CSRN
RCRP
Canadian Seismic Research Network
Réseau canadien pour la recherche parasismique

Funded by NSERC / *Subventionné par le CRSNG*

Institute for Catastrophic Loss Reduction

Western Science

Linking strain and seismicity for earthquake hazard estimation

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ICLR Workshop
Friday, November 16, 2012

Outline

- Earthquake seismicity
- Earthquake forecasting
- Earthquakes and deformation in eastern Canada

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

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.

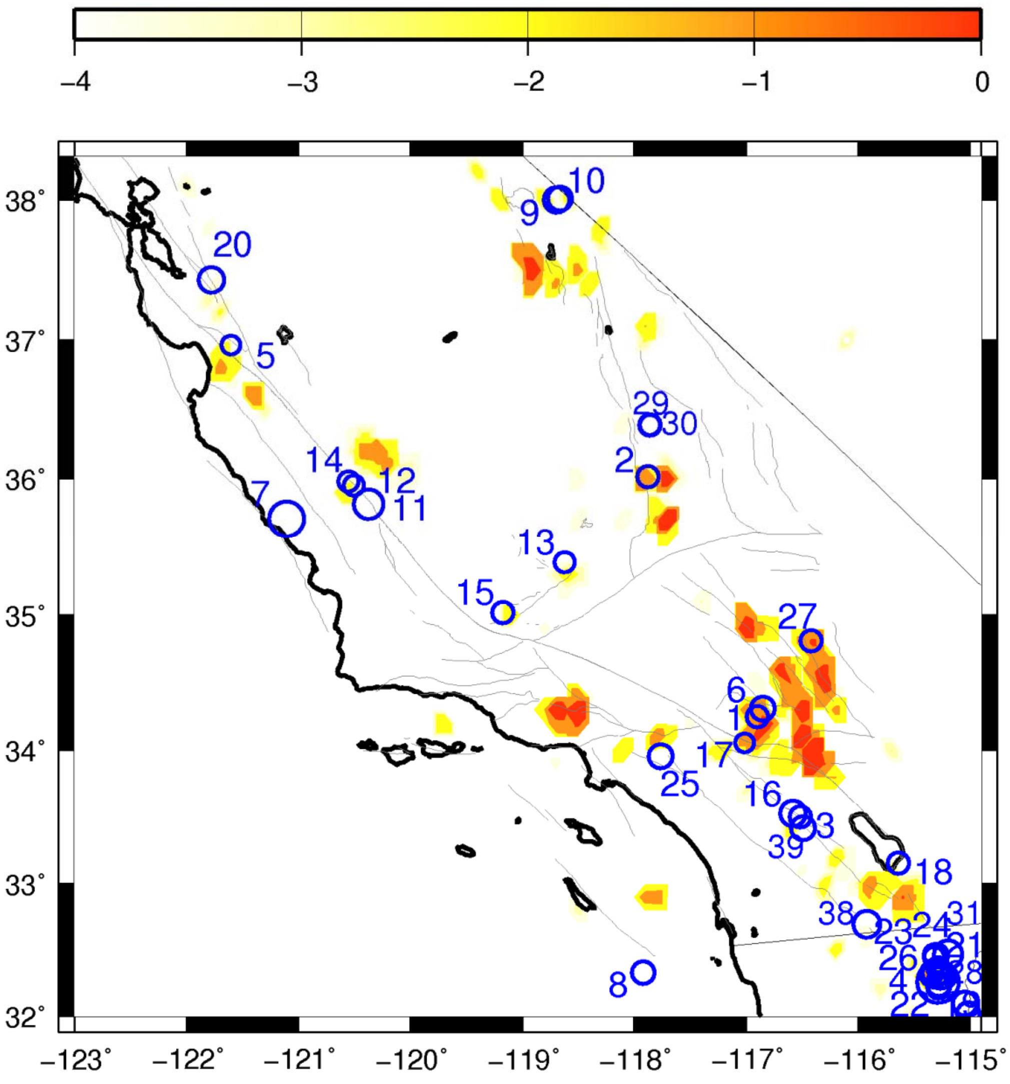
Seismicity Data

- 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.

