19 February 2007

GeoRisk, a Global Earthquake Online Risk Model

A tool to raise awareness, promote mitigation and insurance use, and create a worldwide national catastrophe bond market

Principal Investigators

Ross S. Stein
U.S. Geological Survey, Earthquake Hazards Team, Menlo Park, California
Tel 1 650 329 4840, rstein@usgs.gov, http://quake.wr.usgs.gov/~ross

Domenico Giardini
Director, Swiss Seismological Service, and
Chair of Seismology and Geodynamics of ETH, Zurich, Switzerland
Tel +41-44-633 2610, giardini@sed.ethz.ch, http://www.seismo.ethz.ch

Due to urban population growth, deteriorating construction, and hazard ignorance, the toll of earthquakes is rising over much of the world. To combat this ominous trend, we propose to form an internationally sanctioned group to produce an open global earthquake hazards and risk tool. The tool would increase hazard awareness, permit risk assessment in policy-making, and enable governments of developing nations to issue catastrophe bonds to provide their countries with some disaster relief. These bonds could be packaged into mutual funds as an attractive diversified investment uncorrelated with financial markets. The risk model would complement the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER), alerts issued whenever a large earthquake strikes around the globe. The quake size and location, as well as the projected number of fatalities, are announced beginning 20 minutes after any large shock, and are updated in the ensuing hours as the seismic data stream grows. The risk forecast tool and the post-event alerts are both needed for disaster preparation and response, and both are needed for a successful catastrophe bond market. The tool will require $10 million to build and $1-2 million per year to operate. We are seeking foundation, World Bank, and insurance industry contributions to build it, and a bond transaction fee to sustain it.

During the past 7 years, earthquakes in Turkey, Iran, and Pakistan, Java and Sumatra collectively claimed 420,000 lives. In the wake of these tragedies a new consensus has arisen that a global hazard model is needed to meet the mounting risks of natural catastrophes. 'Preparing for Disaster', the lead editorial in the 15 December 2005 issue of *Nature*, is subtitled, "Earth scientists should find better mechanisms to disseminate facts about the risks of natural disasters, to help local populations make the necessary preparations." 'Disasters: Search for Lessons from a Bad Year', a Breakthrough of the Year article in *Science* (23 Dec 2005), reports that "Aromar Revi, a New Delhi-based disaster mitigation consultant to the Indian government, envisions a public database like Google Earth that would allow researchers throughout the world to map the risk landscape down to the zip code level. Such a system would enable nations with a shared risk to better build warning networks." A global hazard model would also enable governments in countries where no disaster insurance is available to issue catastrophe bonds. " 'Rather than relying on the fickle charity of the international community, countries should invest in a new kind of disaster insurance that transfers the risk to the financial markets,' says Reinhard Mechler, an economist at the International Institute for Applied Systems Analysis in Austria. Such a plan relies on scientists to create finer grained maps of the probability of various disasters and the range of their impacts." We propose to undertake this project under the auspices of the International Association of Seismology and Physics of the Earth's Interior (IAESPI) and the International Association of Earthquake Engineers (IAEE).

