OPINION

Lessons of L'Aquila for Operational Earthquake Forecasting

Editor's note: The following is the text of an address given at the Public Policy Luncheon of the Seismological Society of America (SSA) Annual Meeting on 19 April 2012. In light of the manslaughter convictions handed down for six earth scientists and a public safety official in an Italian court on 22 October 2012, SRL is publishing the content of this presentation. The recorded presentation can be accessed at www.seismosoc.org/italy/. *See SSA's statement on the convictions in the News and Notes column in this issue of SRL or at* http://www.seismosoc.org/news/newsitem.php?id=i20121011183.

The L'Aquila earthquake of 6 April 2009 (magnitude 6.3) killed 309 people, injured more than 1500 people, and left tens of thousands homeless. In June 2010, the vice-director of the Italian Department of Civil Protection (DPC) and six scientists associated with one of its advisory bodies, the Commission on the Forecasting and Prevention of Major Risk, were indicted on charges of criminal manslaughter. After two judicial reviews, the case was ordered to trial, which began last September. The prosecution was completed a few weeks ago, and the trial has now moved into its defense phase. Meanwhile, on the basis of newly revealed wiretaps, which were recorded before the earthquake, charges are being prepared against the former head of the DPC, Guido Bertolaso.

It is well known that large earthquakes cannot be accurately predicted in the short term. Why would an Italian court try to punish scientists for not doing something they didn't (and still don't) know how to do?

The case quickly became a cause célèbre among scientists. When news of the prosecutions broke in June 2010, the reaction was furious. The indictments appeared to blame the scientists for not alerting the local population of an impending earthquake—for failure to predict. It is well known that large earthquakes cannot be accurately predicted in the short term. Why would an Italian court try to punish scientists for not doing something they did not (and still do not) know how to do?

Scientific societies from around the world, including the International Union of Geodesy and Geophysics, the American Association for the Advancement of Science, the American Geophysical Union, and the SSA, wrote letters of protest to Italy's president. In his letter, the SSA president, Rick Aster, stated, "Prosecuting scientists for failing to achieve an earthquake prediction, which is presently impossible, is a disservice to both science and society."

However, court documents that were eventually filed by the prosecution cast the accusations not as sins of omission but as acts of commission. The scientists were charged with conducting a risk assessment that was "generic and ineffective," providing civil authorities and the public with "incomplete, imprecise, and contradictory information about the nature, causes, and future developments of the seismic hazards" and characterizing the seismic swarm that affected L'Aquila for about 3 months before the mainshock as "a normal geological phenomenon." In sending the case to trial, the L'Aquila judge agreed with the prosecution that public statements made by the defendants "thwarted the activities designed to protect the public."

SO WHAT REALLY HAPPENED IN L'AQUILA?

The facts of the case are complex. Seismic activity in the L'Aquila area increased in January 2009, prompting school evacuations and other preparedness measures. Beginning in February, media coverage became inflamed by a series of amateur earthquake predictions issued by Gioacchino Giuliani, a local man who worked as technician at the Gran Sasso National Physics Laboratory near L'Aquila. These predictions, which were based on radon concentrations measured with gamma-ray detectors of his own design, had no official validity but were widely reported and taken seriously, causing some citizens to evacuate their towns. At least two of the predictions were false alarms. There is no hard evidence from Giuliani or anyone else that he had transmitted a valid prediction of the mainshock to the public or any civil authority.

In response to Giuliani's February predictions, government scientists stated publicly that there was no validated method for earthquake prediction, that earthquake swarms were common in this part of Italy, and that the probability of larger earthquakes remained small. These assurances were technically correct, but they did not dispel public concern. On 31 March, the DCP took the unusual step of convening its Major Risk Commission in an open meeting in L'Aquila.

According to recently released translations of a premeeting wiretap, Bertolaso told a local official that the experts were being called together "not because we are frightened and worried" but because "we want to reassure the public."

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Bertolaso explained to the official that the meeting was to be "more of a media operation." In particular, the experts were to going say, "It's better that there are 100 magnitude-4 tremors rather than silence, because 100 tremors release energy and there won't ever be the damaging tremor."

At the meeting, which was short and attended by local officials, the Major Risk Commission concluded, "There is no reason to say that a sequence of small-magnitude events can be considered a sure predictor of a strong event." This statement was scientifically correct, although few seismologists would consider it to be scientifically complete. At a press conference before the meeting, the DCP vice president, Bernardo De Bernardinis, who was not a seismologist or a member of the Major Risk Commission, said, "The scientific community tells us there is no danger, because there is an ongoing discharge of energy. The situation looks favorable." This statement was not scientifically correct.

