershock clusters appear to be related to the distribution of rock units and to joints favorably oriented to allow fault slip.

COMMUNITY VELOCITY MODEL FOR THE CHARLESTON AREA EARTHQUAKE HAZARDS MAPPING PROJECT (CAEHMP): DATA COLLECTION, INTEGRATION AND INITIAL RESULTS

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We will discuss our efforts to collect and integrate existing and new geophysical, geotechnical and hydrological data into a new 3-dimensional model of shear wave velocity in the coastal plain sediments underlying the greater Charleston, South Carolina region. Once completed, this model will be used for studies of deterministic and probabilistic strong ground motion in the CAEHMP region. This presentation will focus on: 1) defining the depth of the base of the coastal plain section, where V_S goes from <1 km/sec to >2 km/sec; 2) estimating the shear wave velocity structure from the base of the coastal plain section up to the Quaternary/Tertiary boundary; 3) defining the depth of the Quaternary/Tertiary boundary, which represents a factor of 2 or more jump in V_S; and 4) characterizing the V_S structure of the overlying Quaternary and anthropogenic units. Of particular interest will be the presentation of recently released borehole data collected as part of a geotechnical baseline study for a port expansion project in Charleston. This data includes a ~240 meter deep borehole with V_P, V_S, resistivity, gamma ray and spontaneous potential logs and a series of SCPT and MASW/ReMi estimates of V_S of Quaternary sedimentary units across the “Neck” area of the Charleston Peninsula. One important finding of the geotechnical baseline study is confirmation that the map unit “artificial fill” in the Charleston region represents highly variable seismic site response conditions, ranging from ~1 meter of fill overlying 9 meters of V_S = 190 m/sec Quaternary sediments to ~2 meters of fill overlying 15 meters of V_S= 55 m/sec Holocene marsh mud. We will also present current plans / beta site for sharing information and data in the Charleston region as part of the larger multi-institutional project.

A SIMPLIFIED FLOOR SPECTRAL RATIO FOR STRUCTURAL HEALTH MONITORING OF HIGH-RISE BUILDING

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In regions with a high vulnerability to natural hazard, real-time structural monitoring have the potential to find rapid answers to important questions related to the functionality or state of "health" of structures during and immediately of a seismic events. While earthquake happened, high-rise building will usually swing or even crack because of resonance between period of earthquake and natural period of building. Moreover, if natural frequency of building has changes, these building can be collapse triggered by next earthquake and it will endanger more people. Consequently, we propose a simple method approach to monitor the structural spectrum of high-rise building in order to risk reduction of civil engineering structures. To find Structural Health Monitoring (SHM) information, some numerical steps on strong-motion data are found helpful. We used 15-storey building in Jakarta as experiment object and some significant earthquakes in the south of Java as triggered strong-motion recorded on accelerographs. We calculate the Floor Spectral Ratio (FSR) between the earthquake response on the ground and top floor. Subsequently, using the fast Fourier for transform from time to frequency domain and transfer function for linking of all floor, we find that building natural frequency (f0) after three earthquakes is keep similar on the each floors. Monitoring in this manner, the peak of FSR curve show no changes value of natural frequency on 0.8 Hz. Rapid monitoring for this building show that building still on good performance. This assessment is very important and useful for help public safety by recommend to rehabilitate the functionality of structures. Keywords: strong motion, structural health monitoring, natural frequency

"CAN I SEE YOUR RICHTER SCALE?": THE CHALLENGES OF TEACHING ABOUT MAGNITUDE WITH EDUCATIONAL SEISMOGRAPHS

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When a fourth grader watching her school's seismograph asks, "How can we tell the magnitude of that earthquake?", how should we respond? Sometimes we need to begin by correcting the misconception that the "Richter Scale" is a physical instrument you can see at earthquake observatories. Having clarified that it is a mathematical formula, we can next explain how the formula is used to correct waves for propagation effects. But, measuring magnitude is complicated: different magnitude scales, different regions and distances, instrument calibration, and subtle issues about different waveforms recorded on different instruments. Earthquakes recorded by an EQ1 seismograph, used for the Boston College Educational Seismology Project, have amplitudes and periods similar to, but not identical to, those of research-quality instruments seismologists routinely use to determine magnitudes. But, if we want students to have a firm grasp of how to make scientific measurements, they should be able to calculate magnitudes from their school seismograph which are consistent with officially reported magnitudes. Here we investigate how body wave magnitude (mb), as measured on an EQ1, compares with that measured on other seismographs at Weston Observatory (WO), including a broadband instrument and a WWSSN instrument (standard instruments for measuring mb). We also measured magnitudes from an EQ1 operated by the Texas Educational Seismic Project (station E1TX). Preliminary results (relative to mb reported by the USGS) are: WO EQ1 magnitudes are, on average, about 0.2 magnitude units (mu) low and E1TX magnitudes are about 0.3 mu high. These differences are reasonable for the usual scatter of magnitude measurements; however, it demonstrates why we also need to teach students about scatter and uncertainties, another point of confusion about magnitude. Calibrating EQ1 magnitude calculations is a good start, but finding effective ways to teach about magnitude remains a challenge.

REPEATING EARTHQUAKE SEQUENCES IN BERNE, NEW YORK, 2009-2015

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In February through May 2009, 17 earthquakes occurred around Berne, Albany County, New York. The earthquakes that occurred were in the magnitude range between 1.1 and 3.0. Then, on 14 February 2010, six earthquakes occurred followed by an additional six earthquakes during February 15–18, 2010. On August 22, 2011, a magnitude 1.7 shock occurred which was followed by 23 earthquakes until 28 August 2011. These 2011 shocks are clustered further north from the 2009 and 2010 sequences. These sequences raised questions: 1) these earthquakes did not occur along known fault(s) and the question is; Why did these shocks occur in Berne, NY with no connection to the seismicity in Adirondacks to the north and Lower Hudson Valley to the south? 2) shocks might have occurred at depth between 10-20 km below surface, and hence, they are in the lower crust or

at the upper- and lower-crust boundary region; 3) these shocks occurred as clusters of small events in magnitude ranges 1.5–3.1, and hence, the shocks in each cluster appeared as repeating earthquakes. We carried out event detection using waveform cross-correlation detector. By using a set of template (master event) waveforms, we detect small shocks based on their waveform similarity through waveform cross-correlations. Double-difference relocation of 2009 & 2010 sequences indicates 35 events in this cluster aligned along a lineation trending NW. The 2009 events are clustered into two groups – at shallow depth of 12 km and about 15 km depth, whereas the 2010 cluster defines a near vertical plane between focal depths 15–19 km. Double-difference relocation of the 2011 sequence shows that events are aligned along a 0.4 km long, NE trending lineation on a plane dipping about 55º to the NW. Temporal distribution of the cluster of earthquakes detected by waveform cross-correlation detector that occurred in Berne, NY area during 2009-2015 suggests that seismicity is not periodic or does not follow an obvious pattern.