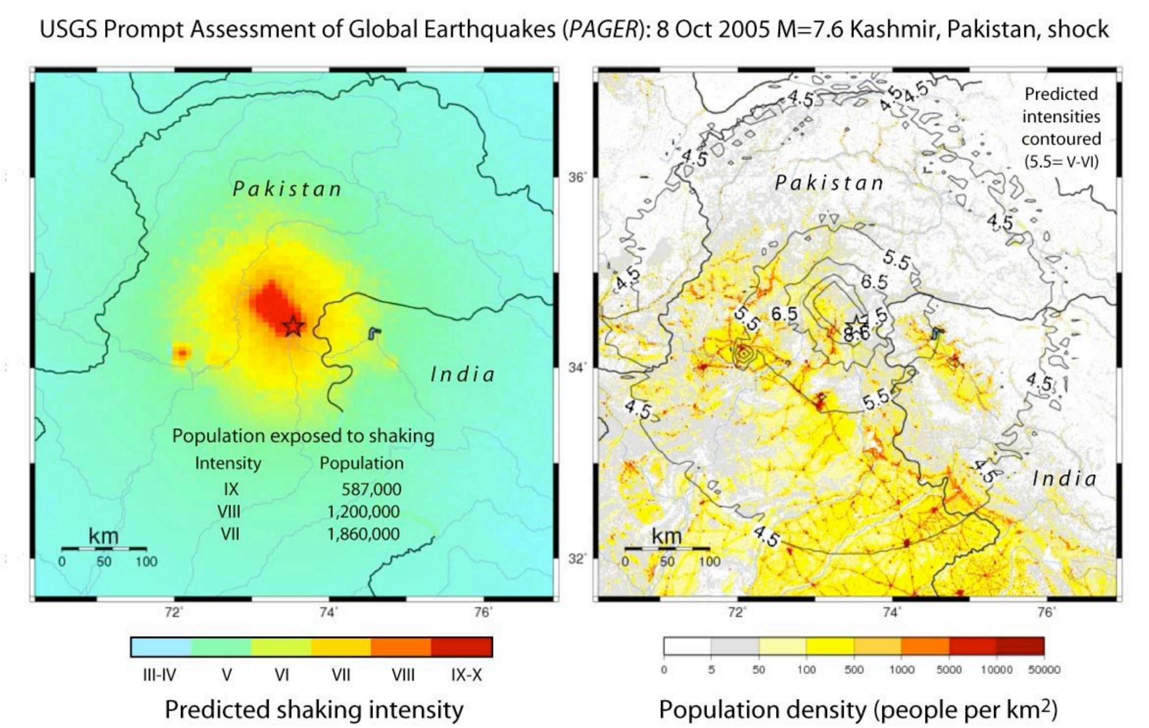

Figure 1. PAGER represents a valuable immediate service offered by the USGS to the world. Such information is first posted 20 minutes after an earthquake and is updated over the next several hours. Some 73,000 people lost their lives in this disaster in a country with no quake risk map.

ESTIMATED POPULATION EXPOSURE		- -	14 million	63 million	19 million	3.8 million	1.6 million	**367,000**	**129,000**
PERCEIVED SHAKING		Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
ESTIMATED MODIFIED MERCALLI INTENSITY		II-III	IV	V	VI	VII	VIII	IX	X+
POTENTIAL DAMAGE	Vulnerable Structures	none	none	Light	Moderate	Moderate to Heavy	Heavy	Very Heavy	Very Heavy
	Resistant Structures	none	none	Very light	Light	Moderate	Moderate to Heavy	Heavy	Very Heavy

Figure 2. PAGER uses the information in *Figure 1* to estimate the number of people exposed to levels of shaking; it will soon estimate fatalities from this information.

There are two fundamental motivations for building the model, each of which alone would justify its construction:

Humanitarian imperative of a global model. The regions of the developed world exposed to earthquakes, such as the U.S., Japan, New Zealand, Italy, and Canada receive substantial attention. But the earthquake risk in the undeveloped world—for example, in India, Pakistan, the Philippines, Bangladesh, Indonesia, China, Turkey, Ecuador, and Algeria—is largely ignored, and because of poor building quality and high population density, the average number of deaths in these countries is about 50 times higher for an earthquake of the same size. Dr. Anselm Smolka, head of geophysical and hydrological risks for the insurance giant, Munich Re, places Manila among the world's top five cities on the basis of the product of their seismic hazard, vulnerability, and exposed financial value. A credible, non-proprietary global model would enable populations worldwide to become aware of the earthquake hazards they face. Lucid and accessible information is the starting point for weighing earthquake risks against competing threats and financial demands.

