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Seismogenic zones are delineated, based on all available information from tectonics, active faulting, geology, geodesy, and past seismic activity, for use in probabilistic seismic hazard assessments (PSHA). Often the delineation of seismic zones is dependent on availability of information and how the seismic hazard specialist interprets and makes a judgement based on the available information.

As these decisions may have a significant impact on the estimation of seismic hazard in a region, we explore the sensitivity of hazard results to the delineation of seismic source zones. We first examine the impact of using a single seismogenic zone model versus using multiple zone models in seismic hazard assessments. We then investigate how altering the source zone boundaries impact the earthquake recurrence characteristics of each zone. Of particular interest are the moderate to large earthquakes or occurrence of large number of small earthquakes near source zone boundaries, and assessment of accurate magnitudes and locations.

New Software for Computing Time Dependent Seismic Hazard During Aftershock Sequences Using the Opensha Platform

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The chaos caused by a major earthquake does not end when the shaking stops. Search and rescue, damage assessment, and lifeline repairs all need to be carried out under the constant threat of damaging aftershocks. In some cases, aftershocks can be even more destructive than the initial event, as was the case in Christchurch, New Zealand . While it may never be possible to predict the exact time, place, and magnitude of an impending earthquake, it is nonetheless possible to make probabilistic assessments of aftershock hazard based on past regional sequences and the specifics of an ongoing sequence. Forecasts, and in particular forecast maps, can provide situational awareness, increase public resilience, and help decision makers to prioritize response and recovery operations. The public has increasingly come to expect such information, and information vacuums are likely to be filled by non-authoritative sources.

The USGS, with support of USAID-Office of U.S. Foreign Disaster Assistance, is developing several lines of aftershock forecasting products with the goal of providing rapid quantitative aftershock information to emergency responders, lifeline operators, and the general public. Here we introduce a software application designed to streamline the process of analyzing and forecasting aftershock sequences within a modified Epidemic-Type Aftershock Sequence framework. Forecasts are a Bayesian combination of a regionalized generic model and a specific model tuned to the ongoing sequence. The software uses the OpenSHA architecture to translate spatio-temporal rate forecasts into time-dependent probabilistic hazard estimates using standard ground-motion prediction equations. The software automatically generates graphical forecast summaries and hazard maps that supplement standard magnitude-probability tables. This poster will describe modifications to the ETAS model that allow for efficient and stable generation of aftershock forecasts, and discuss expected applications of the software.

The Current Unlikely Earthquake Hiatus at California's Transform Boundary Paleoseismic Sites

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If the average interval between paleoearthquakes at 16 high-resolution paleoseismic sites along the major transform faults in California range from 100 to 220 years, what are the odds that none of these sites has experienced an earthquake in the last 100 years? A similar question was posed by Jackson (AGU, 2014) who found the odds were exceptionally low. We revisit the question using full earthquake age uncertainties and subsets of high-resolution sites that sample the five major transform fault sections in California: the Northern and Southern San Andreas Fault, San Jacinto Fault, Hayward Fault, and Elsinore Fault (Biasi and Scharer, SRL, accepted). A 100-year hiatus can be observed in the 1000-year record of sets of a few proximal sites. In contrast, if a single site from each of the five major fault sections is assumed to reflect the complete behavior of that strand, a 100-year period without a major earthquake is not predicted by common time-dependent (lognormal) or time-independent (Poisson) recurrence models. If known rupture behavior complexity (*e.g.*, partial section ruptures like 1812 and 1857) are included, the odds of the 100-year gap are further reduced. To examine the recurrence across all 16 sites, we remove possible double-counted ruptures and find time-independent probability of the current 100-year gap is of order 0.3%. We review published models of earthquake modulation due to post-seismic loading, viscous flow in the deep crust, and Coulomb stress transfer for potential explanations. We also invite discussion of earthquake recurrence for seismic hazard estimation, given that the current models seem, at least, incomplete.

U.S. Geological Survey National Seismic Hazard Model Components

Poster Session · Wednesday · 24 April · Grand Ballroom

Coseismic Deformation of the 2018 Kaktovik Earthquakes Illuminate Active Tectonics in Alaska's Brooks Range