NGA-EAST DATABASE

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We summarize the attributes of a comprehensive ground-motion database for the Central and Eastern North America (CENA) region. The database was developed as part of the Next Generation Attenuation Project for CENA (NGA-East), a large multi-disciplinary project coordinated by the Pacific Earthquake Engineering Research center. The NGA-East database includes the ground-motion recordings from numerous selected events ($M \geq 2.5$, distances < 1500 km) since 1988. The final database contains over 9,600 records from 81 earthquakes and 1379 recording stations. The database is the largest for processed ground motions from Stable Continental Regions. The motivation behind the development of the empirical database was the same as for other NGA projects (NGA-West1 and NGA-West2), which is that it will be used for the development of ground motion models with the metadata. The NGA-East database consists of three sub-databases referred to as the ground motion database, earthquake source database, and station database. The ground motion database includes pseudo-spectral acceleration for 5%-damped elastic oscillators with periods ranging from 0.007 to 10 s, the Fourier amplitude spectra (FAS) of the processed ground motions, and the corresponding time series (acceleration, velocity, and displacement). The earthquake source database includes source parameters, finite fault models, and event classifications. The station database contains information on site condition, housing, and the time-averaged shear wave velocity in the upper 30 m. The summary file called the "flatfile", which contains metadata, ground-motion information, intensity measures and FAS, is developed by combining these sub-databases. The NGA-East database products are also made available to the public through the online ground motion tool. An overview of the NGA-East database attributes and development is presented.

ARRAY DESIGNS FOR THE IRIS WAVEFIELDS DEMONSTRATION EXPERIMENT, OKLAHOMA

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Part of the IRIS Wavefields Demonstration Experiment that was deployed over an active lineament of induced seismicity in Northern Oklahoma last summer consisted of two experimental array designs to explore concepts of self-similar geometries in both frequency-wavenumber analysis and wave gradiometry. 112 three-component, 5 Hz nodal seismometers were installed in a geometry consisting of 7 nested square gradiometers of 16 instruments per square, with the outside gradiometer being 800x800m in dimension. Each internally nested gradiometer was progressively reduced in scale by a factor of 2. In principle, nested scaling produces a "broad band" gradiometer array in that seismic wavelengths from 100m to 10km can be analyzed to determine wave attributes such as horizontal slowness, azimuth of propagation, horizontal strain and rotation. One important characteristic of the redundant geometry is that it allows a study of the influence that station amplitude statics have on computation of the incident wavefield and its derivatives that will define practical limitations on future use of gradiometer arrays. It will also allow studies of the change of wave attributes with frequency for the local and regional seismicity that can be used to understand wave scattering in the local structure. The nested gradiometer was at the northeast edge of an experimental frequency-wavenumber, 6 km aperture, "Golay 3x6" array. 18 broadband stations were installed in 6 subarrays of 3 stations each in such a way to fit at the edges of the north-south grid of farm fields in the area and to retain as much of the self-similar inter-station geometry as possible compared to the ideal design. Geometries of both the gradiometer and Golay array allow the analysis of regional waves with wavelengths of approximately1 to 5 km for direct comparison of array performances. This unique array data set will be freely available through the IRIS DMC.

A HIGH-RESOLUTION STRESS MAP OF THE CEUS FROM MOMENT TENSOR INVERSIONS

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Although the state of stress is not uniform across the intraplate central and eastern United States (CEUS) a limited number of observations from seismogenic depths has precluded mapping of the boundaries/transitions between adjacent settings and quantifying the state of stress in any given region robustly. Recently, induced seismicity, the Transportable Array and temporary seismic networks, and a few notable natural CEUS earthquake sequences have provided a factor of 10 more moment tensors than were available 10 years ago. Inverting these, we show a general trend of ENE-WSW maximal horizontal compression with a transition from thrust faulting along the eastern seaboard to strike-slip in the Midwest to normal faulting on the Great Plains. Nevertheless, three of the four highest-hazard fault zones—New Madrid, Eastern Tennessee, and southern Oklahoma (Meers fault)— host principal stress directions and/or styles of faulting that are anomalous relative to their surroundings. Although historical/pre-historical rates of seismicity at these zones may not reflect the long-term average, time-dependent earthquake rates do not explain stress reorientations. Similarly, low-friction faults or weak lithosphere could elevate strain rates but would not affect fault zone-scale stress. The best explanation for anomalous stresses and Quaternary seismicity rates are localized sources of stress that elevate and/or reorient net deviatoric stress in these intraplate seismic zones. The implication of this hypothesis is that the current appraisal by the National Seismic Hazard Model is valid, with elevated hazard in these discrete seismic zones.

STRUCTURE AND DYNAMICS OF THE MID-ATLANTIC APPALACHIANS: PRELIMINARY RESULTS FROM THE MAGIC EXPERIMENT

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The Mid-Atlantic Geophysical Integrative Collaboration (MAGIC) involves a collaborative effort among seismologists, geodynamicists, and geomorphologists to understand the relationships among surface processes, crustal and lithospheric structure, and deep mantle flow beneath eastern North America. The eastern North American margin (ENAM) represents a passive continental margin that has been modified by multiple episodes of orogenesis and rifting through two complete cycles of supercontinent assembly and breakup over the past ~1.3 Ga of Earth history. It is unclear to what extent deep structures in the crust and mantle lithosphere have persisted over this timeframe, and what role deep structures beneath ENAM may play in controlling intraplate seismicity. Furthermore, the persistence of Appalachian topography remains a major outstanding problem in the study of landscape evolution; there is evidence for relatively recent rejuvenation of this topography, which may be connected to deep mantle flow. The observational seismology component of MAGIC involves the deployment of 28 broadband seismometers as a USArray Flexible Array experiment in a dense linear transect from Charles City, VA to Paulding, OH between 2013-2016. The MAGIC array passes through the Central Virginia Seismic Zone and the region near Harrisonburg, VA that was affected by Eocene basaltic volcanism, and extends across the Appalachian Mountains in West Virginia all the way to the Grenville Front in western Ohio. This presentation will focus on preliminary results from the MAGIC experiment, including crustal and lithospheric structure from receiver function analysis, as well as constraints on mantle anisotropy from shear wave splitting and surface wave observations. We will also discuss results from the geodynamics and geomorphology components of the project, as well as results from the EarthScope USArray dataset in eastern North America more generally.