Scientific imperative of a global model. Probabilistic earthquake hazard assessments if carried out only in the developed countries of the world are essentially untestable, because large shocks are too infrequent to permit us to learn whether we are doing this correctly, and because many of the world's large earthquakes occur undersea, where no national government has an interest. Nor can we be assured that enhancements to these forecasts that scientists and government agencies regularly undertake at great cost in fact improve our success rate. A global model would for the first time enable rigorous testing of seismic hazard assessment methodology within a decade, in a manner akin to weather forecasting, building experience and confidence that would otherwise be impossible to achieve.

Industry beneficiaries of a global model. Multi-national reinsurance companies (which insure insurance companies) would benefit from the global model. Reinsurance companies currently insure the developed world for earthquake risk, basing their risk estimates on proprietary software developed largely by risk modeling companies. Reinsurers reduce their financial exposure by spreading risk among many countries, and by transferring some risk to the much larger capital markets by issuing 'catastrophe bonds.' These bonds pay a high rate of interest unless the specified catastrophe occurs, in which case the investor could lose his principal. In 2006, about $6 billion in cat bonds were issued. The global online model would stimulate the catastrophe bond market by making it easier for investors to assess the underlying bond risks. Insurance linked warranties, or 'derivatives,' function like small cat bonds; they are more liquid and do not include a risk calculation by a risk modeling company. These bonds would most benefit from the existence of transparent, symmetrical information to issuers and investors, and low transaction costs. Finally, the model would hasten insurance availability in parts of the developing world where the reinsurers have yet to investigate hazard and issue policies.

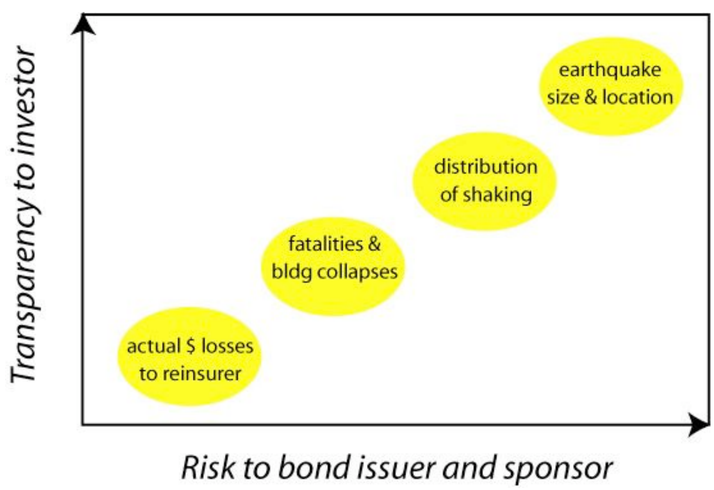

Figure 3. Normally, a catastrophe bond investor receives an interest rate higher than a junk bond. But if the bond is 'triggered' by the specified event (e.g., a Tokyo earthquake), the investor loses his principal. Investors prefer more transparent or quantifiable triggers; insurers prefer triggers tied to their incurred losses. Bonds could be issued that are triggered by earthquake shaking or fatality threshold. A user of the global online model could easily calculate these for a bond, making it easier for investors to assess the underlying bond risk versus the rate of interest paid.

Catastrophe Bonds for Developing Nations. If such a model existed, governments of developing countries could issue national cat bonds. Rather than asking for charity as the only means to respond to a disaster, the bonds would provide the governments with immediate cash for recovery. Pledges of charitable gifts often do not materialize, arrive much too late, or come with strings attached. Such national cat bonds could be packaged into a mutual fund by investment banks, and then sold as an investment instrument that would be uncorrelated with the market to hedge funds or pension funds. The USGS, through its Prompt Assessment of Global Earthquakes for Response (PAGER) alerts, would serve as the 'neutral party' that declares the trigger for any earthquake catastrophe bond or derivative.