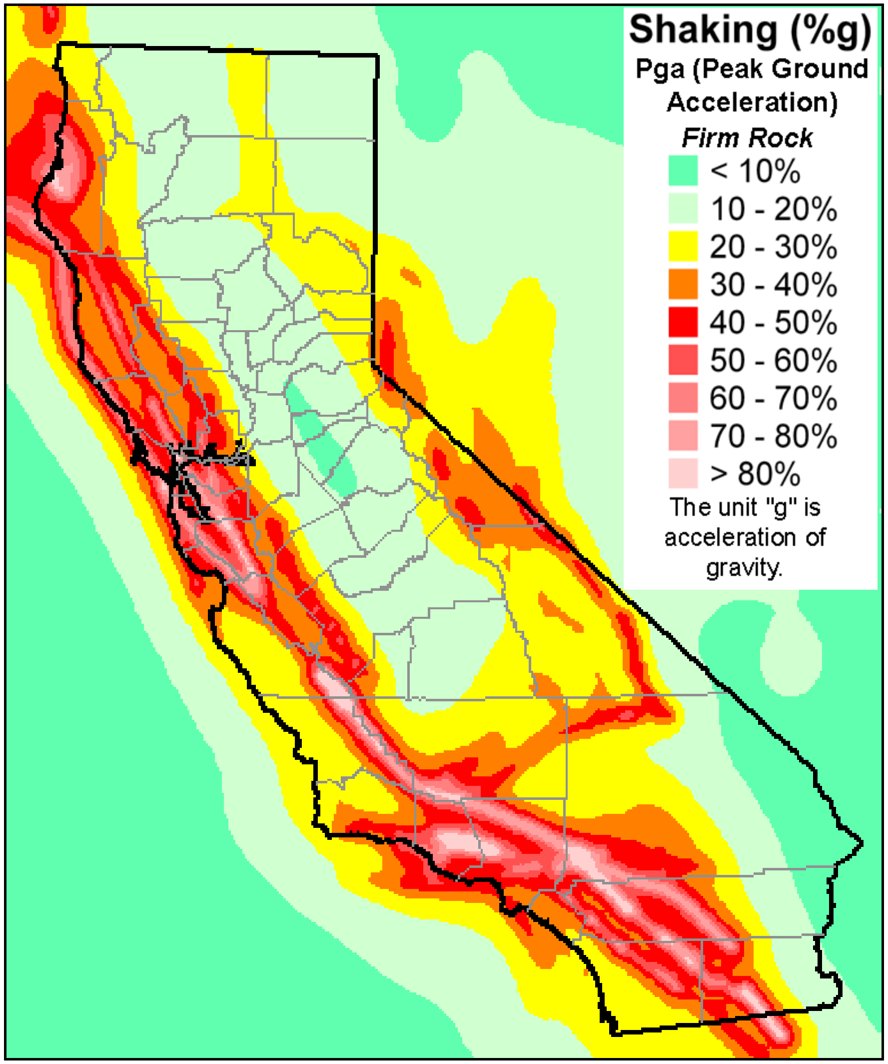
- Today, we record 500,000 earthquake per year, worldwide, and 10,000 in southern California alone.
- Only 100 earthquakes per year cause damage in some part of the world – *the bulk of this data are small events.*