OKLAHOMA EXPERIENCES IT'S LARGEST EARTHQUAKE DESPITE WASTEWATER INJECTION REDUCTION MITIGATION EFFORTS

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On September 3rd 2016, the largest earthquake in Oklahoma history (Mw 5.8) caused moderate to minor to moderate damage in the epicentral region and nearby rural town of Pawnee, and resulted in over 60,000 felt reports throughout the central U.S (max. MMI=VII-VIII). The Pawnee event is the third Oklahoma earthquake larger than Mw 5 in the past five years, representing a distinct increase in the historic rate of moderate (M 5-6) earthquakes. Using improved constraints from a rapidly deployed seismic network, we developed precise hypocenter locations, combined with moment tensor modeling to show that the Pawnee earthquake reactivated a previously unmapped N75W trending left-lateral strike-slip basement fault. The Pawnee fault intersects the previously mapped right-lateral northeast-striking Labette fault zone at a complex junction of conjugate strike-slip structures 1.7 km to the west-northwest of the Pawnee earthquake epicenter. ΔCFS Models indicate that the near optimally-aligned Labette fault zone south of the Pawnee fault now appears to be closer to failure due to stress changes imparted by the Mw 5.8 Pawnee mainshock. Based on this study, key observations of moderate earthquakes in Oklahoma are: 1) they can occur on unmapped structures; therefore avoiding wastewater injection near known fault structures may be an insufficient mitigation strategy; 2) they can occur without a notable foreshock sequence; therefore stop-light style mitigation strategies may also be insufficient; and 3) they can occur at large distances from high-rate wells, illustrating the regional effects of wastewater disposal. Accurate and rapid source-characterization of the Pawnee earthquake sequence is an important step toward providing scientific guidance on the changing earthquake hazard, its relationship to wastewater injection, and potential damage to communities and critical infrastructure in central Oklahoma.

SYSTEMATIC INVESTIGATION OF THE AFTERSHOCK SEQUENCE OF THE 2011 MW5.8 VIRGINIA EARTHQUAKE

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On 23 August 2011, an Mw 5.8 earthquake struck Louisa County, Virginia. The mainshock ruptured a shallow, reverse fault striking N29oE and dipping S51oE in the central Virginia seismic zone. From 1.5 to 6 days following the mainshock, 22 temporary seismic stations from 4 different networks are deployed in the vicinity of the mainshock rupture zone. Such dense monitoring network provides us a unique dataset to study intraplate aftershock sequence. Although previous studies [Chapman, 2013; McNamara et al., 2014] have identified hundreds of aftershocks using these temporary stations, many small earthquakes are still missing in their catalogs. Hence, we apply the waveform matched filter technique to detect small aftershocks that are previously unidentified. We use ~380 aftershocks identified by Chapman [2013] and McNamara et al. [2014] as template events and scan through the continuous data recorded by 22 temporary stations from 23 August 2011 through 30 November 2011. In total, we have detected 4733 events using a threshold of 9 times the median absolute deviation. The detected events can be divided into two groups: aftershocks that occur on the mainshock's rupture plane and off-fault earthquakes that may be triggered by the mainshock. We then calibrate precise relative magnitudes for template and detected events, using a principal component fit to measure waveform amplitude ratios. The magnitude of completeness and b-value of the detected catalog is 0.3 and 0.7, respectively. We are currently relocating the detected events with HypoDD. The accurate temporal-spatial evolution of seismicity should shed light on the triggering mechanism for both on- and off-fault aftershocks. Moreover, ~3 days after the mainshock, hurricane Irene struck near the epicentral region. We will also examine whether such an extreme weather event could affect the occurrence of aftershocks.

SITE RESPONSE STUDY OF THE SEVERELY DAMAGED REGION OF MASHIKI TOWN FROM THE 2016 KUMAMOTO EARTHQUAKES

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Mashiki town was one of the most severely affected regions during the April 14 (M6.2) and April 16 (M7.0) Kumamoto earthquakes in Kyushu, Japan. The recorded instrumental intensity at several sites in the area was JMA 7, the highest level on the JMA scale. There was a very heterogeneous distribution of the affected buildings that varied within a few kilometers from severe damage to almost all structures in a local area, to very light damage. The damage patterns for the two earthquakes were quite similar, indicating that site and construction factors may have played important roles. We investigated the local site characteristics across this area with a survey of microtremor observations at about 50 sites spaced at about 50 meters. The local site response was compared to the distribution of damage of over 1000 buildings. Our results show that the area of relatively less damage has a thick sediment deposit with a low shear-wave velocity, compared to a higher velocity for the surface layer in the more heavily damaged areas. To explain this rather unusual observation, we suggest that there were important non-linear effects which resulted in relatively small amplitudes for 1-2 Hz waves in the areas of the low shear-wave velocity.

A ONE-YEAR SEISMIC HAZARD FORECAST FROM INDUCED AND NATURAL EARTHQUAKES

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The USGS has recently developed new models (Petersen and others, USGS Open File Report 2016-1035) to quantify the seismic hazard from induced and natural earthquakes in the central and eastern United States (CEUS). Our standard hazard models, developed for applications like building codes, are based on long-term patterns in natural seismicity. Induced events pose unique challenges: compared to natural earthquakes they may have distinct recurrence or ground shaking characteristics, their maximum magnitudes may be smaller, and they can stop or start for policy or commercial reasons. To distinguish sequences of induced earthquakes in 21 zones, we rely on published case studies and look for unusual activity within seismicity catalogs. We present an overview of seismic hazard assessment in the CEUS, and describe the new models and some of their limitations. The new models give high weight to seismicity trends during the past year, and provide a hazard forecast that is valid for only one year. Results developed at the beginning of 2016, based largely on 2015 seismicity, show increased hazard and risk of building damage in the most active parts of Oklahoma and Kansas. The M5.1 Fairview earthquake (13 February 2016) and the M5.8 Pawnee earthquake (03 September 2016) occurred within regions of elevated hazard. Seismicity has slowed at some other locations during 2016; if the maps are updated, these changes should be reflected in local hazard decreases.