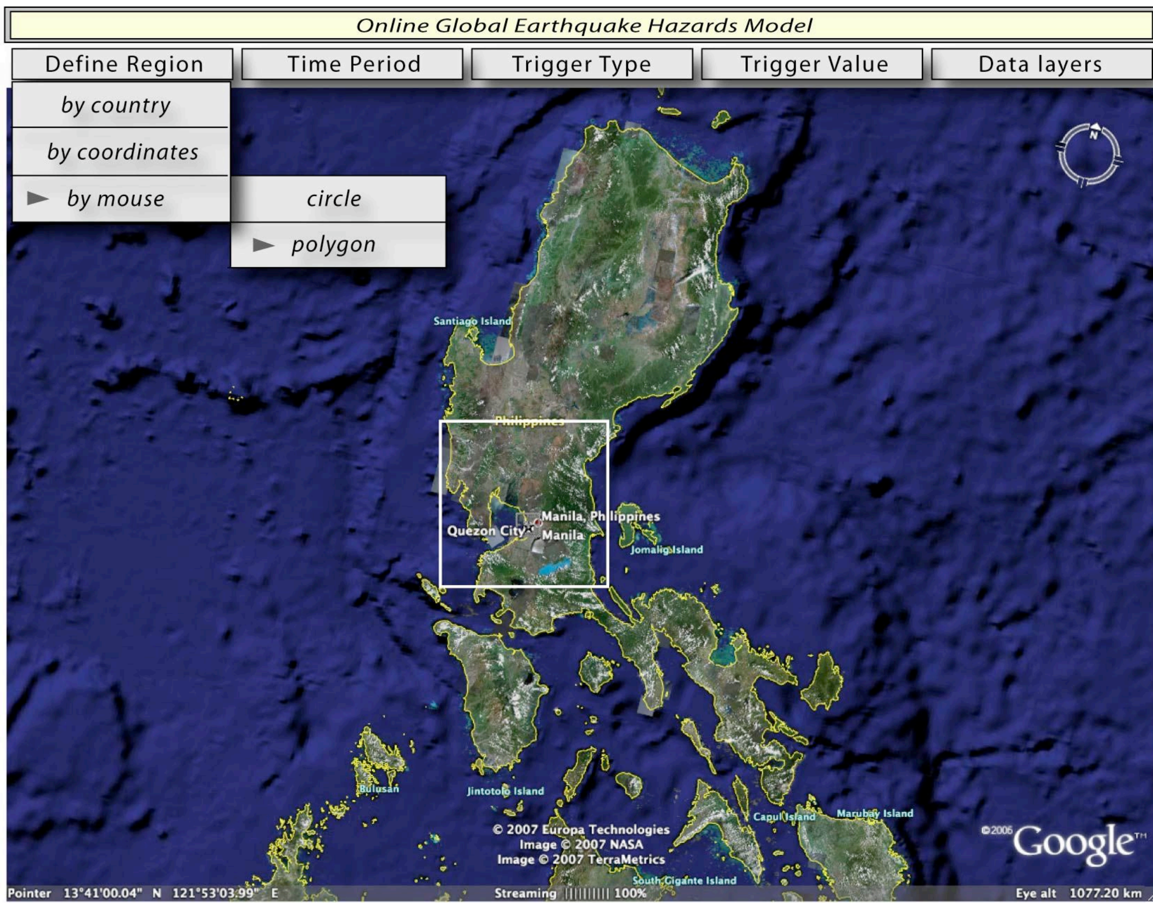

Figure 4. The model would be easily accessible in *Google Earth*. All data layers, such as the earthquake catalog, building vulnerability, population density, plate boundaries and motion rates, and active faults, would be accessible in the 'Data layers' menu. This example is for greater Manila, a megacity at high risk to earthquake destruction.