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

Forecast vs. Hazard



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

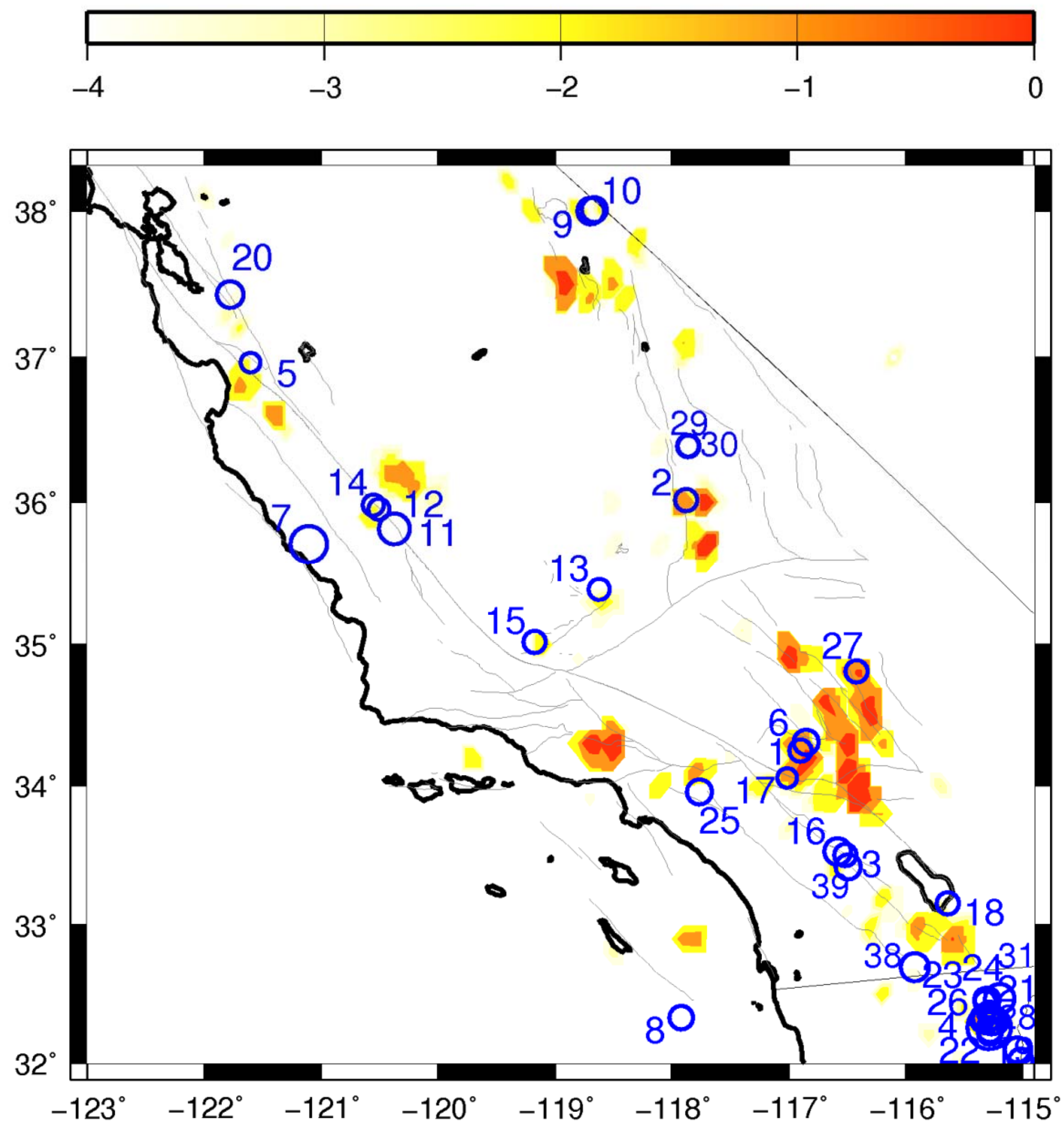


10% Probability of Exceedance in 50 years.
http://www.consrv.ca.gov/CGS/rghm/psha/index.htm

A Prospective Forecast Experiment

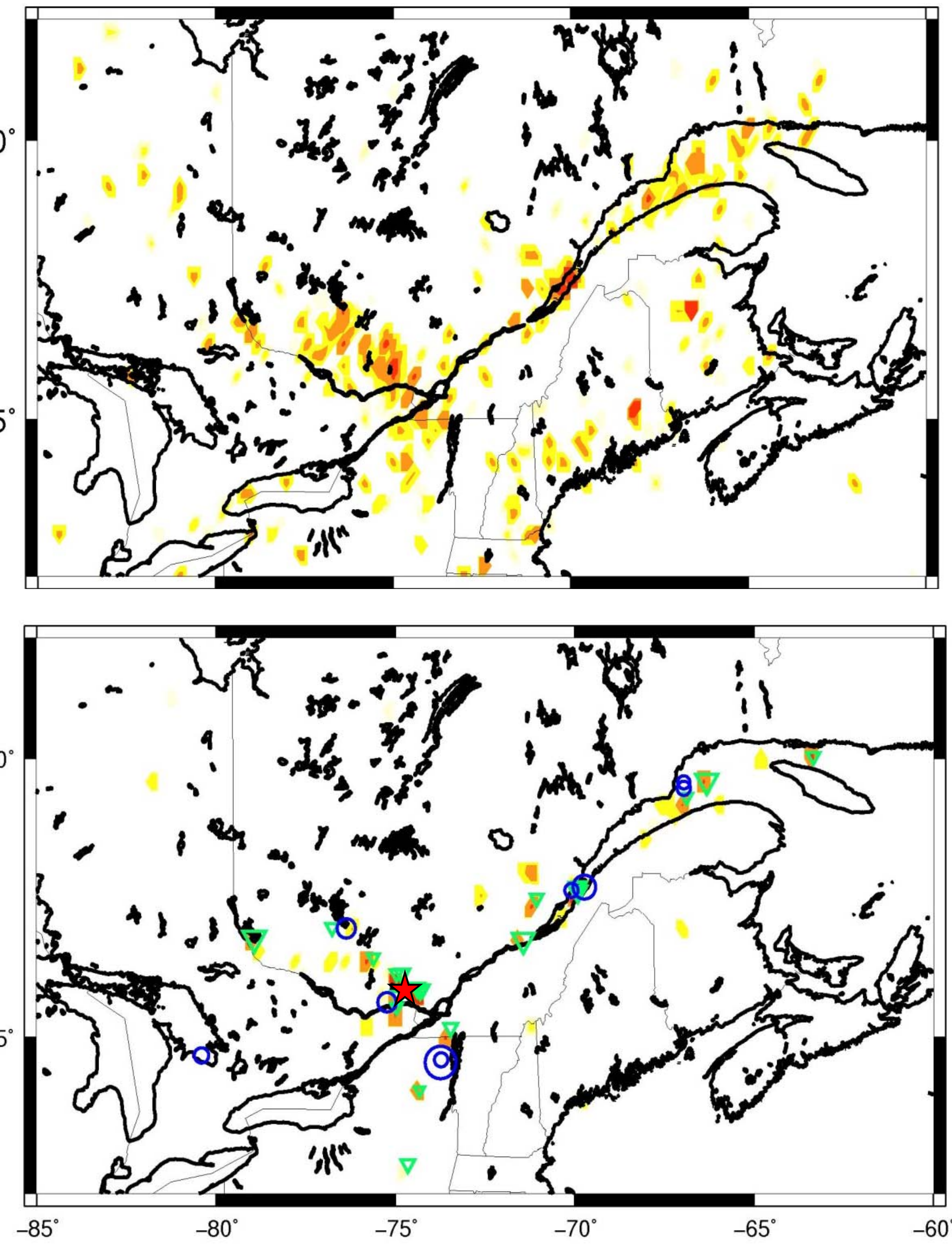
PNAS, 2002

- Here small earthquakes act 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.