The tremors continued into April, prompting more school evacuations. Shortly before 11 p.m. on April 5th, just a few hours before the mainshock, a strong, magnitude-3.9 earthquake shook the city. In an interview in *Nature*, Vincenzo Vittorini describes how he debated with his wife and his terrified 9-year-old daughter whether to spend the rest of the night outside—a customary response to seismic activity in this part of Italy. Recalling authoritative statements claiming that each shock diminished the potential for a major earthquake, he persuaded his family to remain in their apartment building. The building collapsed in mainshock, killing his wife and daughter and five others. Nearly everyone in L'Aquila, including the prosecutor, lost relatives or friends. Tragic testimony such as Vittorini's constitutes much of the prosecution's case.

> **Distracted by Giuliani's predictions, the authorities did not emphasize this increase in hazard, nor did they focus on advising the people of L'Aquila about preparatory measures warranted by the seismic crisis. Instead, they were snookered into addressing a simple yes-or-no question: "Will we be hit by a larger earthquake?"**

A few weeks after the L'Aquila disaster, the Italian government convened an International Commission on Earthquake Forecasting for Civil Protection (ICEF), which was composed of 10 experienced scientists from nine countries: China, France, Italy, United Kingdom, Germany, Greece, Russia, Japan, and the United States. I served as the chair of this commission. We were charged by the DPC to report on the status of short-term forecasting methods and to make recommendations how they might be more effectively implemented for civil protection. We met in L'Aquila, Potsdam, and Rome, and we issued our findings and recommendations on 2 October 2009, in L'Aquila, less than 6 months after the earthquake. Our 77-page final report, fully documenting these findings and recommendations, was peer-reviewed, revised, and published its entirety in *Annals of Geophysics* (Jordan *et al.*, 2011). The report, entitled "Operational Earthquake Forecasting: State of Knowledge and Guidelines for Implementation," can be downloaded without charge from the journal's web site (www.annalsofgeophysics.eu/index.php/annals/article/view/5350).

As defined by the Commission, "operational earthquake forecasting" (OEF) involves two key activities: the continual updating of authoritative information about the future occurrence of potentially damaging earthquakes and the officially sanctioned dissemination of this information to enhance earthquake preparedness in threatened communities.

The ICEF report documented several scientific conclusions relevant to OEF. In particular, there is no validated method to predict earthquakes with high probability. However, seismic hazards do change with time because earthquakes release energy and suddenly alter the tectonic forces that will eventually cause future earthquakes. Statistical models of earthquake interactions capture many of the short-term temporal and spatial features of natural seismicity, such as the excitation of aftershocks and other seismic sequences. These seismicity-based models provide the highest validated probability gains of any short-term forecasting method.

However, we noted that, although under favorable circumstances these probability gains can be high (100–1000 relative to long-term forecasts), the probabilities of large earthquakes remain low even in areas of high seismicity (typically < 1% per day). We studied six high-risk countries (China, Greece, Italy, Japan, Russia, and the United States) and found that preparedness actions appropriate in such high gain, low probability situations have not been systematically investigated. In all of these countries, the standardization of OEF procedures is only in a nascent stage of development, and the incremental benefits of OEF for civil protection relative to long-term seismic hazard analysis have not been convincingly demonstrated. Under these circumstances, governmental agencies with statutory responsibilities for earthquake forecasting have been cautious in developing operational capabilities.

The lack of these capabilities is one of the reasons the Italian authorities got trapped in L'Aquila. From what the scientists could have known a week before the earthquake, a big shock was not very likely: the probability of a false alarm (if an alarm were cast) exceeded the probability of a failure to predict (if an alarm were not cast) by a factor of more than 100. Even so, seismic activity had increased the probability of a large earthquake by a significant factor, perhaps as much as 100-fold, above the long-term average.

Distracted by Giuliani's predictions, the authorities did not emphasize this increase in hazard; neither did they focus on advising the people of L'Aquila about preparatory measures warranted by the seismic crisis. Instead, they were snookered into addressing a simple yes-or-no question: "Will we be hit by a larger earthquake?" They could not answer this question conclusively, but to calm the population, they made reassuring statements that were widely interpreted to be an "anti-alarm," that is, a categorical statement that a large earthquake would not occur. This perception lies at the core of the L'Aquila accusations.

I can see no merit in prosecuting public servants who were trying in good faith to protect the public under chaotic circumstances. With hindsight, their failure to highlight the increased hazard may be regrettable, but the inactions of a stressed risk advisory system and misstatements by non-scientists representing that system can hardly be construed as criminal acts on the part of individual scientists. One can only hope that judicial sanity will prevail.