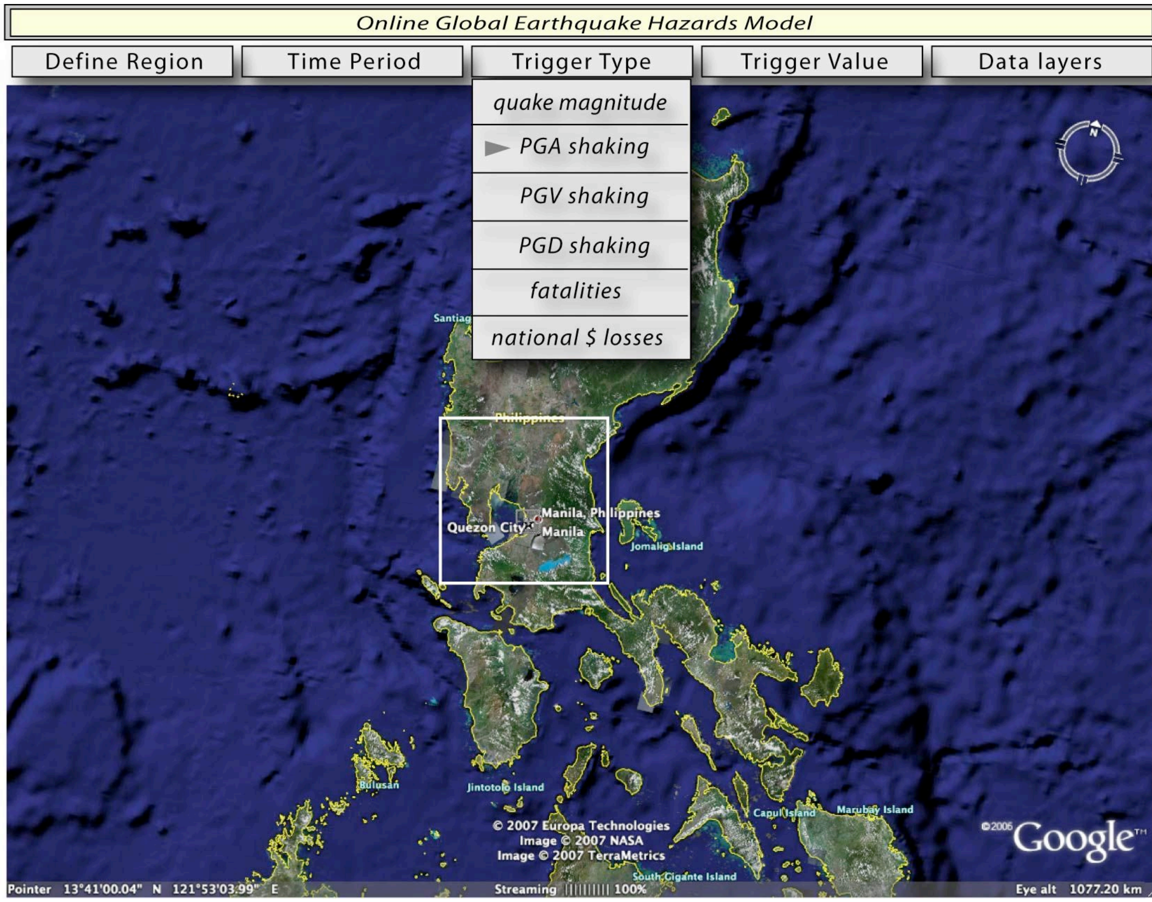

Figure 5. Several options will be available to user, such as the shaking metrics, peak ground acceleration, velocity, or displacement (*PGA, PGV, PGD*); fatalities, and economic losses relative to national gross domestic product. Building vulnerability will be assessed by expert opinion.