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.
- The red star is the location of the 2010 Ottawa earthquake.

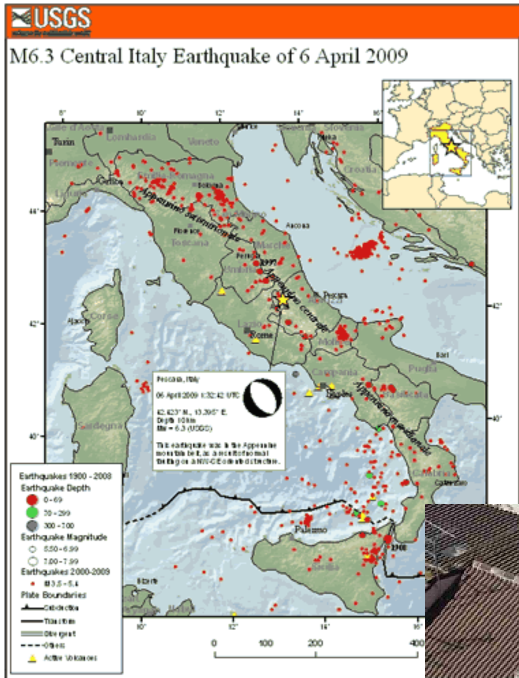


Today

- 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 – **again, based on the idea seismicity is a measure of stress.**

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.
- ***Last month, the seven were convicted and sentenced to time in prison.***

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

What happened?

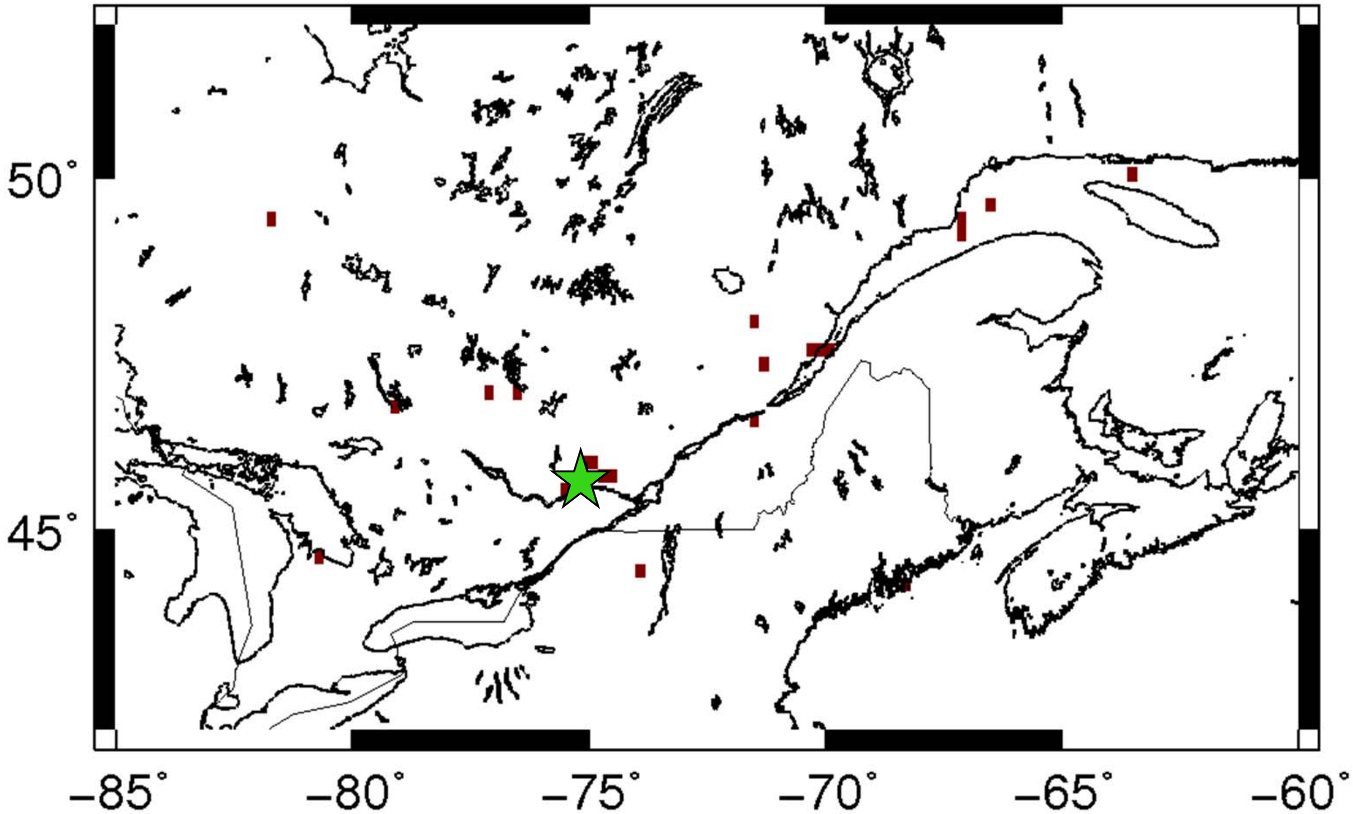
- While foreshocks are one of those patterns that have long been recognized and studied as potential earthquake precursors, less than 10 percent of earthquakes worldwide are followed by something larger within 10 kilometers and three days. *Less than half of the large earthquakes studied to date have 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 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.
- ***These operational forecasts will probably be short-term forecasts (days to weeks) and low probability gains (on the order of 1%).***