FREQUENCY DEPENDENT QUALITY FACTOR OF LG WAVES FOR THE CENTRAL UNITED STATES USING CODA NORMALIZATION

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The coda normalization method is exploited to estimate the quality factor of the *Lg* waves in the central United States. *Lg* waves are the most prominent phase observed in seismograms that travel within the continental crust. Out of 500 records captured by 11 stations located in the New Madrid seismic zone (from 2000 to 2009), 64 vertical component seismograms, with hypocentral distances ranging from 150 to 400 km, were selected to calculate the frequency dependent quality factor function for the*Lg* waves. We used a signal to noise ratio more than 3 to assure the quality of seismograms. Obtained Q_{Lg} values for the frequency range of 3 to 12 Hz are fitted using a power law equation $Q(f)= Q_0 f^{\eta}$. Due to considerably deep sediment site effects and/or their reverberations, we did not include results for frequencies less than 3 Hz in the fitting process. For a 10 second coda window located at twice the shear wave arrival of the farthest source to site, the output of the inversion process is $Q_{Lg}(f)=586\ f^{0.41}$. This result is comparable to Baqer and Mitchell's (1998) work, which implies a moderate seismicity in the region of study. The result of this research is also compared with Zandieh and Pezeshk (2010) and Chapman *et al.* (2014).

NATURAL AND INDUCED SEISMICITY ANALYSED BY USING SMALL APERTURE SEISMIC ARRAY "MIKHNEVO"

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In some opinions induced and triggered seismicity associated with anthropogenic activity. In last 12 years at East-European Platform (EEP) were appeared some platform earthquakes. Tectonic sources consist of local/regional/global earthquakes, as well as tectonic tremors and slow earthquakes. Anthropogenic sources include daily traffic and industrial activities such as quarry blast. In this paper we are exploring the use of Small Aperture Seismic Arrays (SASA) technique to study earthquakes, regional signals classified as man-made events and local signals with noise at the EEP. Observations started in 2004 in Moscow area near Mikhnevo. Some examples are published and the preliminary results were presenting by Sanina et al. [2009, 2011]. Here we present our on-going efforts in constructing an automated toolbox for detection and classification of seismic events. Main algorithms are the STA/LTA detection and beamforming with f-k analysis [Gibbons & Ringdal, 2006]. This waveform cross correlation technique was applied by Schaff & Richards [2011], Gibbons & Ringdal [2006], Bobrov & Kitov [2011]. However, the increased diversity of pattern waveforms and other metadata noticeably form a space of Big Data problems. These somewhat datasets provides additional challenges to making useful detections. Method matched filter with template waveforms, carefully selected from a ten-year archive of digital records SASA "Mikhnevo", allows to create various geostatistics algorithms assisting to relative identification of the quarry blasts. I investigated characteristic features of different seismic events, such as predominant frequency, frequency range, event durations, occurrence frequency etc. The properties of the sources correspond with specified frequency band. Our package could potentially provide a machine tool to accelerate routine processing and give some ideas to physical mechanisms understanding.

INVESTIGATING TIDAL TRIGGERING OF INDUCED SEISMICITY IN OKLAHOMA AND SCHUSTER SPECTRUM IDENTIFIED OUR DATA HAVE CLUSTERS

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Seismic activity in Oklahoma has increased exponentially in the past decade and has been linked to the practice of injecting wastewater into the subsurface as part of enhanced oil recovery methods. The pore pressure increase resulting from wastewater disposal can reactivate faults in a normally quiescent tectonic setting. Within such an increased pore pressure environment, even small stress changes, such as those due to the propagation of teleseismic waves, can trigger earthquakes (e.g. van der Elst *et al.*, 2013). Tidal stresses, though even smaller in magnitude, have been found to trigger earthquakes, particularly in regions experiencing seismic tremor. Here, we test whether the incremental stress change due to solid earth tides is sufficient to trigger earthquakes under the modified stress environment following fluid injection. In order to determine whether statistically significant periodicities coincide with tidal frequencies, we computed Schuster spectra to analyze the timing of earthquakes within different catalogs of Oklahoma seismicity. We found that the extreme heteroscedasticity of Oklahoma seismicity due to the exponential increase in earthquake rate since 2008 rendered Schuster analysis unreliable. Therefore, a straightforward application of Schuster spectra cannot be used to meaningfully analyze periodicity in the full catalog of earthquakes. To sidestep this issue, we identified clusters of seismic activity of short duration where the rate of seismicity did not change appreciably, and detected periodicities of 9-10 days, accompanied by possible higher harmonics. No significant periodicities were observed for any earthquake clusters at any tidal periods, providing a lower bound on threshold stress change required to trigger earthquakes in Oklahoma.

RE-EVALUATION OF THE HYPOCENTRAL DEPTH OF THE 2008 MW7.9 WENCHUAN EARTHQUAKE AND ITS IMPLICATION FOR RESERVOIR TRIGGERED SEISMICITY

