CSRN
RCRP
Canadian Seismic Research Network
Réseau canadien pour la recherche parasismique
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Institute for Catastrophic Loss Reduction

Western Science

Short- and Intermediate-Term Earthquake Hazard in Canada

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Workshop on Seismic Hazard and Microzonation
Friday, January 13, 2012

Motivation

- Earthquakes are generally the most feared of natural hazards because they occur without warning.
- Hurricanes can be tracked; floods rise in a systematic way; volcanic eruptions are preceded by a variety of phenomena.
- While historical records from around the world suggest that large events such as the 2011 Japan or 2004 Sumatran earthquakes (M ~ 9) and associated tsunamis occur elsewhere, data sets are incomplete.
- While rare, similar events have occurred elsewhere, including Alaska, Chile, Iran, and Cascadia.
- Smaller but very destructive earthquakes (M > 6.5) occur every year, many in populated areas.
- Earthquakes, until very recently, have not been forecast with any significant degree of success.

Haiti Earthquake

M ~ 7, January 12, 2010

~200,000 dead, ~ $14 billion in damages

The shaking from significant, although smaller, earthquakes can cause disastrous damage in areas that that are not properly prepared.

http://www.boston.com

The San Francisco Earthquake

M ~ 8, April 18, 1906

The city was destroyed in a few tens of seconds.

The fire that followed finished what the earthquake started.

Courtesy, Museum of San Francisco

Sendai Earthquake & Tsunami

M ~ 9, March 11, 2011

~20,000 dead, as much as $30 billion in damages

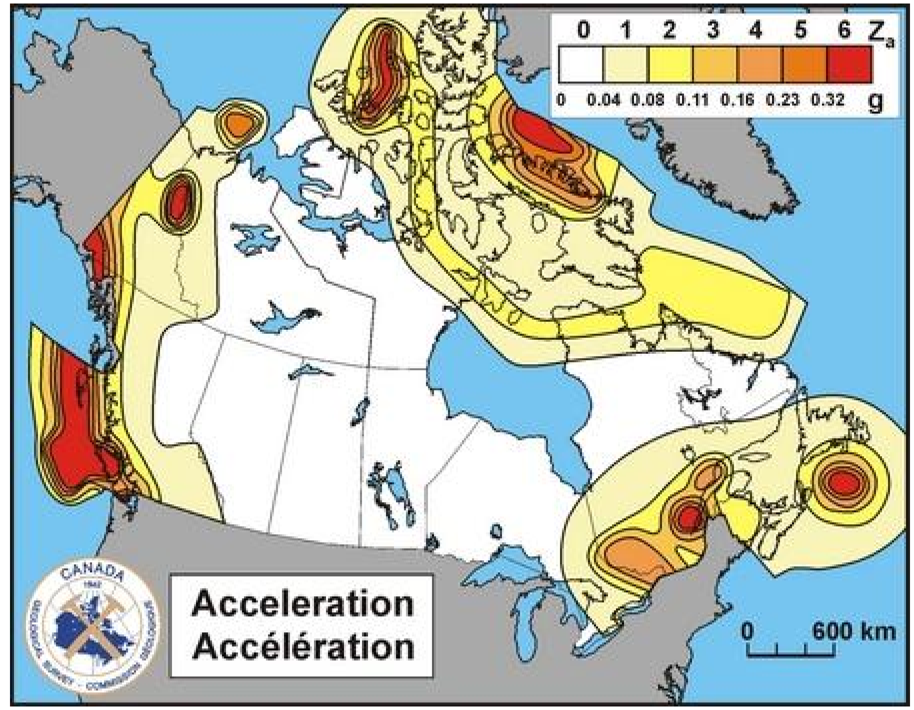
http://www.ibtimes.com

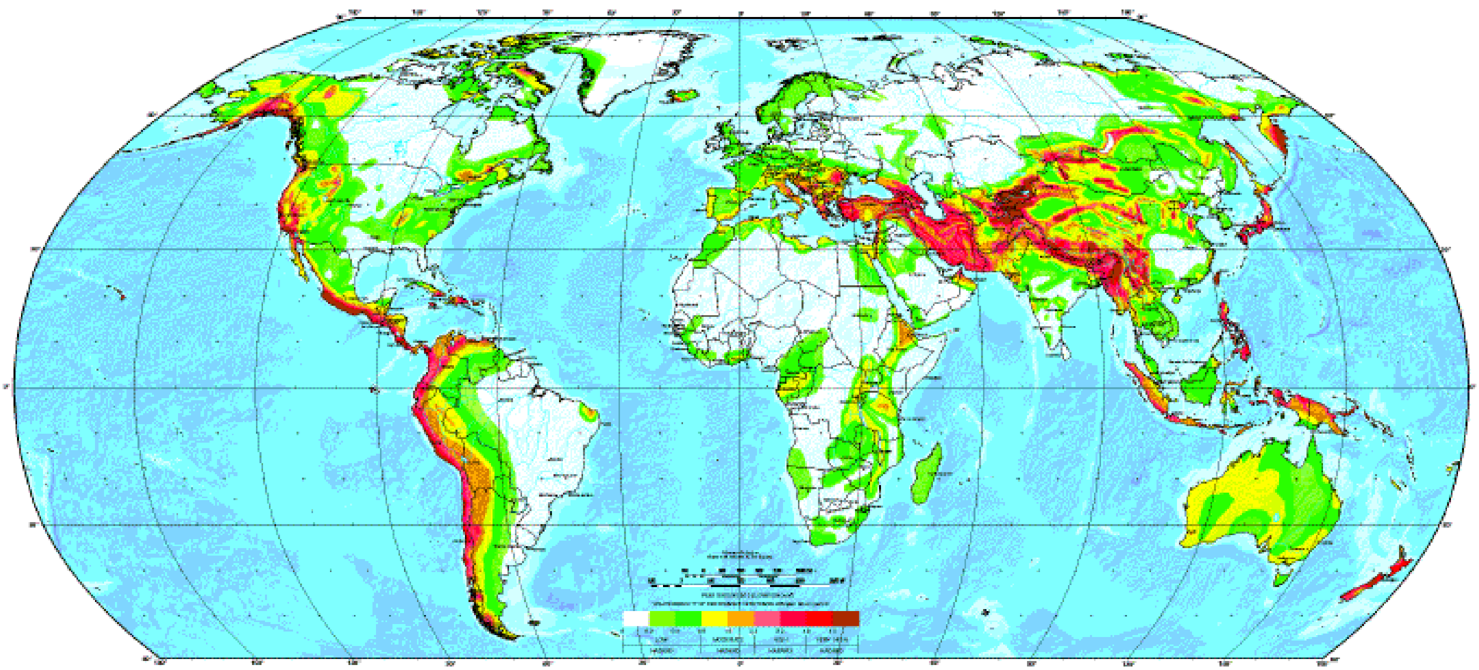
Hazard Maps

Compiled based on historic seismicity records

Right: Probability of Exceedance = 10% in 50 years, 1985.

Courtesy NRCAN





Left: Seismic Hazard, Low to High, 1999

Courtesy Global Seismic Assessment Program

Forecast vs. Hazard

- Hazard maps are widely used to characterize the likelihood of any given region undergoing shaking due to a large earthquake. Hazard maps, however, are not considered earthquake forecasts, but rather a tool for planners, engineers, and emergency managers.
- *Forecasts provide a probability of an earthquake occurring at a specific location over a fixed period of time in the future.*
- Historically, a wide variety of approaches have been applied to the problem of earthquake forecasting.
- Today, in addition to efforts at intermediate-term forecasting, short-term early warning systems are under development as well. These would post warnings at the very first signs of a significant earthquake and/or tsunami.

