Dynamics of Seismicity, Earthquake Clustering and Patterns in Fault Networks Workshop

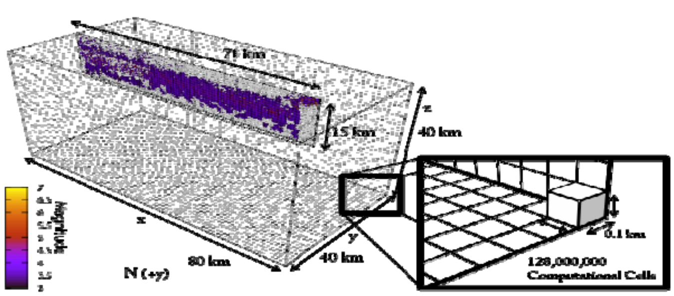
October 9-11, 2013

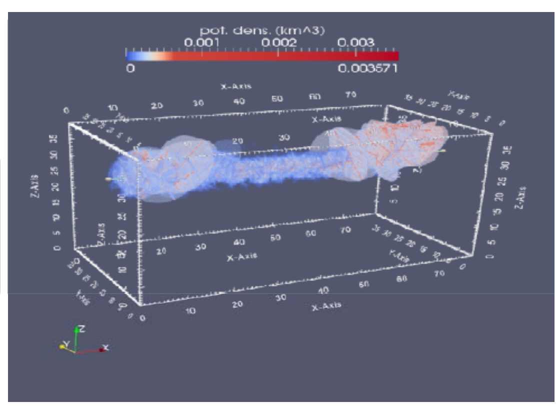
SPEAKER TITLES/ABSTRACTS

Yehuda Ben-Zion
University of Southern California

"Geometry of Seismic Zones at Depth from Quantitative Analysis of Earthquake Catalogs"

The geometrical properties of seismic slip zones at depth have fundamental effects on many aspects of earthquake physics and seismic hazard. Here we use entries of seismic catalog (locations, magnitudes, focal mechanisms) and their associated errors to quantify the continuity and shapes of seismic slip zones in the volume covered by the catalog. For each earthquake, the magnitude *M* is converted to scalar seismic potency based on empirical scaling relation, and is used to estimate the size of the failure zone assuming a circular crack-like rupture. If focal mechanism is available for the event and the rupture size is larger than the location error, the scalar potency is distributed in two focal disks having the rupture size and width (here 200 m) representing the smallest resolved length scale. Otherwise the seismic potency is distributed in the ellipsoid error of the event location. The cumulative potency density of all the analyzed earthquakes provides a volumetric field of the seismic slip density in the examined region. Synthetic catalogs are used to estimate effects associated with limited data and various errors, and to develop a "visual dictionary" of potency distributions associated with basic types of geometrical fault heterogeneities (e.g. stepovers, parallel faults). As an initial application with natural data, we analyze the observed catalog of seismicity in the last 30 years (>100,000 earthquakes with $0 < M < 6$) around the San Jacinto fault zone in southern California. Detailed results will be presented in the meeting. Co-author: Yaman Ozakin





Karin Dahmen
University of Illinois at Urbana Champaign

"A Simple Model for Controlling Stick-Slip Friction and Implications for Effects of Tides on Earthquakes"

Irregular stick-slip friction of slowly sheared rocks, or granular materials is affected by small applied oscillatory stresses. Modeling such systems is important (1) to predict and control the timing of large slips during friction, and (2) to resolve whether or not lab experiments can predict analogous effects of tides on large earthquakes. Recent experiments, contradict traditional friction models and the connection of lab-experiments to earthquakes is controversial.

Here we present a simple model that predicts (I) observed experimental results, (II) new ways to control stick-slip motion, (III) the need for higher oscillation-frequencies than previously used in experiments to mimic the effect of tides on large earthquakes, and (IV) the need for ten-thousands of large earthquakes to observe significant correlations with tidal or seasonal stress variations (while lab experiments require only a few large slips). Our results thus resolve the long-standing controversy about the applicability of experiments to earthquake observations.