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The 2008 Mw7.9 Wenchuan earthquake occurred along the Longmenshan fault zone in the eastern margin of Tibetan plateau. The mainshock ruptured unilaterally to the NE direction, producing a ~240 km surface rupture along the Yingxiu-Beichuan fault, and another ~80 km rupture along the Pengguan fault. The mainshock initiated within ~12 km of the Zipingpu reservoir, with its initial impoundment in September 2005. Many studies have evaluated whether the impoundment of the Zipingpu reservoir has triggered the Wenchuan mainshock [e.g., Ge et al., 2009; Gahalaut and Gahalaut, 2010; Lei, 2010; Tao et al., 2015]. However, due to uncertainties in the hypocentral depths and fault geometries, different conclusions were reached [Tao et al., 2015]. In particular, most previous studies determined the hypocentral depth of the mainshock to be larger than 12 km, which would result in very small values in pore pressures and Coulomb failure changes. Here we re-examined the hypocentral depth of the Wenchuan mainshock by utilizing only seismic stations within 50 km of the mainshock epicenters. These include 7 stations in the Zipingpu Reservoir Seismic Network (ZRSN), and 2 stations in the regional Sichuan Seismic Network (SSN). We manually pick P wave arrivals at these 9 stations, and identify one S arrival at the nearest station BAJ. We then use the NonLinLoc software (http://alomax.free.fr/nlloc/) to perform nonlinear global search for 3D earthquake location. The best-fitting hypocentral depth is the range of 6-10 km, shallower than the previously reported values. This is consistent with results of 6-9 km depth with phase picks from the ZRSN stations only (Ma et al., 2011). At such depths, the stress perturbations from pore pressures and Coulomb failure stresses are on the order of a few tens of KPa, large enough to advance the occurrence time of the Wenchuan mainshock by a few tens to hundreds of years. Our results suggest that the impoundment of the Zipingpu reservoir did play an important role in triggering the Wenchuan mainshock. The next step is to use waveform of small earthquakes recorded by the ZRSN as templates, and compare with the initial few seconds of the mainshock P waves to better quantify the hypocentral location and rupture processes of the mainshock.

EVALUATING MCADAM, NEW BRUNSWICK EARTHQUAKE SWARMS: AN ANALYSIS USING DOUBLE DIFFERENCE RELATIVE LOCATION

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An evaluation of four McAdam New Brunswick earthquake swarms between March of 2012 and February of 2016 is being carried out using a double difference relative location method. Due to the close proximity of the absolute earthquake locations and the short time period over which the events took place in each swarm, we are attempting to obtain a more precise spatial pattern for the earthquakes using the relative location method. For the swarm event on 8 February 2016, seven earthquakes were recorded by Weston Observatory. Of these the P and S waveforms of four of the events strongly correlated with each other as both a master earthquake and a secondary earthquake with precise hypocenters relative to each other. Evaluating the spatial configuration of these four events using planar regression yielded strike and dip angles of 138° and 13° respectively. For the swarm events on 9 February 2016, ten earthquakes were recorded by Weston Observatory. Of these, four earthquakes had strong waveform correlations and yielded precise hypocenters relative to each other. The spatial configuration of these four earthquakes on 9 February indicates strike and dip angles of 72° and 17° respectively. The estimated fault plane for the events from the 8 February relative location analysis have a similar strike to fault planes found from focal mechanisms of some of the swarm events, although the dip is much shallower from the relative location analysis. For the events from the 9 February relative location analysis the estimated fault plane does not match well constrained fault planes from any of the focal mechanisms computed so far. The dips of the calculated fault planes from the relative location analyses for 8 February and 9 February are similar while the strikes of the planes are very different. The two swarms evaluated so far using relative location analyses suggest that the earthquakes in the McAdam swarms probably took place on multiple fault planes.

NEW VELOCITY MODELS AND HYPOCENTER LOCATIONS FOR THE NEW MADRID SEISMIC ZONE

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New 3D P- and S-wave velocity models and hypocenter locations are determined for the New Madrid seismic zone (NMSZ) using local earthquake arrival times in the Cooperative NMSZ catalog for the period 1997 to 2016. Earthquakes are retained for the local earthquake tomography inversion if they are associated with a minimum of 4 P- and S-wave arrivals. The resulting dataset consists of 2,442 earthquakes, 35,361 P phases and 26,214 S phases. The total number of recording stations is 61. Pre-2000 data have been carefully reexamined and are reliable. The velocity models are similar to previous models for the NMSZ region. The large number of relocated hypocenters reveals interesting patterns that can be related to fault complexity in the NMSZ. The major arms of seismicity include two NE-trending strike-slip faults (the Axial fault and the northern arm) offset by a NNW trending reverse fault (Reelfoot fault (RF)). A fourth arm trends EW from the northern termination of the RF. In some tectonic models, the Cottonwood Grove fault branches off the Axial fault and trends parallel to it until both faults intersect the RF. The RF is divided into northern and southern parts at the intersection of the Axial fault. Relocated hypocenters associated with the northern portion of the RF cluster into a clearly defined plane that dips to the SW. Hypocenters are much more scattered in the southern portion of the RF and tend to align in NE trending planes at the proposed intersection of the Cottonwood Grove fault. Near the southern end of the RF, hypocenters once again define a plane dipping to the SW. Hypocenters associated with the northern arm define two, steeply dipping, parallel planes and a steeply dipping plane defines the EW trending arm. The northern and EW arms extend for about 24 and 30 km, respectively, before the hypocenters defining them become scattered.

AMPLIFICATION OF GROUND MOTIONS IN WASHINGTON, DC, BY SHALLOW DEPOSITS

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During the 2011 Mw5.8 Mineral, VA earthquake, many buildings in Washington DC, including national landmarks like the Washington National Cathedral, the Smithsonian “Castle,” and the Washington Monument, sustained damage despite being 130 km from the epicenter. The surprisingly large amount of damage from weak bedrock ground motions raises questions of whether and how the local geologic materials beneath the city amplify ground motions. In particular, how much and at what frequencies do the southeast-thickening sedimentary strata of the Atlantic Coastal Plain (ACP) strata, sitting on crystalline bedrock, amplify and possibly trap energy? Between November 2014 and August 2015, we used 27 seismometers to measure ground motions across the city during teleseismic and regional earthquakes. Four sites on Piedmont crystalline rocks in NW Washington served as bedrock reference sites, and 23 sites were on ACP strata between 11 m and 200 m thick. Recordings of teleseisms and regional earthquakes provide data with sufficiently high signal-to-noise for computing spectral ratios of the horizontal ground shaking relative to the average of the 4 bedrock sites. Results are consistent with the primary influence on the amplitudes of ground motions coming from the ACP strata. At

frequencies below 0.9 Hz most sites showed little difference in amplification relative to bedrock, suggesting that basement rocks beneath the ACP strata exert little influence on ground shaking. Strong spectral amplifications of a factor or 10 or greater at frequencies of 0.9 Hz and above are interpreted as being caused by the ACP strata, with the largest amplitudes at frequencies near the fundamental resonance frequency. A gradual decrease in amplification with higher frequencies above the fundamental peak is consistent with harmonics and resonances from within ACP strata. Results indicate significant amplification of ground motions in the Washington, DC, area by shallow deposits.