Operational Earthquake Forecasting

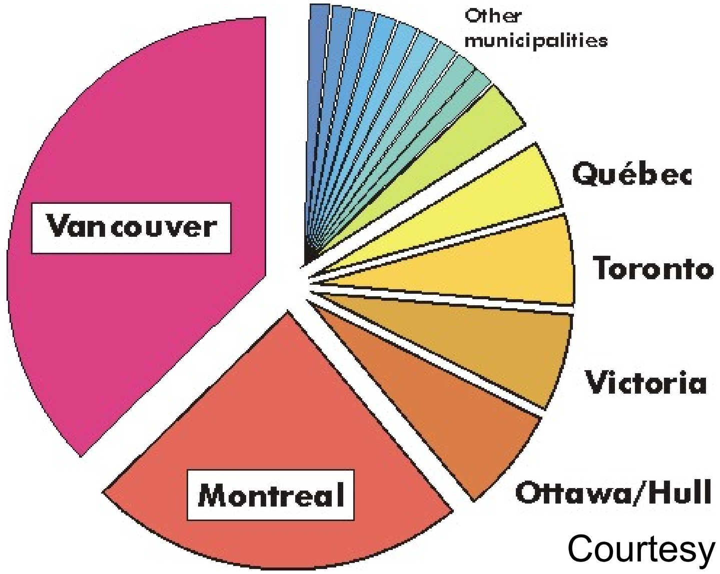
- Using seismicity-based methods, new models are being developed to improve seismic hazard maps.
- These new models are showing success in revising the probabilities of future earthquakes.
- The end result is hazard level warnings by time, location and region.



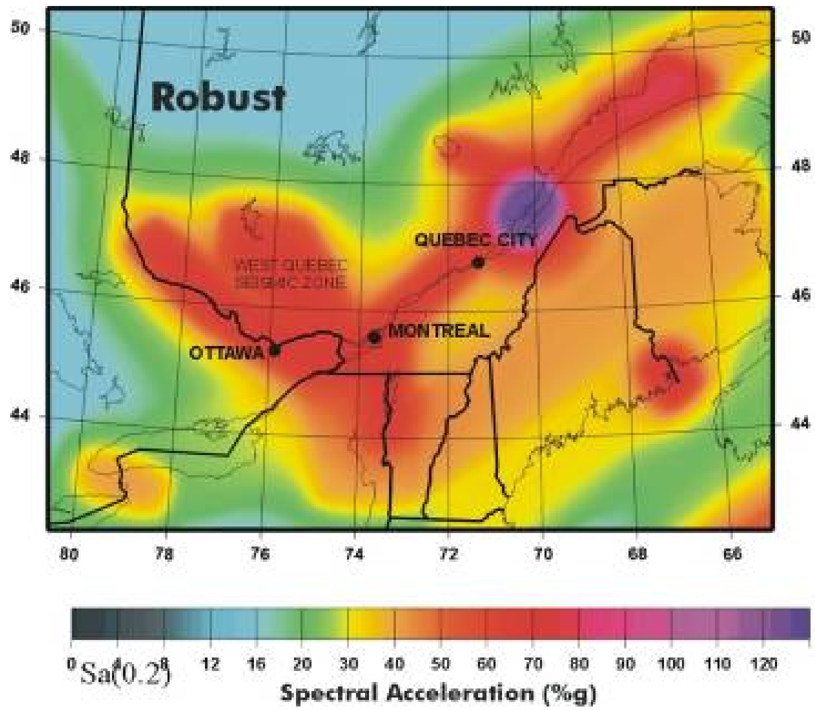
Five year seismicity-based forecast, Eastern Canada

Quantifying and mitigating loss in Canada

The chart on the right shows the cities that contribute to seismic risk in Canada.



