Earthquakes Without Borders

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Where we are

For three decades the Southern California Earthquake Center (SCEC) has performed outstanding basic research, compiled much needed standard databases, applied its knowledge to forecast earthquake rates and hazard estimates, and communicated its results to eager stakeholders. The primary geographic focus has been southern California, although SCEC participants have studied and learned much elsewhere, and SCEC results and wisdom have been applied beyond southern California. The choice of this region as a natural laboratory has proved extremely advantageous in its concentration of available resources at a manageable density. The urge to expand has been discussed throughout its history, but SCEC has officially maintained its original focus even as its efforts crossed porous borders. The most important expansion is the series of Uniform California Earthquake Rupture Forecasts (UCERF), covering the whole state and further engaging USGS and other scientists who concentrate on northern California. UCERF incorporates state-of-the-art seismic source models that inform national hazard maps, building codes, and insurance rates.

Now SCEC is at a crossroads and its geographic scope is due for revision. We believe that SCEC needs two foci with different roles: California, and our whole planet. Experimental, field, and detailed model studies should focus on California, while implementation and testing of the ideas developed there should be applied and tested globally. These and other changes mandated by future circumstance will probably require a new name, but the infrastructure and momentum of SCEC should be central to a renewed organization.

Seismic studies need lots of data, because earthquake behavior involves many factors of varying importance. These include fault geometry and slip rate; surface strain rate; inelastic strain; crustal depth, density, rheology, temperature and composition; fluid pressure and permeability; past earthquakes; and many others. Thus, we need to observe many events for identifying what is important and averaging the consequences of variables we can't observe in detail. The Californian natural laboratory remains an excellent incubator for ideas, hypotheses, and new computational approaches that use as input detailed and trusted observational models. However, the scientific method requires that the models' predictive skill must be evaluated against independent, ideally yet-to-be-collected data. Only a global effort will provide enough of the potentially damaging large events we need for definitive testing.

California

SCEC has measured and documented many of these potentially crucial factors and constructed models that include them. The UCERF earthquake forecasts began with a study of probable southern California earthquakes, and then expanded to cover the entire state. That expansion and the teamwork built with the U.S. Geological Survey have effectively made SCEC the de-facto California center. The UCERF models include: the effects of known past earthquakes, stresses from slip on hundreds of known faults, and surface strain rates inferred from horizontal velocities of hundreds of precise survey markers. The models have become quite complex, using a "logic tree" approach to allow for alternative values of important parameters like maximum magnitude, scaling of magnitude vs rupture length, fault dip, etc. In principle, the models are testable retrospectively against past earthquakes, and prospectively against future ones.

Fortunately for citizens, but unfortunately for scientific progress, the rate of potentially damaging large California earthquakes is so low that meaningful tests might take hundreds or thousands of years. Too many unknowns, and too little data. Consequently, even the best models might be wrong in important ways we could not detect in our lifetimes. Unless, that is, a nasty surprise not anticipated in the model should occur. In any case, California frameworks are important because they will surely be adapted for use elsewhere in the world, as UCERF models are now. Thus, our models should be based on as much earthquake data as possible and evaluated prospectively across the globe. Important general questions for testing include whether the forecasts effectively show where future hazard is concentrated, and whether all of the employed data adds value. Limited models might be very useful in regions lacking the spectacular geological and geodetic data we celebrate in California.

SCEC has pioneered formal community-based testing of probabilistic earthquake forecasts. The Regional Earthquake Likelihood Models (RELM) project, published in a special issue of the *Seismological Research Letters* (Field, 2007), compared over a dozen maps of estimated epicenter rate density for California. Some covered the whole state; others covered only the southern part. An important finding was that earthquakes over magnitude 5 are significantly more likely where events with magnitude 2.5 and above concentrate. Now the Collaboratory for Study of Earthquake Predictability (CSEP) employs and extends valuable statistical tools developed by RELM to represent and test forecasts, as recently documented in another special issue of *SRL* (Michael & Werner, 2018).

Earth

Magnitude 7 and larger earthquakes occur about once per decade in California, and once per month globally. Global studies can both inform and benefit from our advanced regional studies. The Global Earthquake Activity Rate (GEAR) forecast model, developed mostly by SCEC participants (Bird et al., 2015), serves as a great example. It predicts the rate of magnitude 5.7 and larger earthquakes on a dense (0.1x0.1 deg) grid, combining earthquake location data with surface strain rate data inferred from plate tectonics and geodetic measurements. The seismic data are from the Global Centroid Moment Tensor (GCMT) catalog, launched in 1977 and now recording global events complete to magnitude 5.0. The Global Strain Rate Map (GSRM), produced by the Global Earthquake Model (GEM) Foundation, provided the strain rate. Prospective testing shows that earthquakes after 2014 agree well with the GEAR model. Its important features include: a spatial uniformity inherited from the GCMT catalog, high spatial density, and the absence of explicit fault slip data and borders. Thus, regional models like UCERF, those developed for the GEM global hazard model, and many others in Japan, China, New Zealand, Turkey, Iran, Europe, etc. can be tested against GEAR. Such tests can help evaluate the importance of fault slip data and assumptions about maximum magnitudes and other important parameters in regional models.

Our Vision

We envision an organization much like the present SCEC with moderate changes in leadership, management, data collection, product offerings, outreach, and name. Expanding its natural laboratory from southern to all of California and borderlands is natural and to some extent a recognition of fact. The global part would not necessarily involve more global field work or instrument deployment than what SCEC does now. Instead, the newly global efforts would organize and focus data exchange and collaboration with foreign researchers. This would emulate and strengthen current global CSEP activities. CSEP has partners from the UK, Germany, Italy, New Zealand, Japan, and China, with occasional contributions from other countries via online activities and bi-weekly teleconference calls. We have recently presented a vision for the mid-term future (Schorlemmer et al., 2018). Given the present Covid-19 pandemic, we are all learning additional online communication skills that will enable international research.

Presently CSEP focuses on testing earthquake forecast models, some formulated by SCEC participants, and some independently. Ideally, scientists would build testing plans from the very beginning into future UCERF and other models, so that tests could explore the ideas and assumptions driving the models. To that end, we can draw and build on existing CSEP methods and tools. Model evaluations should also be extended into the seismic hazard and risk space to test the quantities that matter most for building codes and insurance rates. This will require software inter-operability with open-source seismic hazard and risk modeling tools like OpenQuake.

SCEC can also lead in tackling “grand challenges of seismogenesis”: developing global forecast models and tests to answer the big questions. What controls magnitude limits? What stops rupture? Is the Gutenberg-Richter b-value a stress indicator? How does Coulomb stress from earthquakes affect the location and rate of future ones? Unfortunately, evaluating these ideas prospectively and independently has yet to show unequivocal predictive power. Furthermore, the limits of predictability and the resulting uncertainty in forecasting hazard and risk can only be understood globally.

Global, community-endorsed benchmark datasets, forecast models, and evaluation techniques are urgently needed to accelerate predictive earthquake science. SCEC can lead such efforts through support for reproducible, open-science research into earthquake predictability. But this will require investing in computational infrastructure to support global collaboration and prospective testing. An organization evolved from SCEC might also host global, grand challenges to draw in new researchers and communities, like the data scientists who exploit machine learning algorithms for prediction problems.

This expanded future organization can become an independent trusted broker by building on SCEC and CSEP experience, expertise and global status.

Reference

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