Probabilistic seismic hazard assessment in the wake of world disasters: New approaches and tests

Devastating—and in at least some sense, unforeseen—earthquakes in Japan, New Zealand, Haiti and elsewhere have triggered a heated debate about the legitimacy and limitations of probabilistic seismic hazard assessment (PSHA). In response, four workshops at USGS John Wesley Powell Center for Analysis and Synthesis, Ft. Collins, Colorado brought disparate groups together to develop tests of what we have built, and to seek viable alternatives. The participants included university, government, and insurance industry scientists from countries straddling plate boundaries and those in plate interiors, making for a rich exchange of experiences and perspectives. There are three crucial aspects of the Powell Center process that we found invaluable to promote this dialogue:

First, we asked each invitee to take what we called the 'Powell Blood Oath': You are welcome to argue passionately for your views, but you must also present and acknowledge the weaknesses in your position. The oath kept everyone humble. No one grandstanded or dismissed others, because no one had all the answers. To reduce temptations, no press was admitted, and those who could not abide by the oath turned our invitation down.

Second, we sat around the table, each with a laptop plugged into the projector, so that anyone could interject with figures or images from their computer by clicking on a monitor control switch. No lectern, no uninterrupted talks, no fealty to the clock; everything was conversational, open, and fluid. The minutes were written into an Etherpad that all could access and modify on the fly, and so no one person shaped the record.

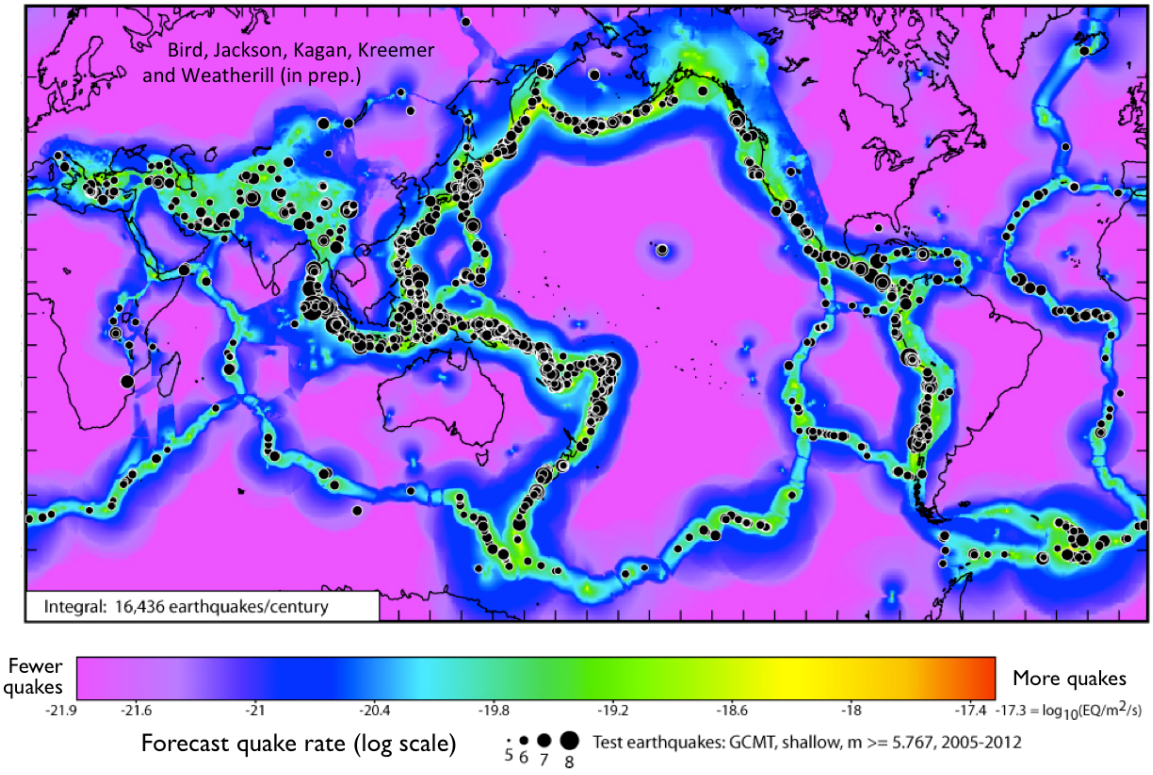
Third, we took a hike in the Rockies during the middle day of each workshop, during

which the scientific conversations only deepened. Talking on a hike is less confrontational and more engrossing than around a table, and so delicate issues got discussed in depth. People who were quiet around the table found themselves in deep discussions on the trail, and so their views had greater impact.