Global Online Model Operation and Structure

The model would use the best available science to calculate time-averaged earthquake hazard, with uncertainties identified. A global plate seismicity model, such as Prof. Peter Bird's PB2002 (UCLA), would provide the framework on which the model could be built. Earthquake rates would be transformed into earthquake shaking using the *OpenSHA* (Open Seismic Hazard Assessment) tools developed by Ned Field at the USGS. Typical data would include Global CMT and International Seismic Centre earthquake catalogs, fault maps, past earthquake dates, fault slip rates where available, GPS-derived strain fields, plate boundaries and motion vectors. Global topography would be used for a simple site amplification model (flat areas correspond to basins, which amplify shaking). Accessible layers would permit the user to view the datasets to evaluate data quality and reliability. The U.S. Oak Ridge National Laboratory's LandScan would be used for population density. Where available, building inventories, expert opinion on building vulnerability, and assessments of economic condition would be used to calculate projected losses in both the risk model and the earthquake alerts.

The model would be accessible to any user via a browser. The user could choose a box or circle, an earthquake moment-magnitude, shaking intensity, peak ground acceleration, number of fatalities, or financial losses as a percent of gross domestic product (GPD), and calculate the probability of exceedance for any time period. The information could also be viewed atop satellite imagery. The USGS would serve as a 'neutral agency' that announces the modeled (and where available, observed) peak ground shaking for each large earthquake, including its spatial distribution, so that reinsurers could rapidly assess portfolio losses. This is essential for a properly functioning cat bond market.

Annual maintenance fee. Once launched, the model must be continually updated as population and building inventories change, as earthquakes occur, and as additional active faults are discovered. We propose that a bond transaction fee or 'royalty' would accrue to the model builders. This way, the more the bonds are purchased, the more funds would be available to run the model. This would keep us from having to continually seek money to maintain the model. If the national cat bond market became more active, the transaction fees could be used to produce a tsunami or volcanic eruptions risk model.

How does the model depart from its predecessors?

The only forerunner for the program we envision is the 1992-1999 Global Seismic Hazard Assessment Program (*GSHAP*), an international collaboration led by Domenico Giardini in which the USGS participated. This produced one unified static map of one ground shaking parameter. However, participating national organizations each created their own map using different methods and data, and so hazard cannot be compared between countries, limiting its usefulness to insurers. Further, the map cannot be used to estimate the likelihood of an earthquake of a given size striking a defined area in a short time period, which is needed to assess a catastrophe bond trigger, the event that would trigger loss of principal.