Courtesy GSC

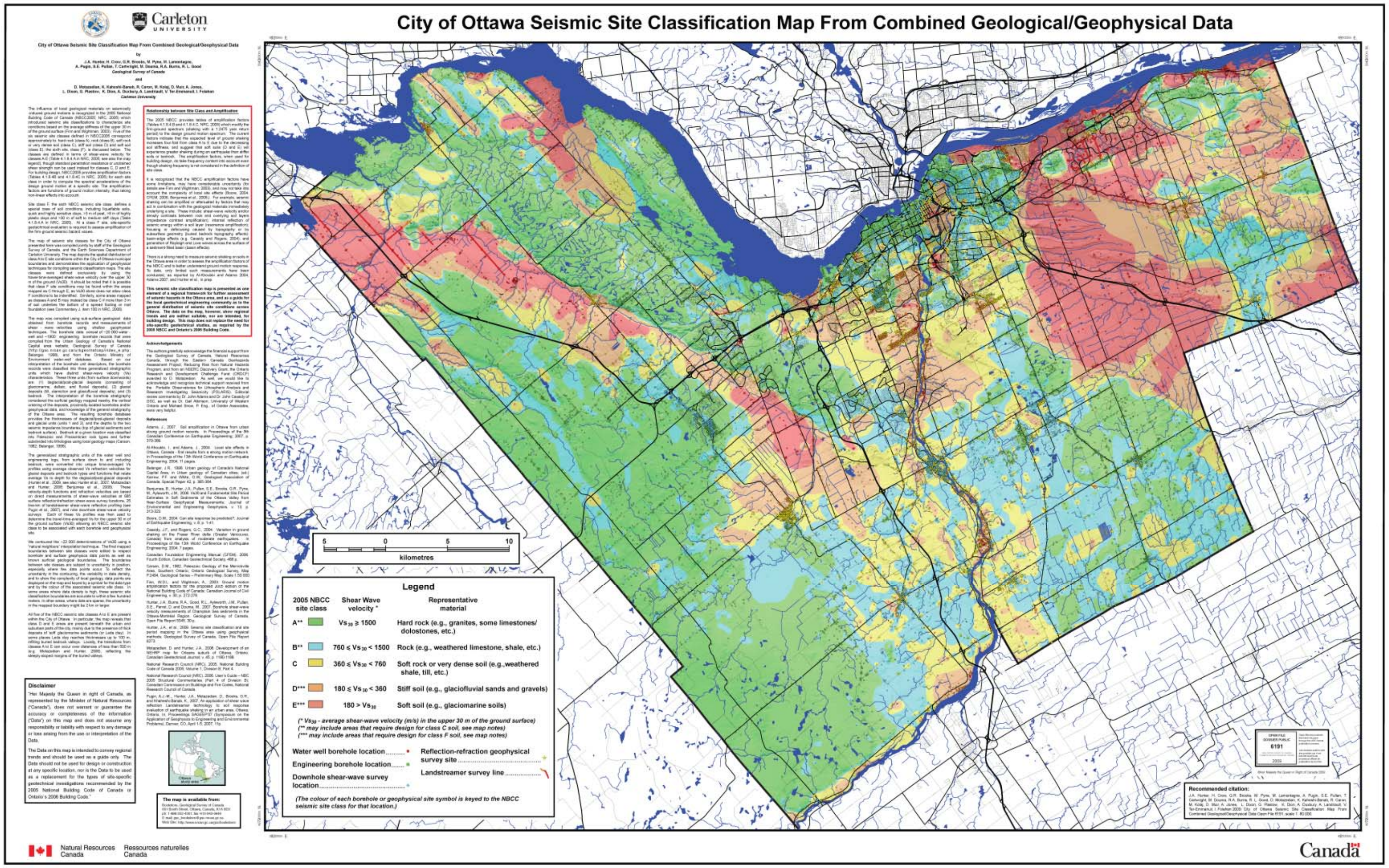


Adams and Halchuk, 2003

The map on the left shows seismic data from 2005 for Eastern Canada.

The most recent seismic maps for all of Canada date back to the early 1990's. Current research is being done to update these maps.