Critics of PSHA, and critics of the co-hosts GEM and the USGS, were invited and listened to. Those who lead the PSHA modeling for their nations saw how others are tackling similar problems with different approaches. Together we identified what tests are most needed to assess the value of PSHA, and what tools are most needed to improve it. Two major efforts, and a set of needed reforms, grew out of the Powell meetings:

GEM Earthquake Activity Rate (GEAR) model

The GEAR model uses the Global CMT catalog seismicity, the GEM Strain Rate Model, plate boundaries. Because GEAR does not use any active fault data, it can be applied uniformly over the globe, so that the quake rate in, say, Tokyo and Tel Aviv are inter-comparable. It can also serve as a reference model for regional efforts that use fault data. GEAR is an extension of Bird et al (2010) and Kagan and Jackson (2013), but the GEM Strain Rate model has four times the GPS vectors as its predecessor, Kreemer et al (2003). Graeme Weatherill from the GEM Foundation is extending GEAR to PSHA. In addition to implementations of national or regional models, GEAR will be one option for users of GEM's OpenQuake software.



Preliminary GEAR model (colors) compared to post-2005 earthquakes (black dots) from Bird et al (2013). This model is based on a weighted combination of 40% GEM Strain Rate Model (Kreemer et al, 2013) and 60% Global CMT catalog, which yields the best forecast of 2005-2012 earthquakes.

Planned test the 1996 U.S. seismic hazard model against observed shaking

We must seek to demonstrate the utility of PSHA in order to provide it to the public. So, another outgrowth of the Powell meetings will be a test of the 1996 US National Seismic Hazard Mapping Project (NSHMP) model, which will be compared to the observed 1997-2013 shaking, which was qualitatively presented in Frankel (2013). The test would use a skill score relative to several null hypotheses, such as uniform hazard, or hazard based on smoothed historical or instrumental seismicity. The test has severe limitations

because of the short duration of observations relative to the intended model use, but we think it is nevertheless important.

Unresolved problems of Probabilistic Seismic Hazard Assessment

Assignments of maximum earthquake magnitudes to faults are some of the least defensible elements in view of the Powell participants. For example, we know only that the longer the observation period, the higher the maximum magnitude we will observe (Merino et al, 2013).

PSHA modeling typically seeks to strip out aftershocks, foreshocks and swarms to isolate mainshocks. Despite a good rationale for this procedure, "declustering" is highly uncertain and can leave anywhere from 80% to 20% of the earthquakes in the declustered catalog. There should also be standardized declustering algorthims and tests of whether the declustered catalog exhibits Poisson behavior (in other words, with no time dependence).

The slowly deforming intraplate regions of the world present some of the most difficult conditions for PSHA. Since little is typically known of the faults or their slip rates, and the strain rate can be too low to measure, the historical record of quakes is most often used, in which the distribution of small shocks is smoothed and scaled to estimate the rate and distribution of larger shocks. But do recent small shocks forecast large ones? And even if this strategy were justified, how much seismicity smoothing is appropriate?

The Powell process generated new models and tests, and raised key unanswered questions. But perhaps even more important, it brought people together with differing and at times opposing views, who worked together around a table and on a trail to find common ground.

References

Bird, P., C. Kreemer, and W. E. Holt (2010), A Long-term forecast of shallow seismicity based on the global strain rate map, *Seismol. Res. Letts., 81*, doi: 10.1785/gssrl.81.2.184

Bird, P., C. Kreemer; Y.Y. Kagan, and D.D. Jackson (2013), Global earthquake activity rate models based on version 2 of the global strain rate map, Abstract S13C-03, 2013 Fall meeting, AGU.

Frankel, A. (2013), Comment on "Why earthquake hazard maps often fail and what to do about it" by S. Stein, R. Geller, and M. Liu, *Tectonophysics, 592*, 200–206, http://dx.doi.org/10.1016/j.tecto.2012.11.032

Kagan, Y.Y., and D.D. Jackson (2013), Statistical earthquake focal mechanism forecasts, submitted to Geophys. J. Int. (Also, abstract S22A-08, 2013 Fall meeting, AGU).

Kreemer, C., W. E. Holt, and A. J. Haines (2003). An integrated global model of present-day plate motions and plate boundary deformation. *Geophys. J. Int., 154*, 8–34.

Kreemer, C., G. Blewitt; E.C. Klein; Z.-K. Shen; M. Wang; L. Estey; S. Wier (2013), A new global geodetic strain rate model, Abstract G43C-03, 2013 Fall meeting, AGU.

Merino, M., S. Stein, and J. Adams (2013), Have we seen the largest earthquakes in eastern North America? Submitted to *Bull. Seismol. Soc. Amer*.

Stein, S., and J.L. Stein (2013), How good do natural hazard assessments need to be?, *GSA Today, 23*, doi: 10.1130/GSATG167GW.1.

Acknowledgements

We are grateful for support from the USGS Powell Center and the GEM Foundation, and for the outstanding efforts of the Powell Center's co-director and host, Jill Baron.

— ROSS S. STEIN, U.S. Geological Survey (and GEM Scientific Board Chair), Menlo Park, CA; email: rstein@usgs.gov; MARK W. STIRLING, GNS Science, Lower Hutt, New Zealand; email: M.Stirling@gns.cri.nz