Joern Davidsen
University of Calgary

"Spatiotemporal clustering within aftershock sequences"

The best known example of spatiotemporal clustering of seismicity is the observation that the local rate of seismic activity increases significantly after large earthquakes and continues to be high for time scales up to months or even years. From a physical perspective, such spatiotemporal clustering of earthquakes indicates that the large event somehow triggered the following ones, which are historically called aftershocks. Applying a recently established general procedure for identifying aftershocks, I will discuss the statistical features describing the spatiotemporal clustering of aftershocks. This includes the validity of a proposed generalized Omori-Utsu law for the aftershock sequences of the Landers and Hector Mine earthquakes. This law unifies three of the most prominent empirical laws of statistical seismology — the Gutenberg-Richter law, the Omori-Utsu law, and a generalized version of Bath's law — in a formula casting the parameters in the Omori-Utsu law as a function of the lower magnitude cutoff. I will also discuss the decay of the aftershock density with distance and provide evidence that its form is more complicated than typically assumed. This is supported by an analysis of a high-resolution catalog for Southern California and surrogate catalogs generated by the Epidemic-Type Aftershock Sequence (ETAS) model, which take into account inhomogeneous background activity, short-term aftershock incompleteness, anisotropic triggering and variations in the observational magnitude threshold. Our findings indicate specifically that the asymptotic decay in the aftershock density with distance is characterized by an exponent larger than 2, which is much bigger than the observed exponent of approximately 1.35 observed for shorter distances. This has also important consequences for time-dependent seismic hazard assessment based on the ETAS model.

David Harte
GNS Science

"Stochastic Earthquake Models: Ways to Improve and Insights into the Physical Process"

We present a version of the ETAS model where the offspring rates vary both spatially and temporally. This is in response to deficiencies discussed in Harte (2013, GJI, Vol 192(1)). This is achieved by distinguishing between those space-time volumes where the interpoint space-time distances are small, and those where they are considerably larger. In the process of modifying a stochastic earthquake model, one needs to justify assumptions made, and these in turn raise questions about the nature of the underlying physical process. We will use this version of the ETAS model as the basis for our discussion, and by focussing on aspects where the model does not perform so well, attempt to find physical explanations for such lack of fit. Some possible discussion points are as follows.

What is the nature of the so called background process in the ETAS model? Is it simply a temporal boundary (t=0) correction or does it represent an additional tectonic process not described by the aftershock component? Or are these two alternatives on completely different time scales?

An epidemic (the basic analogy underpinning the ETAS model), or a living organism, can evolve by reproducing offspring that are slightly different to that of their parents -- randomness or gene mutation. Certain "modified" individuals will be able to adapt to the environment better and tend to survive over others. In the ETAS context, a lower value of α will cause more "generations" in the aftershock sequence. This allows for a richer and more complex evolution of the process, both spatially and temporally. Alternatively, if α is large, then more of the aftershocks are direct offspring of the mainshock. In the epidemic context, this implies that the mainshock contains much more of the "DNA" which governs the evolution of the overall sequence.

What is the relationship between fractal dimension and clustering? Does the fractal dimension provide a better discrimination between those space-time volumes with higher offspring rates and the others? If so, does the fractal dimension provide a more obvious physical description of the difference between these high rate volumes and the lower rate volumes, and hence a suggestive physical explanation?

Egill Hauksson
Caltech University

"Crustal Seismicity, Geophysics, and State of Stress Along the Pacific North America Plate Boundary in Southern California"

To understand the 3D spatial distribution of seismicity along the southern California plate boundary, we analyze the geographical distribution of seismicity in the context of crustal geophysics and the presence of mapped late Quaternary faults or principal slip zones (PSZ). We measure the Euclidian distance from every hypocenter to the nearest PSZ. In addition we assign crustal geophysical parameters such as heat flow value and shear or dilatation strain rates to each hypocenter. We use this new dataset to investigate seismogenic thickness and fault zone width as well as earthquake source processes. We find that the seismicity rate is a function of location, with the rate dying off exponentially with distance from the nearest PSZ. About 80% of the small earthquakes are located within 5 km of a PSZ. For small earthquakes, stress drops increase in size with distance away from the PSZs. The magnitude distribution near the PSZs suggests that large earthquakes are more common close to the PSZs, and they are more likely to occur at greater depth than small earthquakes. In contrast, small quakes can occur at any geographical location. An optimal combination of heat flow and strain rate is required to concentrate the strain along rheologically weak fault zones, which accommodate the crustal deformation processes and cause about 80% of the seismicity.