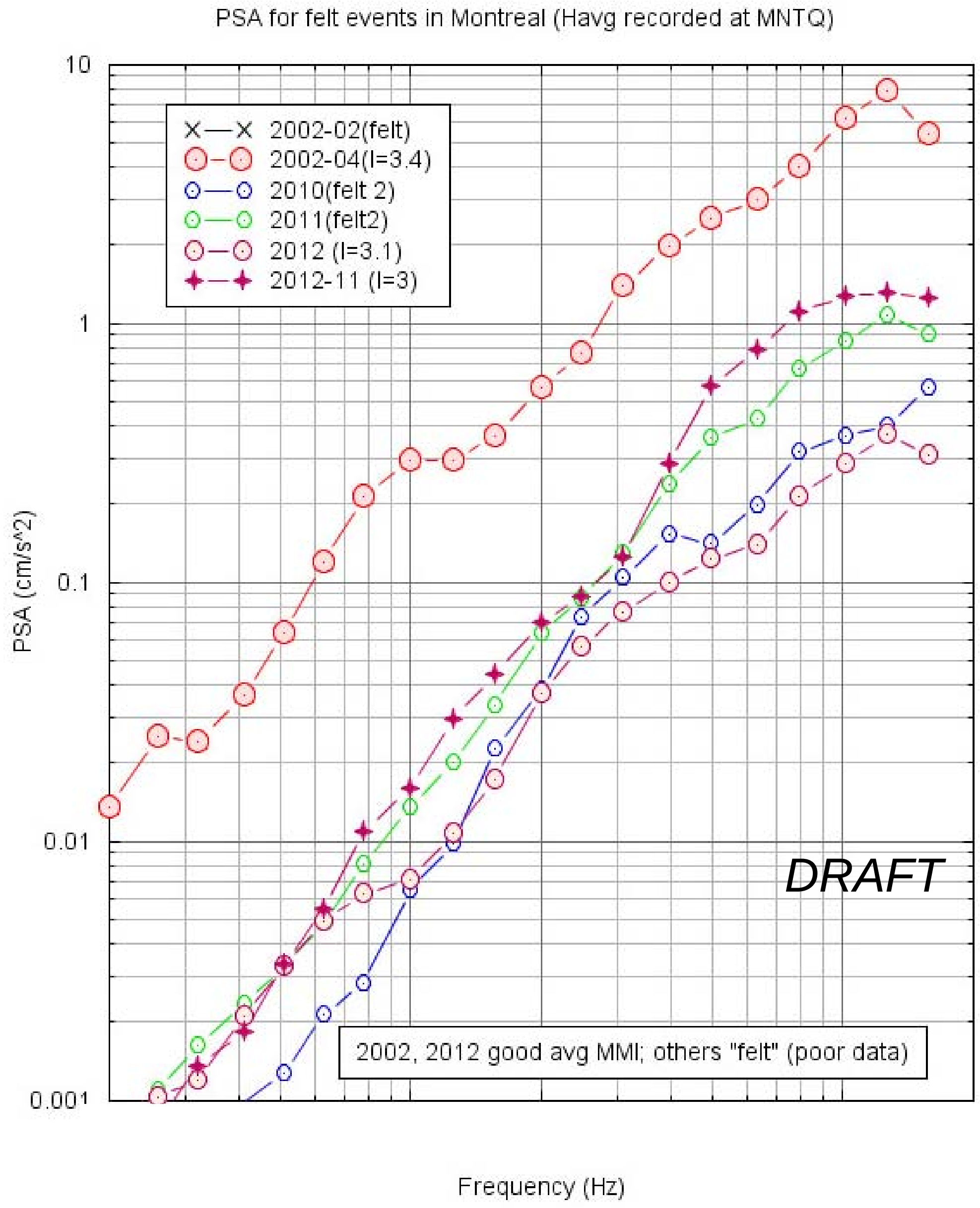
Microzonation issues in eastern Canada (CSRN)



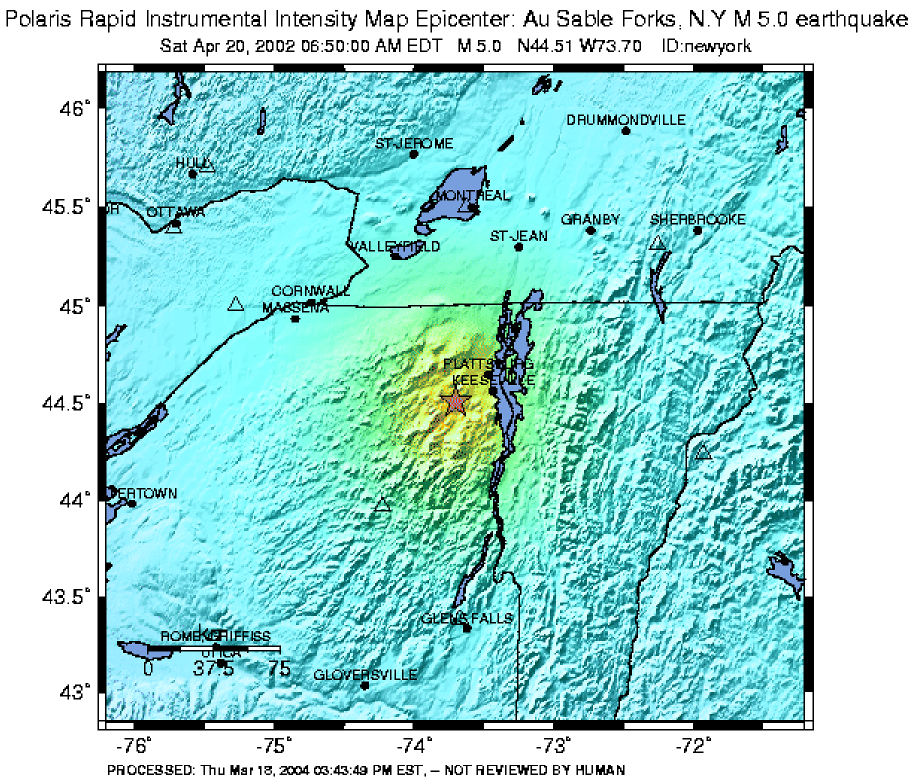
VS30 studies of ground conditions in Ottawa (Motazedian 2010)