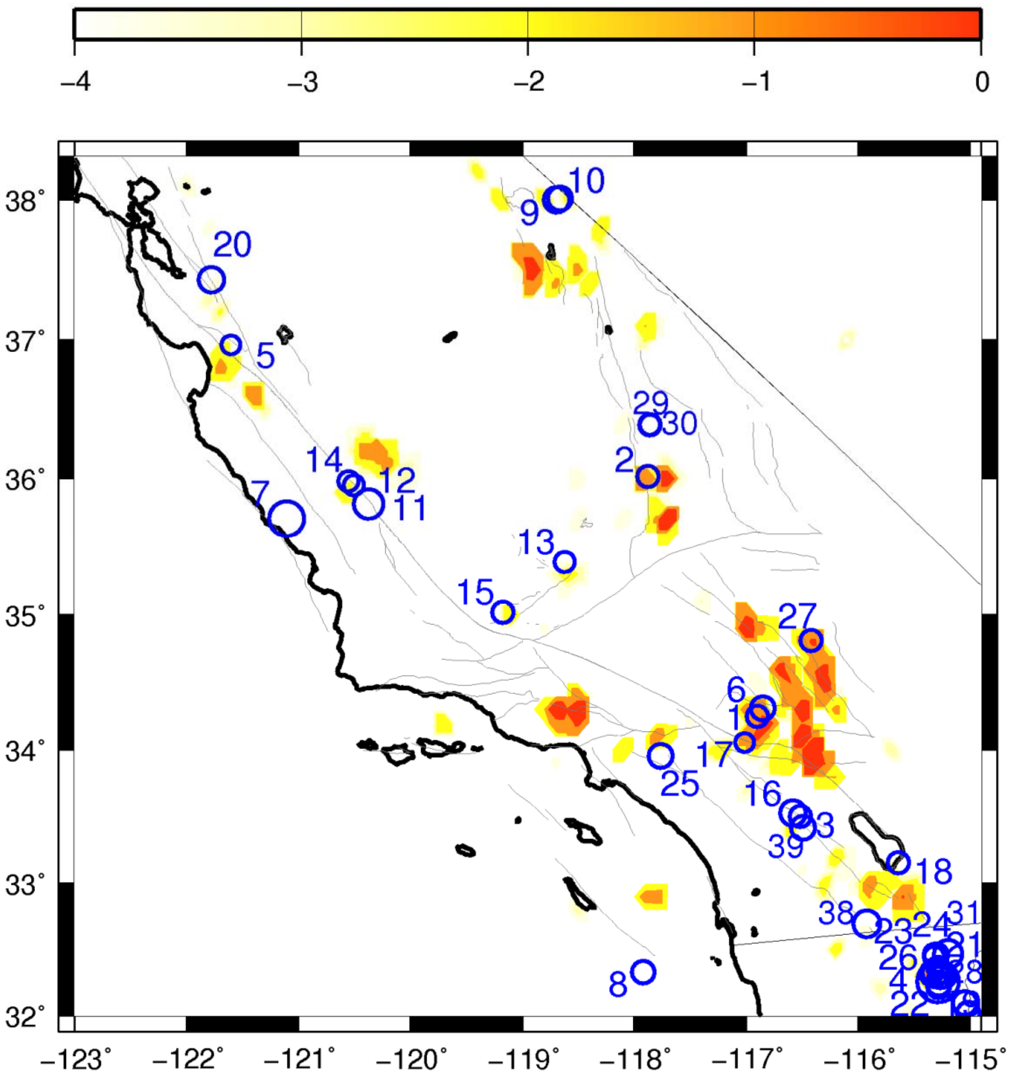
Seismicity Data

- The first known, historic earthquake recorded was in 1831 BC in China, and the first seismometer was invented by Chang Heng in the first century AD.
- Pendulum seismographs were invented in the mid-1700s, but digital recording devices were not widely implemented until the late 1960s.

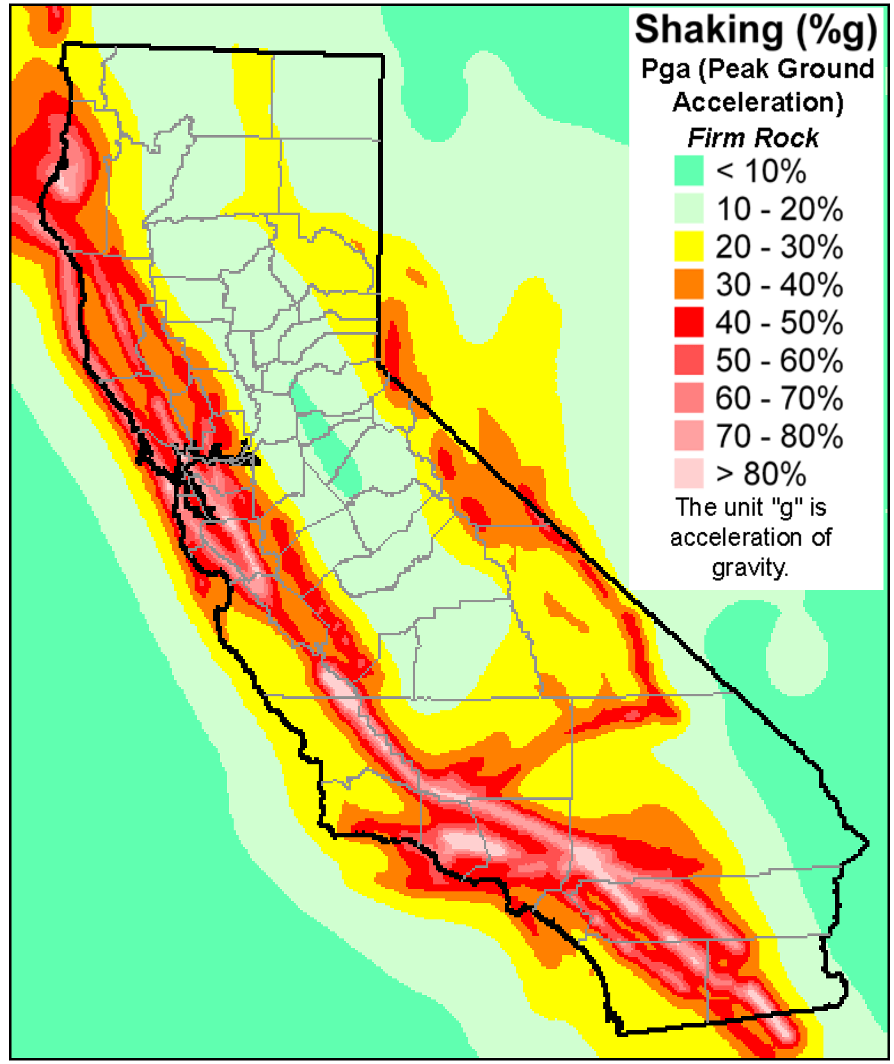
- Today, we record 500,000 earthquake per year, worldwide, and 10,000 in southern California alone.
- Only 100 earthquakes per year cause damage in some part of the world – *the bulk of this data are small events.*