COMMUNICATING HAZARD AND RISK

Yet the situation has provided us with an opportunity to think through some larger issues that will surely recur for scientists involved in hazard management and risk communication. Among the main lessons of L'Aquila is the need to separate the role of science advisors, whose job is to provide objective information about natural hazards, from that of civil decision makers, who must weigh the benefits of protective actions against the costs of false alarms and failures-to-predict. L'Aquila shows that confusing these roles can lead to trouble.

The ICEF concluded that that the best way to achieve this separation was to use probabilistic rather than deterministic statements in characterizing short-term changes in seismic hazards. We recommended that the DPC should support development of seismicity-based forecasting methods to quantify short-term probability variations, and we made a series of recommendations on the implementation of OEF systems:

1. The public should be provided with open sources of information about the short-term probabilities of future earthquakes that are authoritative, scientific, consistent, transparent, and timely.
2. This information should be made available at regular intervals, during periods of normal seismicity as well as during seismic crises. The public must be educated into the scientific conversation through repeated communication of what can be expected. Agencies should not try to deliver new types of information during times of crisis.
3. Public advisories should be based on operationally qualified, regularly updated seismicity forecasting systems that have been rigorously reviewed and updated by experts in the creation, delivery, and utility of earthquake information.
4. The quality of all operational models should be evaluated for reliability and skill by retrospective testing, and they should be under continuous prospective testing against established long-term forecasts and alternative time-dependent models. Our report specifically recommended that the international Collaboratory for the Study of Earthquake Predictability (CSEP) be used as an infrastructure for blind performance testing.
5. Alert procedures should be standardized to facilitate decisions at different levels of government and among the public.
6. Earthquake probability thresholds should be established to guide alert levels based on objective analysis of costs and benefits, as well as the less tangible aspects of value of information, such as gains in psychological preparedness and resilience.
7. The principles of effective public communication established by social science research should be applied to the delivery of seismic hazard information, for example, consistency of messaging.

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In this age of nearly instant information and high-bandwidth communication, public expectations regarding the availability of authoritative short-term forecasts are evolving rather rapidly, and there is a greater danger that information vacuums will spawn informal predictions and misinformation. L'Aquila demonstrates why, in this media-rich environment, the development of OEF capabilities is a requirement, not an option.

Italian earthquake experts are in the forefront of the research needed for the implementation of OEF. The ICEF report highlighted their accomplishments and provided a roadmap for building upon their recent efforts. Although it was written for this purpose, I hope that the ICEF study will be useful not only in Italy, but also in other seismically active regions where operational earthquake forecasting may be warranted. Its recommendations should be studied carefully by both the National Earthquake Prediction Evaluation Council (NEPEC) and the California Earthquake Prediction Evaluation Council (CEPEC). I sit on CEPEC and have to admit that our procedures are not really up to the standards set forth by the ICEF.

Of course, we must keep our perspective and not allow a focus on short-term forecasting undermine sustained efforts to reduce risk. The ICEF emphasized that long-term models are currently the most important forecasting tools for civil protection against earthquake damage because they guide earthquake safety provisions of building codes, performance-based seismic design, and other risk-reducing engineering practices, such as retrofitting to correct design flaws in older buildings.

Nevertheless, properly done, short-term forecasting complements long-term seismic hazard analysis in promoting earthquake preparedness.

The report was written prior to the damaging 2010–2011 earthquake sequence in Christchurch, New Zealand, and the catastrophic Tohoku earthquake of 11 March 2011. However, what we have learned from these tragedies supports the ICEF findings and recommendations. Both earthquake sequences underline the need for authoritative information about time-dependent seismic hazards, especially in the wake of major earthquakes. For example, like it or not, time-dependent hazard models will be necessary for guiding the rebuilding of Christchurch and in assessing the current hazard in Tokyo, the world's largest city.

These form a continuum, ranging from long-term seismic hazard analysis and OEF to earthquake and tsunami early warning and post-event information for emergency response.

The age of OEF has arrived, and there is much that the SSA can do in assembling, exchanging, and disseminating the knowledge needed to improve time-dependent forecasting. In considering our activities, we should put OEF in its proper place among the other technologies for risk reduction. These form a continuum, ranging from long-term seismic hazard analysis and OEF to earthquake and tsunami early warning, and post-event information for emergency response. Taken together, these technologies can be used to track earthquake cascades and thereby reduce seismic risk before, during, and after their occurrence.

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