WAVEFORM ANALYSIS OF THE 2015-2016 MCADAM, NEW BRUNSWICK EARTHQUAKE SEQUENCE

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Beginning in November 2015, a series of small earthquakes has been located under the town of McAdam, New Brunswick. These events have continued to June 2016. The largest event was magnitude 3.3 but most have been magnitude 2 or lower. Canadian seismologists operated an aftershock survey around the town and detected events down to magnitude -0.7. The 136 events are spread over an area of approximately 2X2 km and are relatively shallow. Many were felt and some were heard. In this study, we focused on the recordings made by the Central and Eastern US network stations to the west of the epicenter, in particular G65A at 48 km, F64A at 85 km and F63A at 139 km. Thirty eight events were included in this analysis. High-resolution time-frequency analysis was used to identify arrivals and measure group velocities. At G65A, the P-wave arrives at a velocity of 6.0 km/sec, followed by a sharp S-wave at 3.6 km/sec. The Rg wave packet consists of two Rg waves with separable dispersion curves. Three component recordings were integrated to displacement and rotated to radial and transverse motion. The radial P-waves at G65A show evidence of depth phase interaction and cluster into four distinct waveform groups. Corner frequencies are in the range of 15-20 Hz, implying source durations less than 0.1 seconds. The waveforms were modeled including pP and sP surface bounces with a top layer P-wave velocity of 4.5 km/sec. Although the depth resolution is poor, the model fits imply very shallow source depths around 200 meters. The last event in the sequence appears to be a triple event, each separated in time by 0.2 seconds.

SEISMIC AND HYDROACOUSTIC ANALYSIS OF THE JUNE/JULY 2016 UNDERWATER EXPLOSIONS OFF THE EAST COAST OF FLORIDA

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On June 10, June 25 & July 16, 2016, the US Navy detonated three large underwater explosions off the east coast of Florida as part of shock wave testing for the Littoral Combat Ship USS Jackson. Originally listed as magnitude 3.7 earthquakes 150 km east of Daytona Beach in USGS bulletins, the source types were changed to “Experimental Explosion” on July 22 as the Navy released information to news stations. Two of these 10,000 lb explosions were recorded on US seismic stations to distances of ~2000 km and on the hydroacoustic array at Ascension Island at a distance of ~8100 km. The water depth at the explosion site is 900 m. Photos and videos of the events show a surface breach of the shock wave. We have detected no seismic or hydroacoustic signals coming from the source area for the June 25 event. Seismic signals for these events are complex, as would be expected for an explosion that generates large amounts of reverberation in the water column. High-resolution time-frequency analysis reveals a train of P- and S-waves over the frequency band 1-10 Hz. The observed pulse interval of 1.2-sec and corresponds to the two-way travel time in the 900-meter water column. A weak Rg wave can be seen at the closest station at a frequency of about 0.5 Hz and a group velocity of 2.7 km/sec. At the Ascension hydrophone array, the signal from the first explosion arrives at an RMS signal level of 6.5 Pa, or 136 dB; for the third explosion, the RMS level is 5.5 Pa, or 135 dB. Frequency-wavenumber spectra indicate a back azimuth of –55 deg, pointing to the source area. Propagation modeling using range-dependent oceanography and high-resolution modeling from the Ascension Island receiver to the Atlantic Seaboard has been performed. The resulting propagation loss is on the order of 110-120 dB. There is significant seafloor interaction as the sound travels across the Outer Continental Shelf into deep water. There is some evidence of a bubble pulse signature in the data.

ATTENUATION OF HIGH FREQUENCY BODY WAVES IN THE NEW MADRID SEISMIC ZONE

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We estimated the attenuation characteristics of body waves in the New Madrid seismic zone (NMSZ) from 157 seismograms of 46 earthquakes with moment magnitudes less than 4.1 and hypocentral distances out to 60 km. Seismograms were obtained from local earthquakes in the NMSZ, recorded by the Center for Earthquake Research and Information (CERI) at the University of Memphis. We used the coda normalization method to derive Q values at 13 center frequencies. We found that assuming $1/R^{1.0}$ as the geometrical spreading function yields a better fit to the data than $1/R^{1.3}$. The Q_P estimates increase with increasing frequency from 354 at 4 Hz to 729 at 24 Hz, and Q_S values vary from 426 at 4 Hz to 1091 at 24 Hz. By fitting a power law equation to the *Q* estimates, we found the attenuation models for the *P*-waves and *S*-waves in the frequency range of 4 to 24 Hz as $Q_P = (115.80 \pm 1.36) f^{(0.495\pm0.129)}$ and $Q_S = (161.34 \pm 1.73) f^{(0.613\pm0.067)}$, respectively. $Q_S / Q_P > 1$, for $4 \leq f \leq 24$ Hz, suggests that the crust beneath the NMSZ is partially fluid-saturated. Further, the relatively high attenuation of *P*- and *S*-waves indicates a high level of heterogeneities inside the crust in this region.

EXPLORING THE SUITABILITY OF THE QUAKE-CATCHER NETWORK IN THE USGS SHAKEMAP: CASE STUDIES FROM AFTERSHOCKS OF THE 2010-2011 DARFIELD AND CHRISTCHURCH, NEW ZEALAND EARTHQUAKES