earthquake.usgs.gov
hua.umf.maine.edu

Forecast vs. Hazard



10-year forecast for earthquakes of M > 5.0, 2000 to 2010

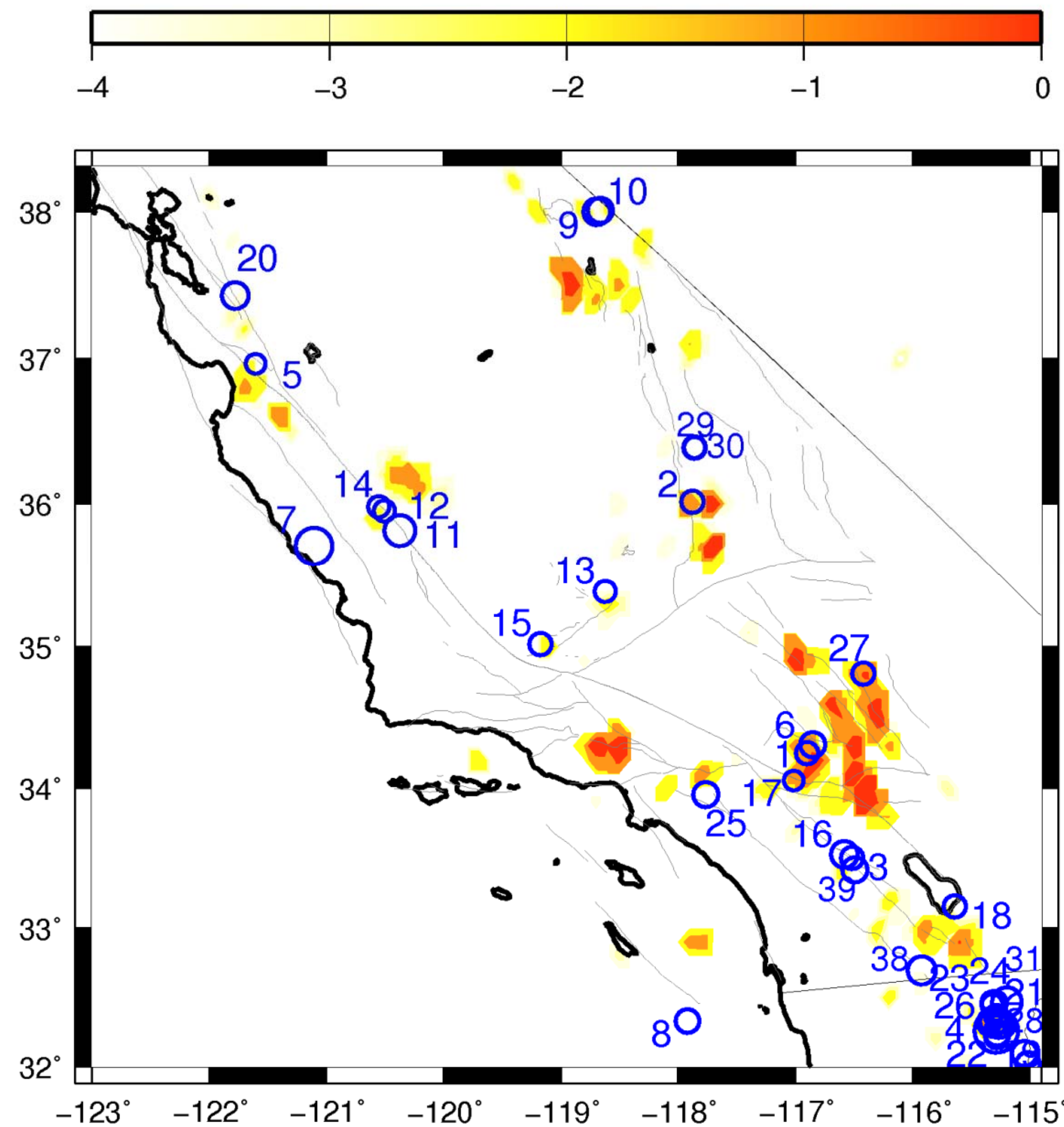


10% Probability of Exceedance in 50 years.
http://www.consrv.ca.gov/CGS/rghm/psha/index.htm

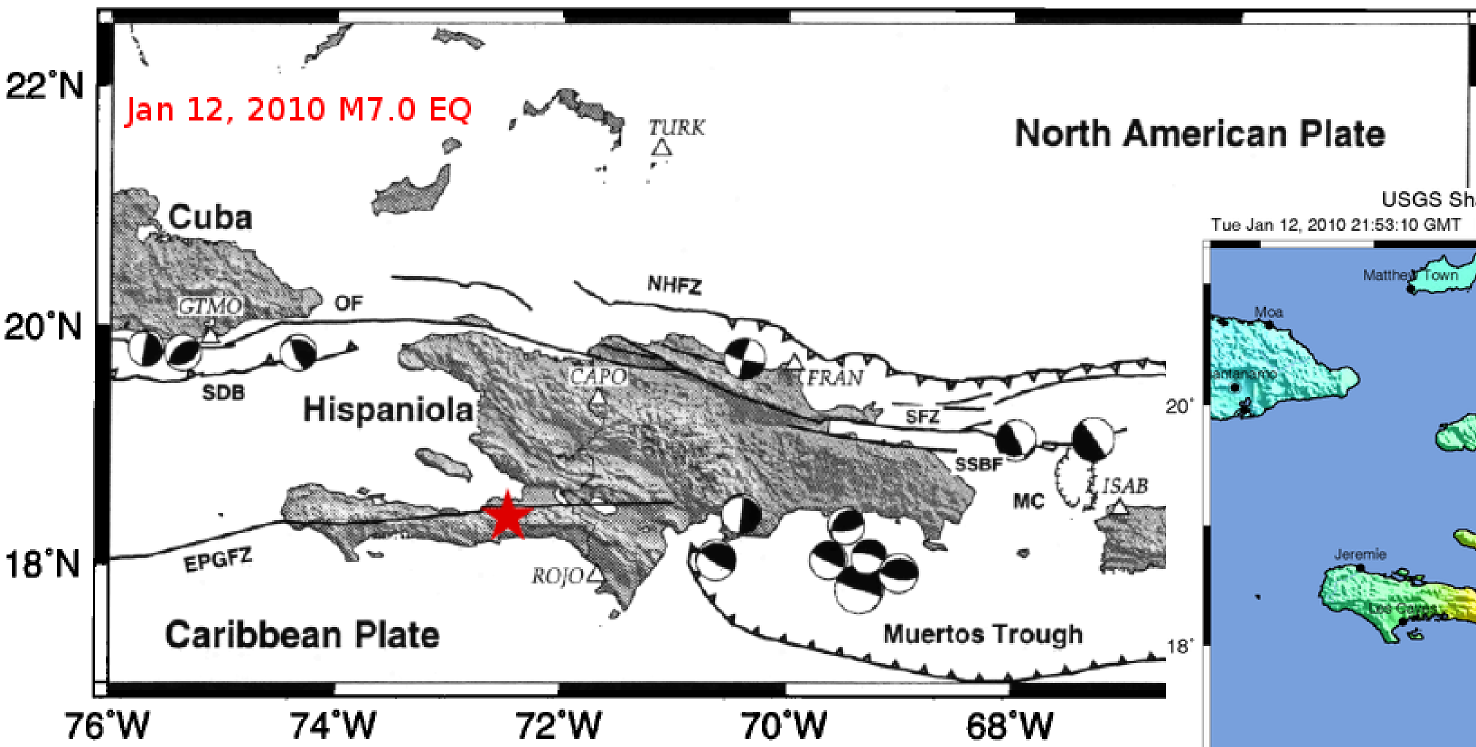
A Prospective Forecast Experiment

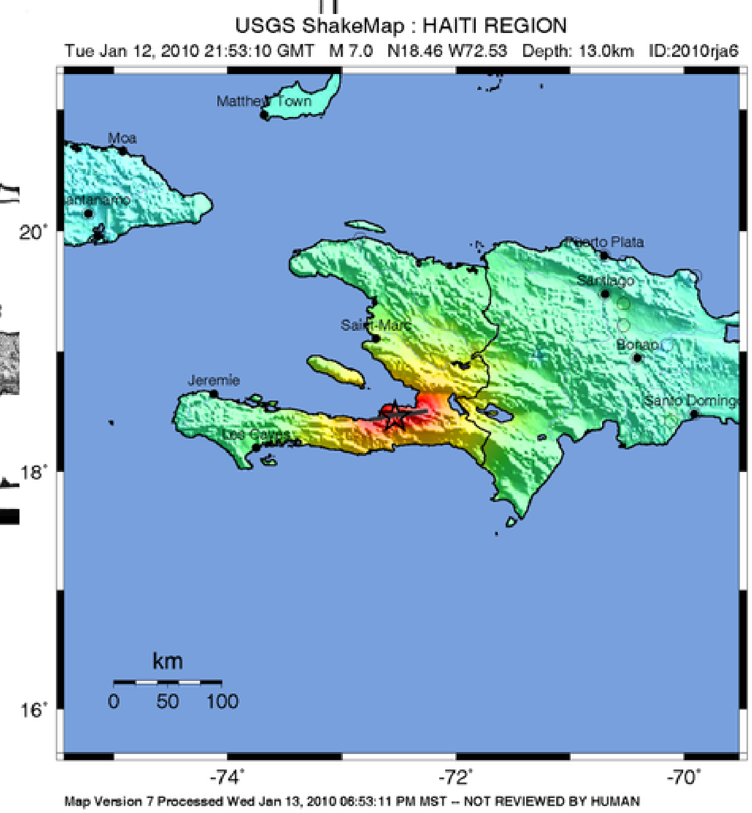
PNAS, 2002

- Small earthquakes can be used as sensors for stress changes prior to large events.
- Forecast for large earthquakes, M ≥ 5, 2000 to 2010.
- Blue circles represent those events that occurred during the forecast period.
- 37 out of 39 events that occurred in California during 2000-2010 were successfully forecast.