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The M6.4 and M6.0 August 8th 2018 Kaktovik earthquakes occurred in the northeastern Brooks Range, ~80 km SW of Kaktovik, Alaska. Despite northern Alaska being seismically active, the tectonics of this area remain enigmatic due to its remote location. However, Sentinel-1 satellite radar imagery captured the coseismic ground deformation of the M6.4 event and the M6.0 aftershock, the largest-magnitude earthquakes ever recorded in the Brooks Range and North Slope, providing an opportunity to investigate regional tectonics. We use Sentinel-1 InSAR data and elastic modelling, calibrated main shock and aftershock relocations, and a seismic back-projection to characterize the fault geometry and rupture process of the Kaktovik earthquakes. Our InSAR models show that the rupture occurred on a roughly E-W right-lateral fault in the Sadlerochit Mountains, composed of two distinct south-dipping fault segments. The rupture initiated on the western sub-vertical pure right-lateral fault segment, and propagated onto the shallower-dipping (63°) oblique (dextral-normal) fault segment to the east. The rupture likely did not reach the surface, with slip concentrated between depths of 4 and 8 km. Notably, the location of the fault indicated by the InSAR data suggests the reactivation of a previously identified south-dipping Paleogene thrust fault east of the conjugate NNE-SSW left-lateral Canning Displacement Zone. The E-W right-lateral faults that ruptured in the Kaktovik earthquakes could accommodate NNE-oriented left-lateral shear by rotating about vertical axes through time, in a pattern similar to that observed in some other continental belts. The Kaktovik earthquakes thus demonstrate the potential for large-magnitude earthquakes in the Brooks Range and the presence of unknown active faults whose kinematics may be influenced by inherited geological structures.

Landslide and Megaturbidite Records Reveal a 2.5 Kyr History of Seismic Shaking in Skilak Lake, Alaska

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On 27 March 1964, a M_w 9.2 megathrust earthquake ruptured an 800-km-long segment of the Alaska-Aleutian Subduction Zone (in south-central Alaska). In order to better understand the recurrence pattern of such large earthquakes in that region, we studied the sediments of Skilak Lake, a proglacial lake located in the area affected by the 1964 earthquake, using a combination of high-resolution seismic stratigraphy (3.5 kHz), multibeam bathymetry (50 kHz) and sediment cores (~13-16 m). Seismic profiles and bathymetric maps reveal 23 lacustrine landslide deposits caused by the 1964 megathrust earthquake. We also identified a series of six older landslide events in the subsurface, which we infer to result from multiple, coeval slope failures, and can thus be attributed to past seismic shaking. Sediment cores in two sites show varved "background" sedimentation that is occasionally interrupted by megaturbidites and slump deposits. From this megaturbidite record we can infer five large mass-wasting events, which can also be observed in the upper part of the landslide record. In order to precisely date our paleoseismic records, we organized a student crowdsourcing project, in which continuously varved core sections were counted by multiple observers. Varve counts, combined with 10 ^{14}C ages, provide a high-resolution age framework for our 2.5 kyr-long paleoseismic record. As Skilak Lake lies in a position between a more fully locked part of the megathrust beneath Prince William Sound, and a more creeping part of the megathrust offshore the Kenai Peninsula, the results of this study may elucidate the extent of past ruptures, rupture pattern variability and interplate coupling.

Regionally Optimized Background Earthquake Rates from ETAS (ROBERE) for Probabilistic Seismic Hazard Assessment

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U.S. Geological Survey probabilistic seismic hazard assessments (PSHA) often use background earthquake rate estimates determined by spatially smoothing a single declustered earthquake catalog from which aftershocks have been removed using the method of Gardner and Knopoff (hereafter GK74; 1974). Declustering seeks to remove aftershocks and leave behind a suite of independent, or background, events that can be modeled as a Poisson process. We expect declustering to reduce the estimated earthquake rates because it removes earthquakes from the catalog, but this is not always the case. During development of the 2018 1-year PSHA model for the Central and Eastern United States (Petersen *et al.*, 2018), the total number of M≥3 earthquakes in Oklahoma and Kansas decreased from 2016 to 2017 but the number of events in the declustered catalog using GK74 rose. This can partially be explained by a number of spatially scattered events in western Oklahoma, but Petersen *et al.* also noted that GK74 may not work well in regions of induced seismicity. There are more general problems. GK74 and many declustering methods reduce the Gutenberg-Richter b-value. While declustering lowers the overall number of earthquakes, reducing the Gutenberg-Richter a-value, the estimated rate of large earthquakes can be higher after declustering due to the extrapolation to larger magnitudes using an artificially low b-value. We seek to improve these hazard assessments with a method for determining Regionally Optimized Background Earthquake Rates from ETAS (ROBERE). ROBERE produces a spatially-smoothed background earthquake rate model by applying existing spatial smoothing techniques to a suite of declustered catalogs, each of which was produced with the stochastic Epidemic Type Aftershock Sequence (ETAS) (Zhuang *et al.*, 2002) declustering method. This method optimizes parameters for the region being studied, includes parameter uncertainty, and has the advantage of preserving the original b-value.