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Following the 2010 M7.1 Darfield earthquake, the Quake-Catcher Network (QCN) team rapidly deployed ~200 low-cost seismic sensors around Christchurch to record aftershocks, which included the 2011 M6.1 Christchurch event. In terms of performance, QCN sensor tests suggest these data are potentially useful for ground-motion studies, which could include ShakeMap [*Evans et al.*, 2014]. Previously, the QCN Mexico team illustrated that ground-motion results from a dense array of QCN sensors can be used to produce an accurate ShakeMap for a M5.9 earthquake [*Dominguez et al.*, 2015]. Therefore, the purpose of the present study is to conduct a feasibility test to show if aftershock data collected by QCN sensors deployed in the epicentral region of the 2010-2011 Darfield and Christchurch earthquakes are suitable for integration into the USGS ShakeMap software. We compare the residuals between our ground-motion results with distance as compared to the *Bradley* [2013] ground-motion prediction equation with both QCN and traditional GeoNet strong-motion data and find that the QCN sensors provide on-scale data. *Cochran et al.* [2011] found that the ground motions recorded by QCN sensors are comparable to those measured by GeoNet stations, thus we expect that the individual QCN and GeoNet ShakeMaps will look very similar. In addition, *Kaiser et al.* [2011] concluded that the dense QCN array in Christchurch provides comparable estimates of ground-motion and site response as the nearby GeoNet stations, and that QCN sensors can be useful in microzonation studies. We therefore conclude that QCN provides a cost-efficient method to obtain accurate ground-motion data for use in ShakeMaps. In areas of low station density, where traditional networks are limited, QCN sensors can increase local station density and provide higher-resolution mapping of ground-motion across urban areas that may help to inform earthquake response.

LEVERAGING EARTHSCOPE USARRAY WITH THE CENTRAL AND EASTERN UNITED STATES SEISMIC NETWORK

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Recent earthquakes, such as the 2011 M5.8 Mineral, Virginia earthquake, raised awareness of the comparative lack of knowledge about seismicity, site response to ground shaking, and the basic geological underpinnings in this densely populated region. With this in mind, the National Science Foundation, United States Geological Survey, United States Nuclear Regulatory Commission, and Department of Energy supported the creation of the Central and Eastern United States Seismic Network (CEUSN). These agencies, along with the IRIS Consortium who operates the network, recognized the unique opportunity to retain EarthScope Transportable Array (TA) seismic stations in this region beyond the standard deployment duration of two years per site. Stations were selected using multiple criteria, including proximity to known regions of seismic hazard, nuclear power plants and other critical facilities, and general areal coverage. The CEUSN mission is to produce data that enable both researchers and federal agencies to better understand the basic geologic questions, background rates of earthquake occurrence and distribution, seismic hazard potential, and associated societal risks. This multi-agency collaboration is motivated by the opportunity to use one facility to address multiple missions and needs in a way that is rarely possible. The CEUSN encompasses 158 broadband TA stations, more than 30 with strong motion sensors added. The stations (network code N4) transmit data in real-time, with broadband and strong motion sensors sampling at 100 samples per second. The CEUSN, together with the existing backbone coverage of permanently operating seismometers in the central and eastern United States, form a network of roughly 300 broadband stations. In this presentation, we will highlight the CEUSN operational capabilities and some of the applications (e.g., induced seismicity) that are leveraging this network.

ESTIMATING STABLE CONSISTENT SEISMIC MAGNITUDES

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Magnitudes are meant to be an estimate of the energy released by a seismic event. However, it is common for the various magnitude estimates for an event to vary by as much as 1 to 1.5 magnitude units (mu). There are a number of reasons for this variation including the fact that our magnitude scales do not have a common, fixed baseline. Calculations of the energy distribution among the various seismic phases (Pg, Lg, Pn, Sn, P, S, and core phases) can show how much of the source energy could be contained in each phase. For a simple explosive source, the calculations show that of the total source compressional wave energy, the amount which may be confined to the crustal layers (Pg) varies from as little as 55% for a high velocity source region such as the Balapan Test site to about 85% for a low velocity source medium such as Yucca Flats. Correspondingly, of the total compressional wave energy, the total teleseismic P wave energy may vary from only about 15% for Yucca Flats to as much as 40% for Balapan; effects which are purely from the source region velocity structure. Similar calculations for earthquake sources shows the greatest differences occur between Strike-Slip and Thrust/Normal source mechanisms. The former events radiate more energy in the horizontal direction while the latter radiate more energy vertically. As a result, for two sources that release exactly the same amount of total seismic energy, the Mb estimate for a Thrust/Normal fault could be as much as 0.4 mu larger than that for a Strike-Slip fault. Calculations for shear waves suggest that the distribution of energy among the various types of shear phases is more consistent and could generate magnitude differences of less than about 0.1 mu. Amplitude data from the western U.S. and Iran are used to illustrate the magnitude variations. Various types of correction factors are presented and evaluated.

PRELIMINARY GROUND SHAKING AND DAMAGE OVERVIEW FROM THE M5.8 EARTHQUAKE NEAR PAWNEE, OKLAHOMA

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The Mw 5.8 Pawnee earthquake occurred on 03 September 2016 (07:02:44 local time; depth 5.6 km) in a rural area of north-central Oklahoma. About 60,000 U.S. Geological Survey (USGS) "Did You Feel It?" (DYFI) reports show that it was felt from Houston, TX, to Minneapolis, MN, and Chicago, IL, and west to Denver, CO. The USGS estimates that about 3.8 million people felt light to moderate shaking effects (Modified Mercalli Intensity, MMI, IV-V), whereas the nearest town, Pawnee (pop. 2000), about 15 km southeast of the main-shock, experienced mostly MMI IV, with 3 individual reports of MMI VI, VII, and VIII. There were eight total reports of DYFI MMI VIII within about 25 km of the epicenter. The Pawnee Fire Department reported one injury related to the earthquake when falling bricks from a chimney struck a man on the head. The nearest seismic station (USGS station OK033), located 40 km south of the epicenter, recorded a peak ground acceleration (PGA) of 6.5%g, while another USGS station (OK005), located 87 km south-southeast of the epicenter, recorded 8.5%g PGA. A reconnaissance survey, data from the Oklahoma Department of Transportation (ODOT), and web-based news media sites, indicate that damage was quite variable and ranged from minor to moderate, with brick and stone veneer failures on homes being common. Masonry chimney failures were common within 10 km of the epicenter, yet some survived undamaged. Sand blows occurred in farm fields underlain by sandy floodplain deposits 5-10 km from the epicenter. ODOT reported only cosmetic damage to a few bridges within 100 km of the epicenter. Some buildings at Oklahoma State University in Stillwater, Oklahoma (at about 35 km epicentral distance), suffered minor damage including cracked brick veneer on a parking garage. The U.S. Army Corps of Engineers inspected all dams within 83 km of the epicenter and found no damage. The sparse population around the epicenter appears to have limited damage from this earthquake.