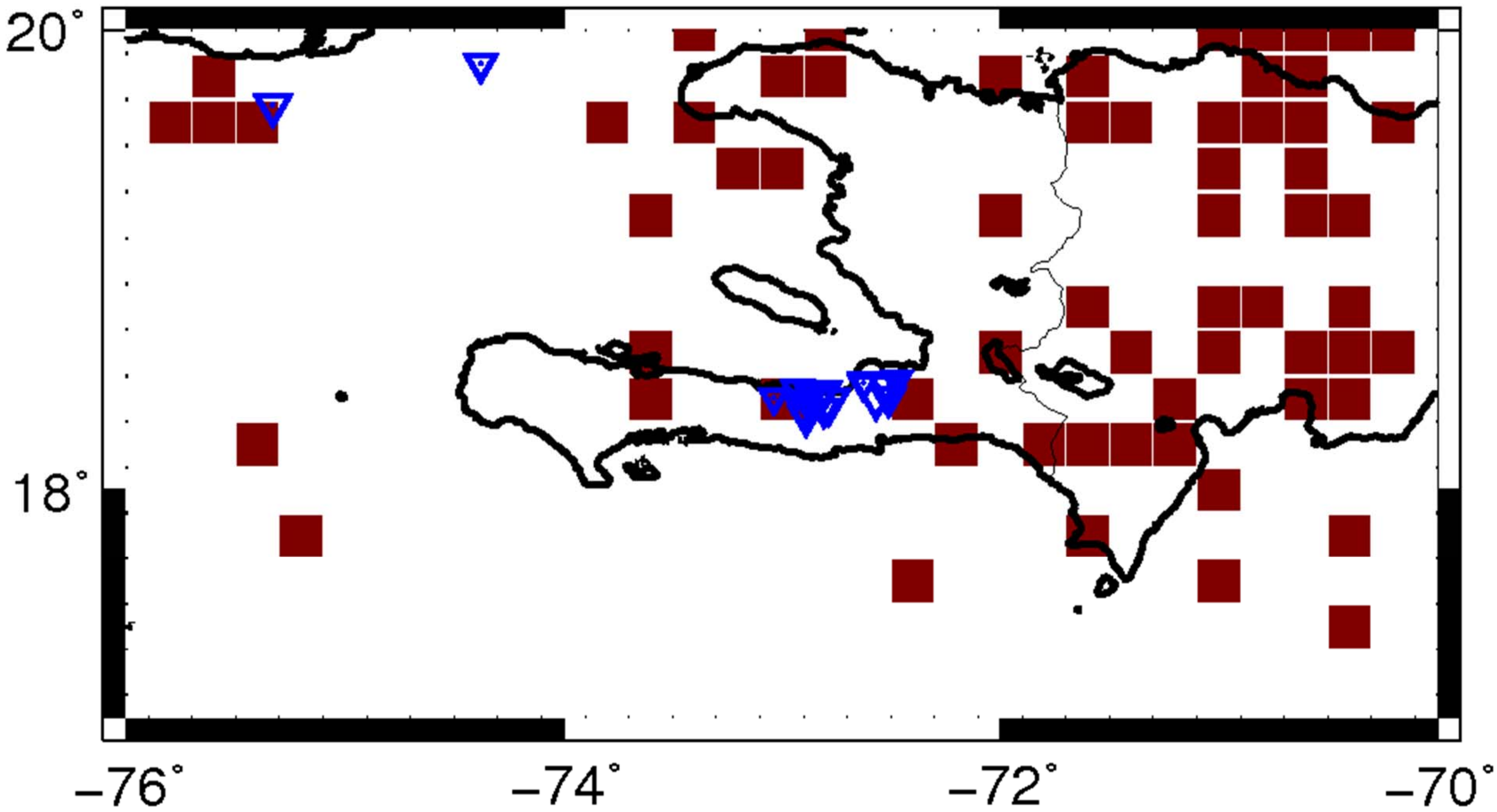
Haiti M ~ 7.0 Earthquake, January 12, 2010





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

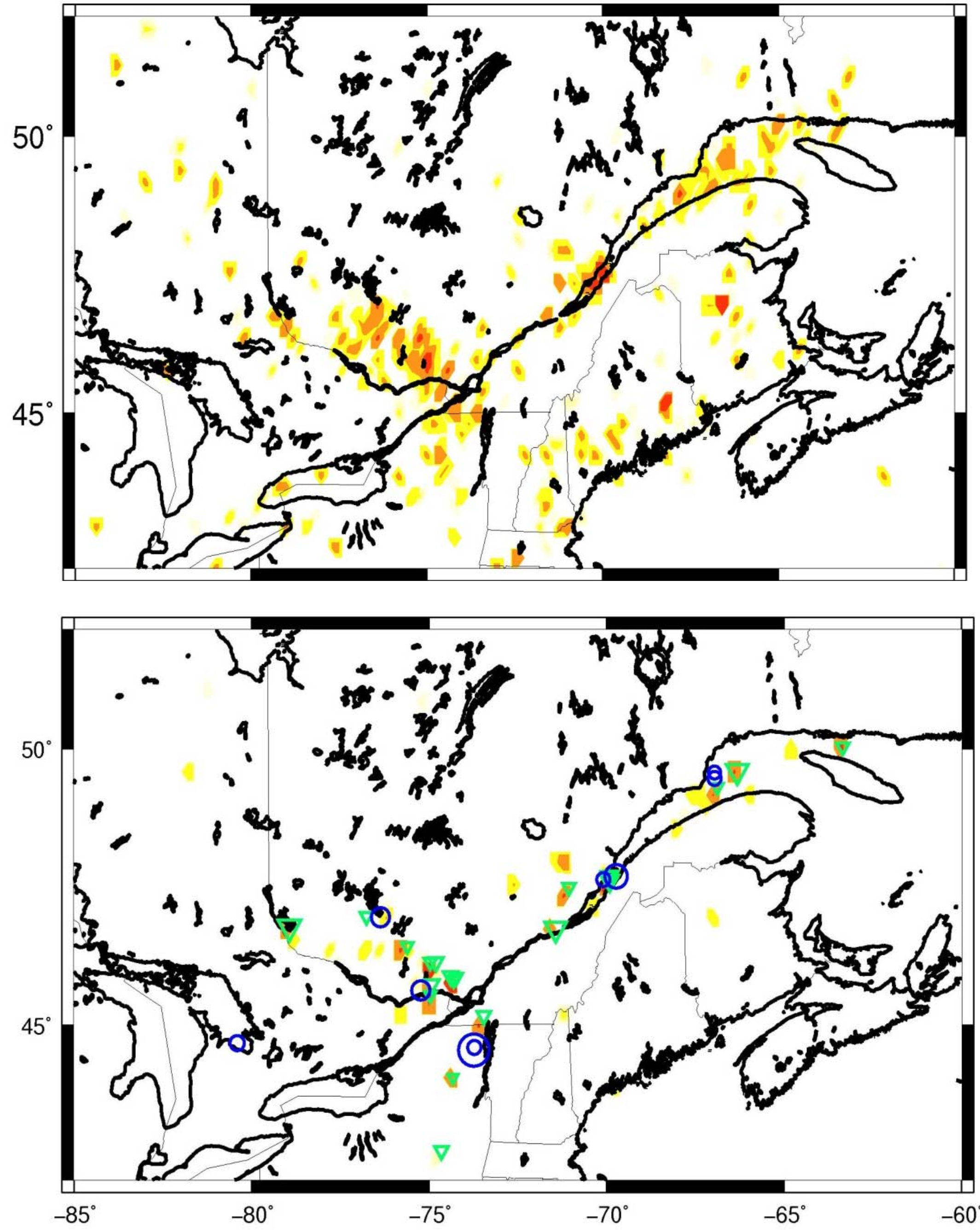
Regional PI Forecast
Haiti, 2010



Despite the false positives, partially a function of network coverage, the earthquake and aftershocks are successfully forecast