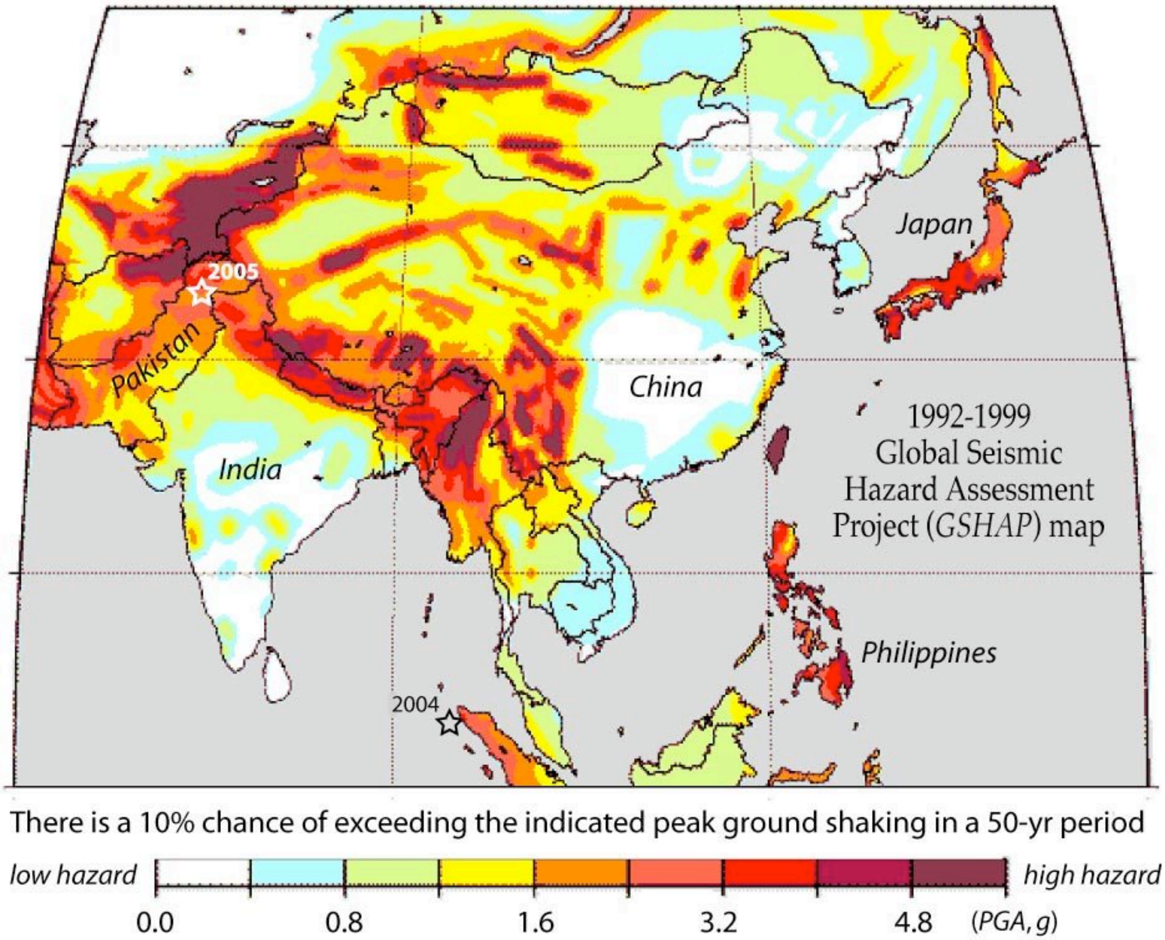

Figure 6. Part of the landmark *GSHAP* map that depicts one measure of earthquake hazard; the global online model will build upon this approach. Despite *GSHAP's* limitations, the 2004 Sumatra and 2005 Kashmir earthquakes struck in hazardous regions identified in the 1999 map.

Apart from the *GSHAP* map, many governments have produced hazard maps, with variable approaches and quality. Risk consulting companies, such as Risk Management Solutions (Newark, California), produce proprietary models that cannot be inspected by users and are not publicly available. Haresh Shah, former Chairman of RMS, is supportive of the global online model because it would enable the consultants to calibrate their models against a credible open source alternative. Reinsurance companies conduct write some earthquake insurance in companies with no credible hazard map, such as Tehran and Bangladesh, and would benefit from such a global tool. Thus, we believe that there will be broad industry, government, and academic support for the online model.

Model building centers

We envision four centers, in the Americas, Europe, and Asia, where the model would be built, including the Swiss Federal Institute of Technology (ETH) Zurich, the GeoForschungsZentrum (GFZ) Potsdam, the USGS in California and Colorado, and either the Disaster Prevention Research Institute of the University of Kyoto or the Active Fault Research Center of the AIST in Japan. Foreign scientists would visit the centers for stays of several months to participate in the model construction, bringing knowledge and expertise about faults and engineering practice in their own countries, and building support, awareness, and credibility for the model in their home countries.

Management Structure and Staffing Plan

Board of Directors (about 6-10 people): Representatives of the major foundation and industry donors, Dr. Brian Tucker, President of the non-profit GeoHazards International, and Prof. Dwight Jaffee, U.C. Berkeley Hass School of Business.

Executive Committee (5-6 people): The Principal Investigators and three other people who will run the Model Building Centers.

Scientific Review Panel (4-5 people): The Science Director of the Collaboratory for the Study of Earthquake Predictability, the Presidents of IAESPI and IAEE, and the head of the national hazard mapping project for one developed country (e.g., John Adams in Canada) and one developing (e.g., Mustafa Erdik in Turkey) country.