STRESS DROP AND SOURCE SCALING OF RECENT EARTHQUAKE SEQUENCES ACROSS THE UNITED STATES

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Knowledge of source scaling and variation in stress drop are essential to a better understanding of source physics and strong ground-motion prediction. Due to the large uncertainties in stress drop measurements, many previous studies have found results showing both self-similar and non-self-similar scaling relationships between large and small earthquakes. Moreover, the validity of the recently proposed idea that induced earthquakes in the central US have low stress drops needs to be tested in a reliable and systematic way. We investigate the stress drop and source scaling of four recent earthquake sequences across the US: the 2011 Mw 5.7 Mineral, Virginia earthquake, the 2011 Mw 5.6 Prague, Oklahoma earthquake, the 2014 Mw 6.0 South Napa, California earthquake and the 2016 Mw 5.1 Fairview, Oklahoma earthquake. We propose a multi-window coda spectral ratio method, which enables us to efficiently separate the source effect from the path propagation and site response effects, to obtain stable and reliable estimates of corner frequencies and stress drops. We carefully examine the decay of coda envelopes to select qualified event pairs, and the corner frequencies and stress drops are estimated by modeling the observed source spectral ratio with the omega-squared source spectral model.

Our results shed light on the yet un-resolved question whether potentially induced earthquakes are different from tectonic earthquakes in terms of stress drop and source scaling across the US.

REPEATING AFTERSHOCKS FOLLOWING THE 2013 MW6.6 LUSHAN EARTHQUAKE

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The 2013 Mw6.6 Lushan earthquake occurred along the southern Longmenshan (LMS) Fault that straddles the eastern Tibetan Plateau and Sichuan Basin, and was followed by numerous aftershocks. Relocated aftershocks revealed that the Lushan earthquake ruptured a blind thrust fault [Fang et al., 2015], and showed spatial expansion along both the fault strike and updip directions [Wu et al., in revision], similar to other recent studies showing that early aftershocks were mainly driven by afterslip. Here we present a detailed analysis of repeating aftershocks following the Lushan mainshock, which rupture approximately the same fault patch and have nearly identify waveforms. First, we run cross-correlations (CC) among all events listed in the standard regional earthquakes and identify all repeating event pairs with median (or mean) CC value above 0.90. It results in ~2050 repeating pairs. Then we group event pairs into clusters using a simple Equivalency Class (EC) algorithm, which would connect two different pairs once they share a common event. So far we have identified ~120 clusters with at least 4 events. Our next step is to apply hypoDD relocation to each cluster to ensure significant source patch overlaps among events within each cluster. We plan to examine their occurrence patterns, and estimate the amount of aseismic afterslip in surrounding regions, as well as use their waveforms for monitoring temporal variations following the mainshock. Updated results will be presented at the meeting.

EQUIVALENT LINEAR OR FULL NONLINEAR – WHICH METHOD SHOULD BE USED IN PERFORMING SITE-SPECIFIC RESPONSE ANALYSES

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In multitude of cases such as important buildings and long span bridges, there is a need to obtain site-specific design response spectrum. To obtain the site-specific seismic response spectrum, we initially perform probabilistic seismic hazard analysis (PSHA) to determine ground motions at the rock level underlying the study site. Then, we select time histories, which closely match the de-aggregation magnitude and distance results obtained from the PSHA. Then, we scale and match the selected time histories to the uniform hazard response spectrum at the rock level for the study site. We generate the soil profiles of Mississippi embayment by finding the deep layers of the soil in this area and their corresponding shear wave velocities. When performing one dimensional site response analyses, engineers are faced with two choices: (1) equivalent linear; and (2) nonlinear analyses. The purpose of this study is to perform a comprehensive study to make recommendations on when it is appropriate to use the equivalent linear and when it is appropriate to use full nonlinear analyses. The focus of the study area will be the Mississippi embayment. For this study, we use the computer program SHAKE91 for modeling and performing equivalent linear analysis, and we do consider several nonlinear programs (e.g., DMOD2000). We will perform a complete parametric study to determine patterns that signifies which method is appropriate to use for the Mississippi embayment.

ESTIMATION OF SITE RESPONSE IN CENTRAL EASTERN NORTH AMERICA USING EARTHQUAKE DATA

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Obtaining the site amplification in Central Eastern North America through an inversion method is the main purpose of this study. Several analytical and experimental approaches have been developed for the local site effect estimation. One approach is based on removing the source and path effects. This technique takes into account the ratio between the response spectrum acceleration at a site of interest and the response spectrum acceleration at a reference site for various frequencies, which is usually a nearby rock site. If the two sites have similar source and path effects, then the resulting spectral ratio creates an estimate of site amplification. The spectral ratio method; however, depends on the availability of a proper reference site for which the amplification is negligible. The critical assumption in this method is that the record of a surface reference rock site is equivalent to the input motion at the base of the soil layer. We use moderate earthquake events (Mw 3.9-4.8) recorded by the Oklahoma and Arkansas seismic networks. These records have been recorded at different stations with different Vs30 (shear-wave velocity of the top 30 meters). We compare the amplification results calculated based on the proposed inversion approach with the traditional site response approaches such as the equivalent linear response analysis using the computer program SHAKE91 at different sites.

USE OF SEISMIC HAZARD CALCULATIONS IN THE NGA EAST SSHAC PROCESS

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An important component of the SSHAC Process is the use of seismic hazard feedback to inform the Technical Integration (TI) team on the identification of important issues and the implications of alternative assessments on the outcome of the model building. Because the focus of the NGA East project was on developing a ground motion model for the assessment of hazard at critical facilities in the central and eastern United Sates (CEUS), the natural choice for a seismic source model for providing hazard assessments is the CEUS SSC model developed by EPRI/DOE/NRC (2012). In order use the CEUS SSC model efficiently for hazard feedback, it was condensed to produce mean hazard across the epistemic uncertainty in earthquake recurrence rates. The resulting condensed model was then used to provide feedback to the TI team on the effects of alternative representations of median ground motions, alternative representations of aleatory variability, and alternative representations of the epistemic uncertainty in the median models and aleatory variability. Additionally, the condensed model was used to provide a comparison of hazard produced by the NGA East model compared to that produced by the current model used for assessing hazards at nuclear facilities in the CEUS.