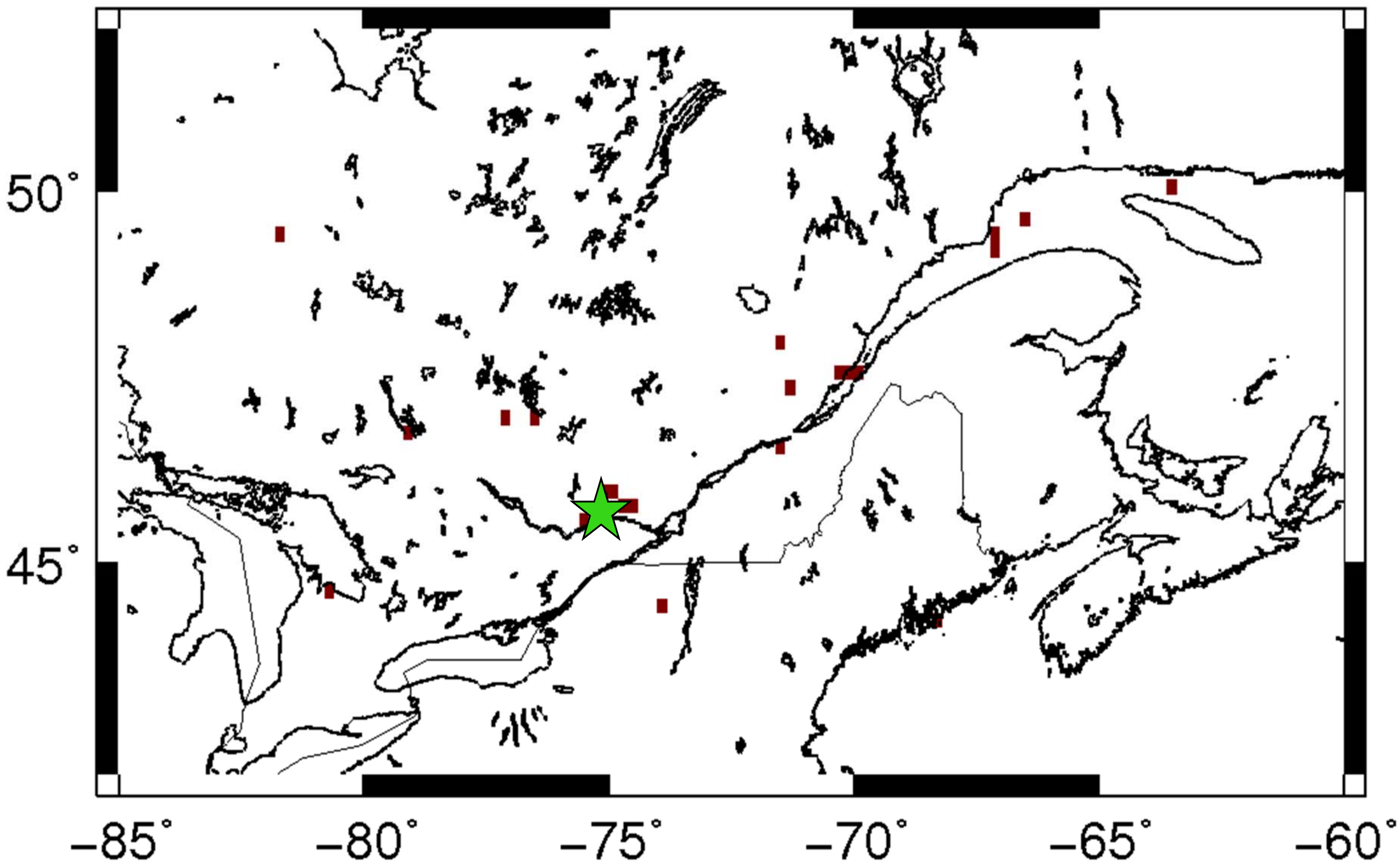
PI Index Eastern Canada

- PI forecast for eastern Canada, 2002-2012. On the top is a forecast for M ≥ 3, at the bottom is shown the same forecast for M ≥ 4.
- Note that we have significantly decreased the false positive rate shown at the top.

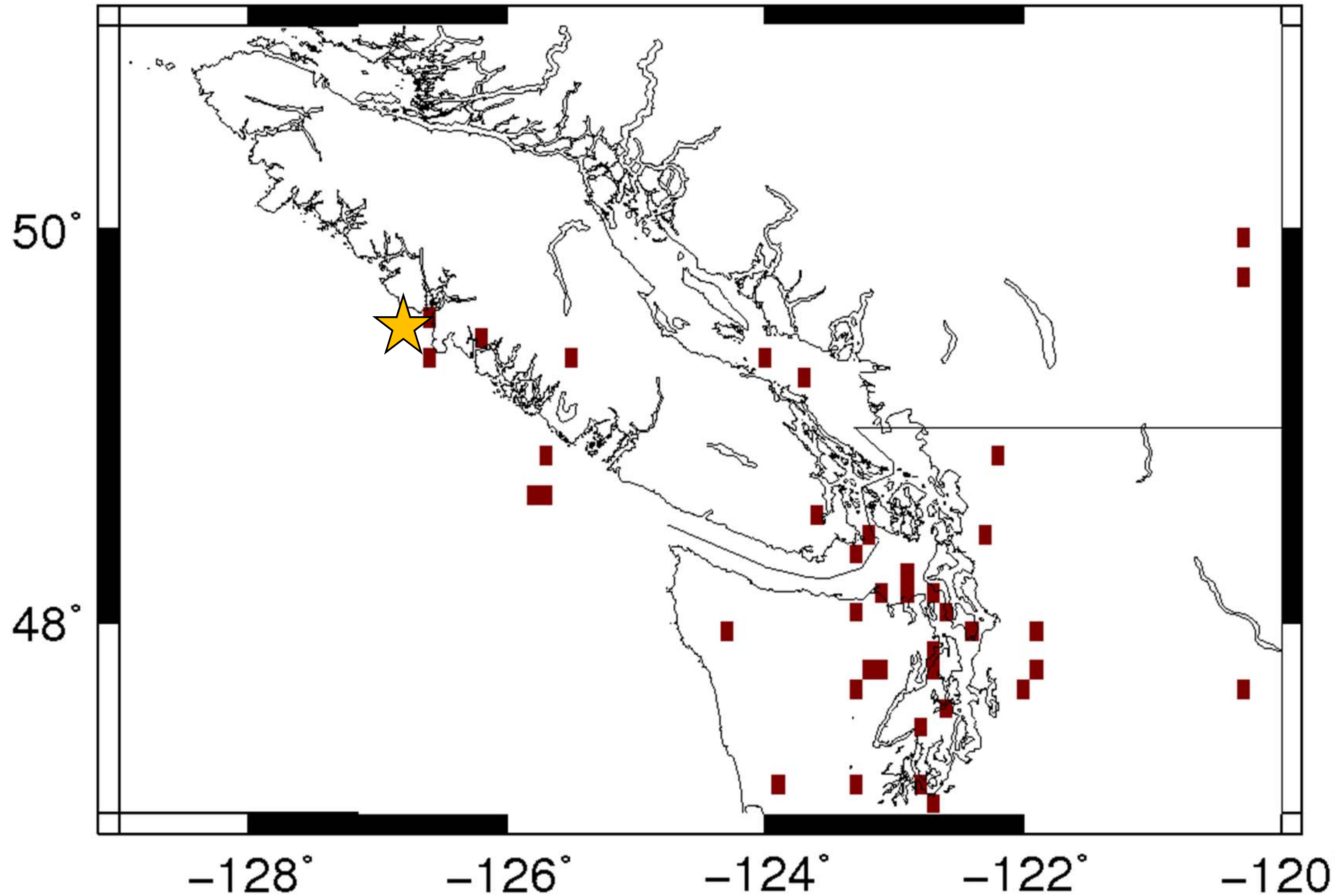


Ottawa Earthquake, June 2010, M ~ 5.0

PI forecast for eastern Canada, 2008-2013. The location of the Ottawa earthquake is shown with a star.



PI Forecast, Western Canada
2011-2017

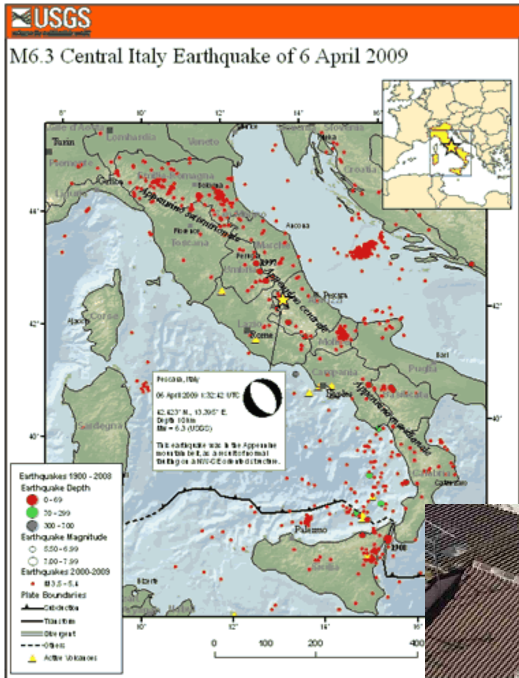


Today

- Time-dependent earthquake forecasts provide a probability of an earthquake occurring at a specific location over a fixed period of time in the future.
- *"Data other than seismicity have been considered in earthquake forecasting (e.g., geodetic measurements and geoelectrical signals), but so far, studies of non-seismic precursors have not quantified short-term probability gain, and they therefore cannot be incorporated into operational forecasting methodologies. Accordingly, our focus … will be on seismicity-based methods that are enabled by high-performance seismic networks."* Jordan & Jones, 2010.
- The exponential increase in the collection of seismic data at all sizes over the past 30 years has directly led to an increase in our ability to provide time-dependent earthquake hazard estimates.