The state of stress determined from focal mechanisms varies across the plate boundary both in response to geometrical complexities as well as different tectonic styles. The regional trend of S_{Hmax} is almost bimodal, trending almost north along the San Andreas system, and to the north-northeast on either side. The transition zones from one state of stress to the other is sharp, following a trend from Yucca Valley to Imperial Valley to the east, and the western edge of the Peninsular Ranges to the west. The local scale variations in the S_{Hmax} trend include north-northwest trends along the San Andreas Fault near Cajon Pass, Tejon Pass, and the Cucapah Range. The regional variations in the S_{Hmax} trends are very similar to the pattern of the GPS-measured maximum shortening axes of the surface strain rate tensor field. However the GPS-strain field tends to be smoother, in part because it captures some of the long-wavelength upper mantle deformation field.

Bala Rajaratnam
Stanford University

"Complex Network Models for Statistical Seismology"

We study the scope for using recent advances in high dimensional covariance estimation and graphical or network models for clustering and other purposes in the modeling and analysis of seismicity. Both methodology and theory are presented together with applications.

Philip Stark
University of California, Berkeley

"Ontology of Earthquake Probability: Metaphor"

Where does earthquake probability come from? What does "the chance of an earthquake" mean? Stochastic models for seismicity have a peculiar ontological status that makes it difficult to interpret earthquake probabilities. The compelling appeal of probability models for seismicity seems to derive in part from confusion in the literature about the crucial distinction between empirical rates and probabilities. The underlying physics of earthquakes is hardly understood, but does not appear to be intrinsically stochastic, merely unpredictable. Earthquake probabilities reflect assumptions and metaphors rather than knowledge: They amount to saying that earthquakes occur as if according to a casino game--a thesis for which there is little evidence. Many stochastic models have been invented to produce features similar to features of real seismicity. Those models contradict each other; none is a great match to what is believed about the underlying physics; none seems to hold up statistically when there enough data for a reasonably powerful hypothesis test; and none has been demonstrated to predict better than a very simplistic "automatic alarm" strategy. I contend that probabilistic models for earthquakes lack adequate scientific basis to justify using them for high-consequence policy decisions, that such models obfuscate and confuse more than they illuminate and edify, and that for the purpose of protecting the public they should be abandoned in favor of common sense.

Antoinette Tordesillas
University of Melbourne

"Topology, Structure, Function and Dynamics: Understanding Granular Failure using Optimisation and Complex Systems"

We report on a series of fundamental studies of granular failure, including that of stick-slip, using techniques and concepts from optimization and complex systems. With special attention paid to high-resolution (grain-scale) data from experimental studies of synthetic as well as natural (sand and rocks) granular materials, we quantitatively characterize the relationship between topology, structure, function and dynamics that accompanies the process of self-organization in the lead up to and during failure.

Ilya Zaliapin
University of Nevada, Reno

"Spatio-Temporal Evolution of Seismic Clusters in Southern and Central California"

We examine evolutionary patterns of seismic clusters and their relations to (i) heat flow, rock types and seismogenic depth, (ii) structure of the regional fault network and (iii) occurrence times of large near-by earthquakes. The analyses are based on our recent methodology for detection and classification of seismic clusters, and new high-quality relocated catalogs of southern and central California. The novelty of this study is in systematic uniform analysis of thousands of robustly detected seismic clusters of small-to-medium magnitude events, as opposed to the handful of largest clusters analyzed in most studies. Our previous research established the existence of three types of earthquake clusters (burst-like, swarm-like, and singles) of small-to-medium magnitude, and demonstrated that the cluster type is closely related to the heat flow and other properties governing the effective viscosity of a region. The continuing work focuses on spatio-temporal evolution of different cluster types in relation to seasonal patterns, activity switching between different areas, and systematic patterns preceding large events. The results so far document (i) activity switching of small-to-medium magnitude earthquakes between different faults, (ii) mild seasonal fluctuations of intensity of such events, and (iii) several premonitory patterns that are seen most clearly near Parkfield.