Staff: At each of the four centers, one full-time young PhD scientist or engineer, and one full-time MS-level programmer. Contributions to the salaries of the two principal investigators.

Deliverable Plan and Budget

Stage 1. ($1.0 million) 2007 preparatory efforts: Convening international conferences on the model design, obtaining international sanctioning, writing the charter, and negotiating logistical arrangements with hosting institutions.

Stage 2. ($1.0 million) Earthquake rate module (PB002 model; and Kagan/Jackson smoothed seismicity model as a control standard for null hypothesis testing)

Stage 3. ($0.8 million) Model performance tracking from this point forward (by the Collaboratory for the Study of Earthquake Predictability, University of Southern California)

Stage 4. ($2.0 million) Earthquake Hazard module (*OpenSHA* tools used with local attenuation relations and topographic slope employed for site amplification)

Stage 5. ($3.0 million) Earthquake Loss module (fatalities/injuries, building collapses/damage, and economic losses module)

Stage 6. ($2.2 million) Loss scenarios tool (Effect on fatalities and losses if buildings were retrofitted or if population changed)

Stage 7. ($1.9 million per year) Regular maintenance and enhancement (continuous updates of all modules; continuous improvements to model ease of use, functionality, and utility)

Acknowledgements. For expert guidance and advice, we thank Haresh Shah (*RMS & Stanford University*), Martin Bertogg (*Swiss Re*), Mariagiovanna Guatteri (*Swiss Re Capital Management*), Craig Tillman (*Renaissance Re*), Anselm Smolka (*Munich Re*), Erik Ruettener (*Converium*), Bill Pace (*Kurt Salmon & Associates*), Dwight Jaffee (*U.C. Berkeley*), Howard Kunreuther (*University of Pennsylvania*), Art Lerner-Lam (*Columbia University*), David Wald, Wayne Thatcher, Ned Field, and David Applegate (all at the *USGS*). We are also grateful for USGS Venture Capital funding.

Qualifications of the Principal Investigators

Ross Stein is a Fellow of the American Geophysical Union (AGU) and the Geological Society of America, was Editor of the *Journal of Geophysical Research* during 1986-1989, and chaired AGU's Board of Journal Editors in 2004-2006. Stein received the Eugene M. Shoemaker Distinguished Achievement Award of the USGS in 2000, and the Outstanding Contributions and Cooperation in Geoscience Award from NOAA in 1991. He received his PhD from Stanford University in 1980. He presented the Francis Birch Lecture of the AGU in 1996, the Frontiers of Geophysics Lecture of the AGU in 2001, Thomas Crough Memorial Lecture of Purdue University, Andrew C. Lawson Lecture of U.C. Berkeley, and the Condon Public Lecture of Oregon State University, in 2004. He was a visiting professor at the Institut de Physique du Globe de Paris and Ecole Normale Supérieure in 1989, 1993, and 1999. He has worked collaboration with Swiss Re to carry out non-proprietary earthquake hazard assessments for Istanbul and Tokyo.

Domenico Giardini has been Director of the Swiss Seismological Service and the Chair of Seismology and Geodynamics at ETH Zurich since 1997. In 2006, he has concurrently directed the Environment and Sustainability Competence Center of the ETH Domain. Before his arrival at ETH, he was Professor of seismology at the University of Rome III, and a senior researcher at the Istituto Nazionale di Geofisica e Vulcanologia. During 1982-1986, he was a Research Associate at Harvard University. He received his Laurea in physics from the University of Bologna in 1981. He directed the Mediterranean broadband seismic network (*MEDNET*) during 1989-1992, and the Global Seismic Hazard Assessment Project in 1992-1997, and chaired the Global Federation of Digital Seismic Networks in 2002-2006. He currently chairs the Organization and Research Facilities for European Seismology (*ORFEUS*).