Operational Earthquake Forecasting

- The success of seismicity-based earthquake forecasting methods such the PI index has led to the establishment of agencies for the testing and assessment of the various models, such as the Collaboratory for the Study of Earthquake Predictability (CSEP).
- Short- and intermediate-term models demonstrate a probability gain in forecasting future earthquakes relative to the long-term, time-independent hazard models typically used in seismic hazard analysis.
- The goal of operational earthquake forecasting is to provide the public with considered, useful information on the *time dependence* of regional seismic hazard.
- The challenges came to both scientific and public attention with the occurrence of the L'Aquila earthquake in 2009.



L'Aquila Earthquake

M ~ 6.3, April 6, 2009

~300 dead and ~$2.5 billion in damages,

20,000 buildings destroyed

Courtesy, USGS & boston.com

L'Aquila Earthquake

- In early 2009, prior to the earthquake, seismic activity in the L'Aquila area increased. A number of small earthquakes, potential foreshocks, were felt widely and prompted school evacuations and other preparedness measures.
- In addition, a technician working at the Laboratori Nazionali del Gran Sasso issued a series of predictions based on radon concentrations (measured using unpublished techniques). These predictions had no official auspices. At least two of Mr. Giuliani's specific predictions were false alarms, but they generated widespread concern and official reactions.
- The Commissione Nazionale per la Previsione e la Prevenzione dei Grandi Rischi, convened by the Dipartimento della Protezione Civile (DPC) on 31 March, concluded that "there is no reason to say that the sequence of events of low magnitude can be considered precursory to a strong event."
- The M ~ 6.3 struck on April 6, 2009, killing ~300 people leaving more than 40,000 homeless.

L’Aquila Earthquake

- One year ago, seven scientists and other experts were indicted on manslaughter charges for allegedly failing to warn residents sufficiently before that earthquake in central Italy in 2009.
- Defence lawyers condemned the charges, saying it was impossible to predict earthquakes.
- The judge, however, directed that the members of the national government's great risks commission, which evaluates potential for natural disasters, will go on trial in L'Aquila in September of this year.
- The judge reportedly said the defendants "gave inexact, incomplete and contradictory information" about whether the smaller tremors that occurred near L'Aquila in the six months before the earthquake should have constituted grounds for a warning.

http://www.smh.com.au/world/italian-scientists-arrested-over-deadly-quake-20110526-1f6ec.html

What happened?

- While foreshocks are one of those patterns that have long been recognized and studied as potential earthquake precursors, less than 10 percent of earthquakes worldwide are followed by something larger within 10 kilometers and three days. Less than half of the large earthquakes studied to date have had detectable foreshocks.
- In Italy, seismic swarms are relatively common and most occur without large events. However, given what we know about the statistics of clustering, many seismologists would agree today that the short-term probability of a large earthquake in the L'Aquila region was slightly higher in the weeks before the 2009 mainshock than in a typical, quiescent week.
- A forecast consistent with this understanding was not communicated properly to the public, and was supplanted by amateur predictions instead.
- ***Quantifying that increased probability, and how to communicate it to the public, remains our biggest challenge.***

Operational Earthquake Forecasting

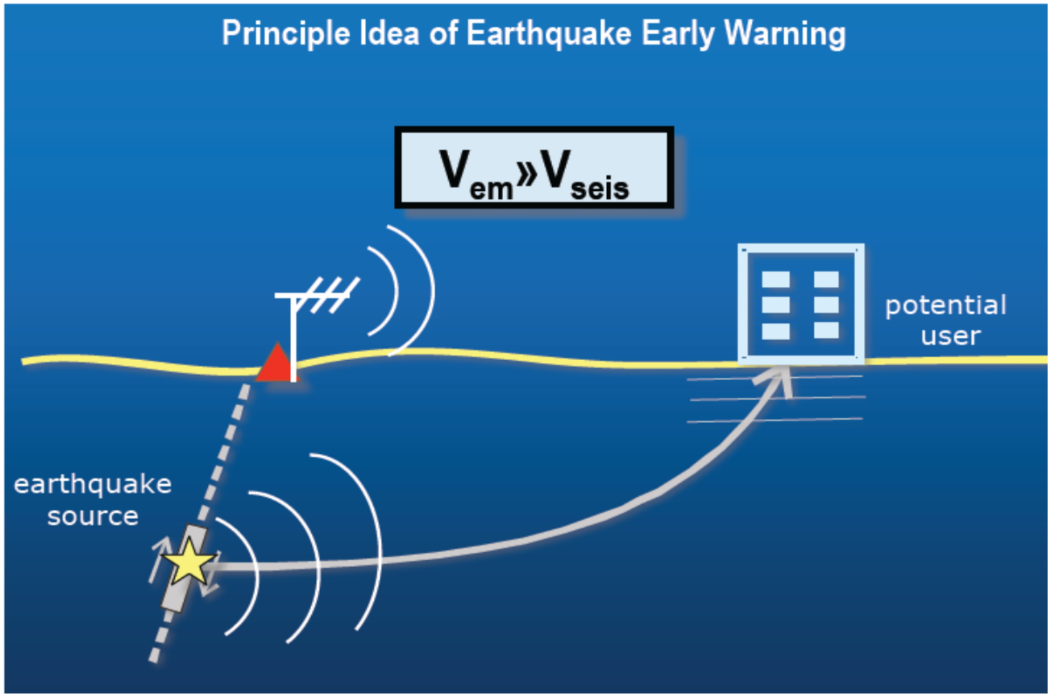
- Many modern societies today have some form of agency with statutory responsibility for earthquake assessment, include the mandate to use 'the best available science' in estimating earthquake hazard.
- Today, that definition should include time-dependent seismicity-based earthquake forecasts such as the PI method, although they generally do not (the Chinese are one notable exception).
- To date, these agencies have been extremely cautious in developing new operational forecasting capabilities. ***But that will change.***
- For example, the USGS has proposed a program to establish a prototype operational earthquake forecasting activity in southern California which will develop a formal process for issuing forecasts in response to seismic activity. This program will include forecast research and development, testing, validation, and application assessments.
- *How can operational forecasts such as this best be used by all parties?*

Industry Applications for Real-Time Analytics and Stream Computing

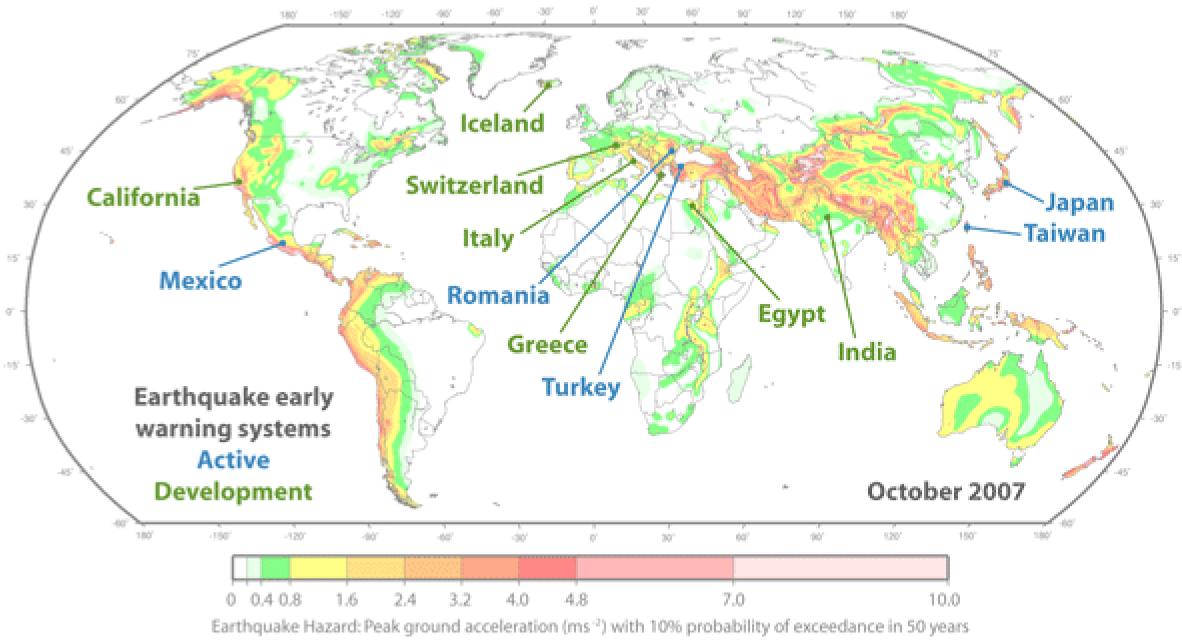
- Real-time seismicity data are used to look for patterns that could tell us about short-, intermediate- and long-term increases in the probability of an earthquake. That would fit well into the earthquake hazard community's current interest in 'operational earthquake forecasting‘
- Industry would use stream computing to run their impact algorithms to produce projections of damage due to these increased probabilities, the resulting potential losses and estimate what is needed to meet and cover those eventualities, again in real-time.
- Another potential application is to provide estimates of business interruption, and other end-users (emergency hazard providers).
- This could be integrated with other kinds of hazard estimators. For example, we plan to integrate it with ShakeMap, which produces real-time estimates of ground shaking from interactive web services that allow victims to record, on-line, what they felt.