Recent Trends in Seismicity Catalogs for the USGS National Seismic Hazard Model

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Seismicity catalogs and seismicity-based earthquake rate models for the conterminous United States were updated for the 2018 USGS National Seismic Hazard Model (NSHM). Since the previous NSHM update in 2014, new earthquakes in 2013–2017 were added, and parameters for some pre-2013 earthquakes were revised. Although the basic procedures for catalog construction and gridded-seismicity hazard modeling were unchanged, some details of the methodology such as regional moment magnitude estimation and catalog-completeness modeling were updated for 2018. There were significant rate changes where new earthquakes occurred in previously quiescent areas (for example, local increases in Delaware and southern Ohio) or where magnitudes were revised for some older earthquakes (local increases or decreases throughout the U.S.). Regional decreases in the intermountain west are attributed to a revised procedure for estimating moment magnitudes there. Induced earthquakes were included in special hazard studies in 2016, 2017, and 2018. Changes occurred in the Oklahoma–Kansas induced-seismicity belt, where an increase in activity in 2013–2014 was followed by a decrease in 2015–2017 (presumably reflecting efforts to mitigate earthquakes and trends in hydrocarbon production), and new earthquakes occurred westward of the established active zones. Interestingly, the recent overall decrease was not apparent in the declustered catalog; this paradoxical behavior in 2016 and 2017 may be related to the strong, but only short-term, declustering that followed three magnitude 5+ earthquakes in Oklahoma in 2016, and to limitations in our standard declustering methodology as applied to the Oklahoma-Kansas catalog. Changes will be illustrated with maps comparing results from the 2018 and 2014 NSHM.

A Comprehensive Offshore Quaternary Fault Database for California

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In the last decade, a number of new marine geophysical datasets collected by the U.S. Geological Survey (USGS), the Ocean Exploration Trust, and other organizations has led to substantially improved high-resolution mapping of the seafloor in areas including California's mainland State Waters and the southern California continental borderland. Data include comprehensive multibeam bathymetry, seismic-reflection, and marine magnetic data in numerous offshore areas. Most of these data have been processed, merged, and released by the USGS in maps, data releases, and journal publications in support of the California Seafloor Mapping Program and the U.S. West Coast and Alaska Marine Geohazards Project. Improved data coverage has allowed researchers to better map offshore faults in areas previously unmapped or covered only by low-resolution data. Additionally, subsurface imaging and seafloor sampling has led to better understanding of fault kinematics and recency of deformation, which are highly relevant for assessing California's seismic and coastal hazards. For example, inclusion of updated offshore faults resulted in a 37% increase in calculated seismic hazard for the San Diego area in a 2015 rupture forecast.

Here, we present a fault geodatabase with comprehensive metadata including accurate locations, geometries, ages, slip rates, and relevant published references. This represents a significant update to previous national and regional fault compilations, developed without the benefit of new high-resolution datasets. The geodatabase has been designed for easy ingestion by partners including the California Geological Survey and the USGS Quaternary Fault and Fold Database, and to be used to improve seismic hazards products, especially the USGS National Seismic Hazard Maps and the Uniform California Earthquake Rupture Forecast. Other stakeholders include the Southern California Earthquake Center and the academic and consulting communities. We plan to expand this effort in the near future to include work now in progress in other regions offshore of the Pacific Northwest and Alaska.

Coseismic Ground Failure and Impacts on the Built and Natural Environment

Poster Session · Wednesday · 24 April · Grand Ballroom

The New USGS Near-Real-Time Ground Failure Product and Its Performance for Recent Earthquakes

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As of September 2018, a new USGS earthquake product called "Ground Failure" provides quantitative estimates of the severity and extent of earthquake-triggered landslide and liquefaction hazards in near-real-time to the public through the USGS webpages. The product provides a generalized summary of hazard and population exposure, communicated through alert levels and summary statistics, as well as interactive maps of the estimated spatial distribution. The product is intended to provide situational awareness of areas with higher probability of experiencing ground failure to officials, responders, and the public in the time window between the event and reconnaissance. Ground failure results were publicly available for three significant earthquakes in late 2018: Hokkaido, Japan (M6.6), Palu, Indonesia (M7.5), and Anchorage, Alaska (M7.0). Each of these earthquakes tested the product in different ways, revealing both strengths and weaknesses of the underlying models, product design, and communication effectiveness. Overall, we found that the alert levels, which span four logarithmic levels from green to red, were effective at communicating the general importance of ground failure for these events. However, their definitions are qualitative and are thus hard to test quantitatively. Both the Palu and Anchorage earthquakes triggered lateral spreads, flow-slides, cracking, and subsidence that were societally impactful but were not well-represented by either model. In addition, the liquefaction model tends to overestimate hazard for areas of weaker shaking while the resolution of the landslide model slope data (~250 m) is too coarse to effectively capture important smaller steep slopes such as coastal bluffs or road cuts. Beyond evaluating model performance, we also discuss how the product has been received by the scientific community, officials, the media, and the public. The feedback and lessons learned from the response to recent earthquakes will guide the path