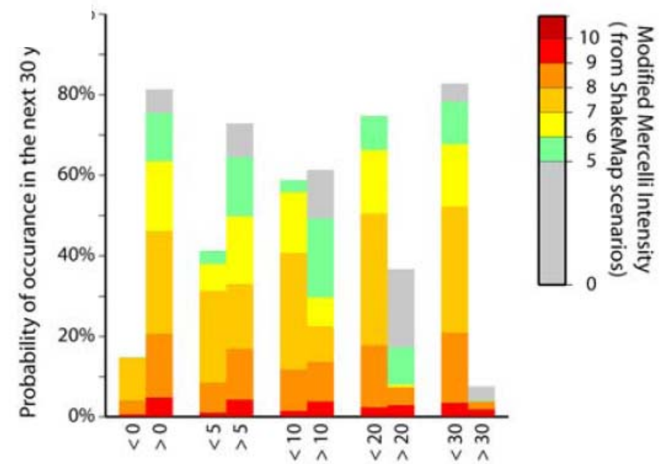
Earthquake Early Warning

- Studies into earthquake early warning systems, which can provide rapid notification of ground shaking, tsunami generation, and preparation of critical facilities such as nuclear power plants.
- The basic idea is to use the fact that information transmission from the first seismometers to sense a large earthquake is faster than seismic wave speed.
- The few seconds that are gained can be used to warn people and facilities of the upcoming shaking and automatically shut down critical equipment.



Earthquake Early Warning



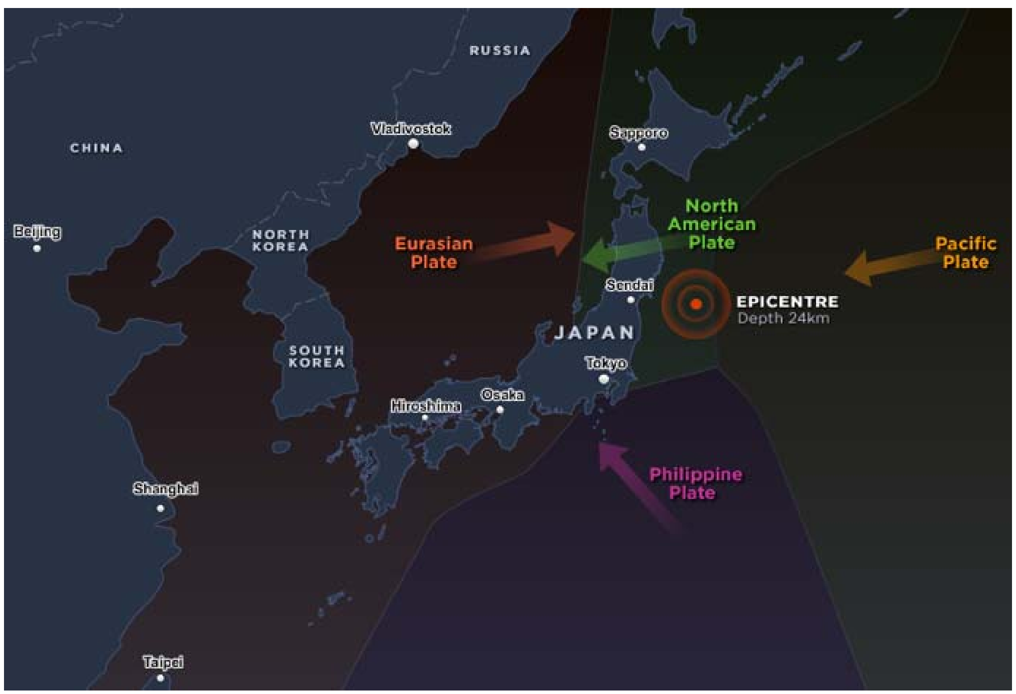


Probability of greater than or less than 0, 5, 10, 20, and 30 seconds warning for San Francisco for all identified WG02 earthquake scenarios

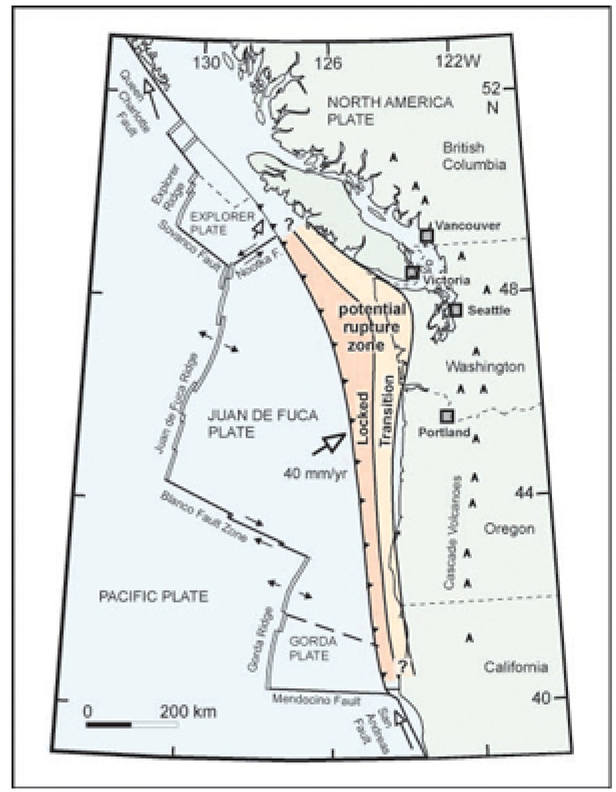
http://www.elarms.org/

Earthquake Early Warning

- At Western, we are studying what would be required to improve our early warning capability in Canada.
- Initial studies have focused on both Canadian and Japanese data.
- The tsunami-generating earthquake in Sendai, Japan last year provided a wealth of data for a large subduction zone event.
- Our studies show, for the first time, that the use of borehole data, instead of surface stations, significantly improves the first estimate of event magnitude.



cegrp.cga.harvard.edu/japan



www.nrcan.gc.ca

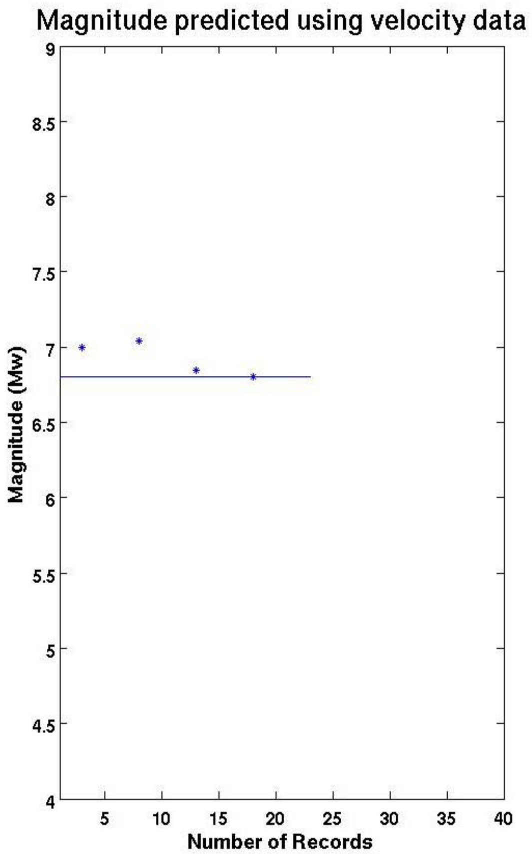
Earthquake Early Warning

- Earthquake early warning relies on developing an empirical relationship between known quantities, such as peak ground acceleration (PGA), or peak ground velocity (PGV) and earthquake magnitude.
- Previously, these relationships are developed for surface seismometers. Borehole seismometers generally less noisy, and early results are promising.

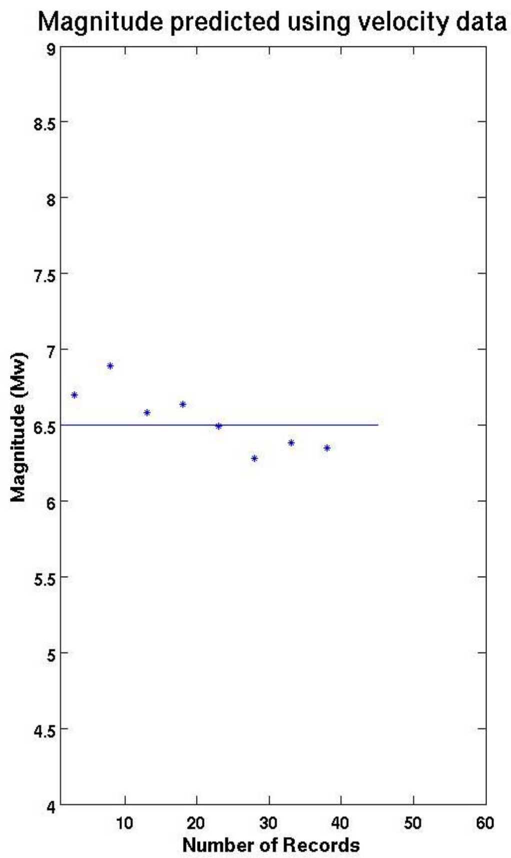
	KIK_NET (surface)	K_NET (surface)	Borehole
No. of Records	554	1117	316
Standard Deviation, PGA	0.3864	0.397	0.3067
Standard Deviation, PGV	0.2475	0.287	0.1925

Earthquake Early Warning

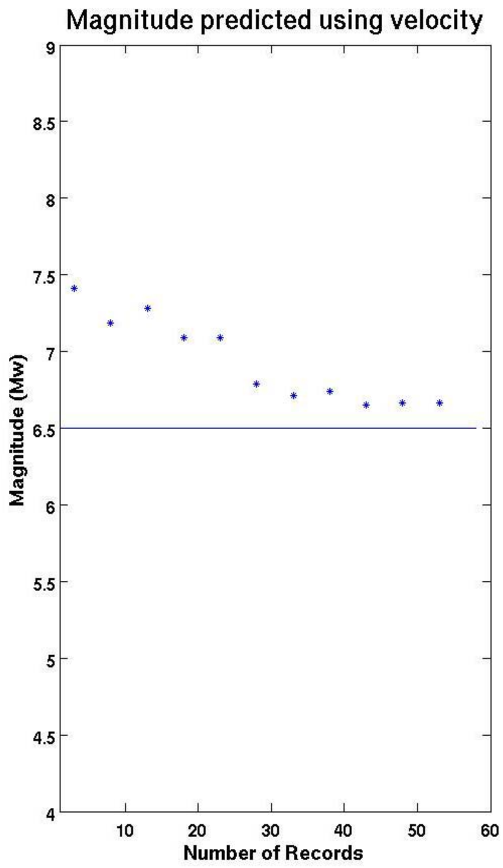
Magnitude = 6.5



Borehole Data



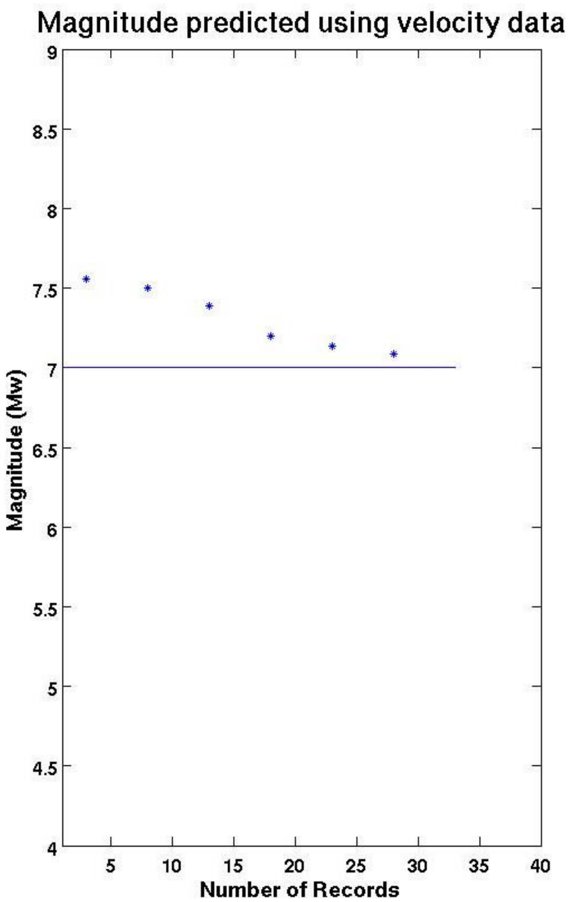
KIK_NET Data



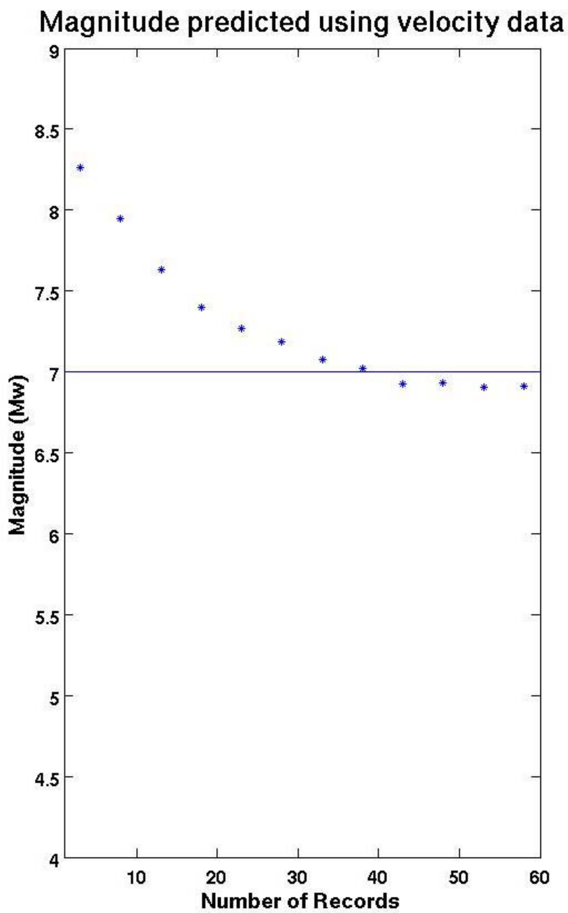
K-NET Data

Earthquake Early Warning

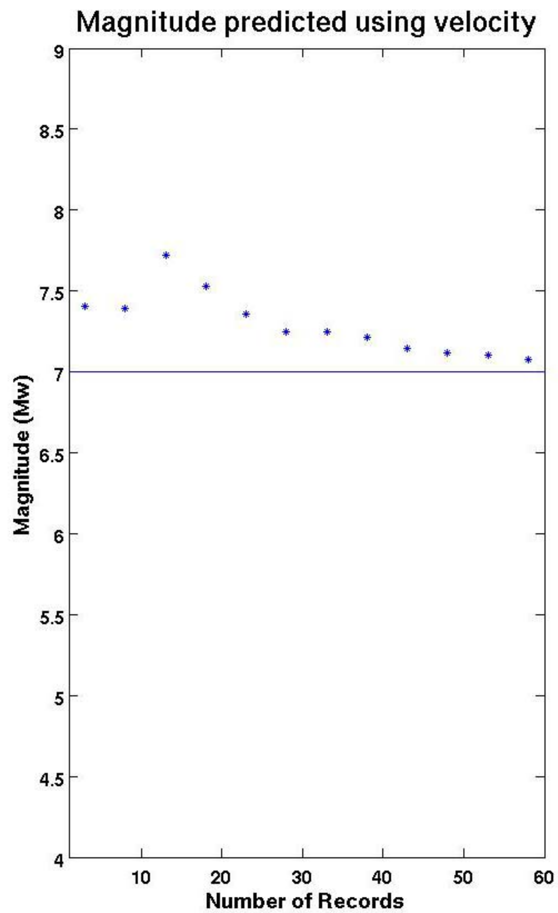
Magnitude = 7



Borehole Data



KIK_NET Data



K-NET Data

Conclusions

- The exponential increase in the collection of seismic data at all sizes over the past thirty years has led directly to an increase in our ability to provide time-dependent earthquake hazard estimates.
- This data, both on short- and intermediate-scales, provides the ability to estimate earthquake hazard at improved accuracies, including time-dependent earthquake forecasts.
- Computational advances and (near) real-time estimates of both hazard and the losses will provide critical information to both emergency hazard providers and industry after large events.
- Operational earthquake forecasting, over days and months, will soon be considered the function of a responsible government.
- Advances in earthquake early warning will have an important impact on the reduction of both seismic and tsunami hazard in Canada.