Spectral Acceleration, Montreal

- From these microzonation maps, generate estimates of potential ground shaking



Synthetic and Real-Time ShakeMaps (CSRN)

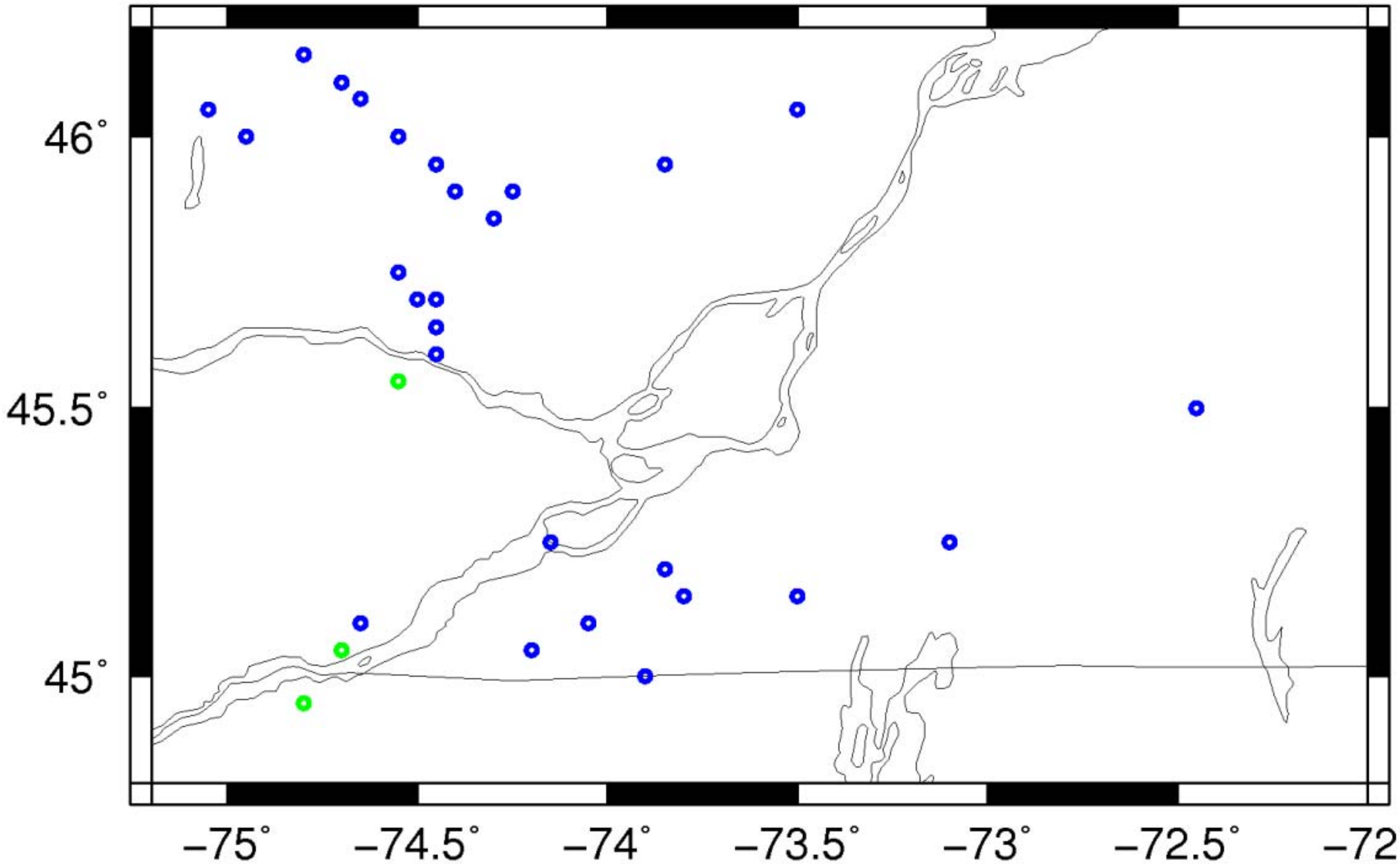


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16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

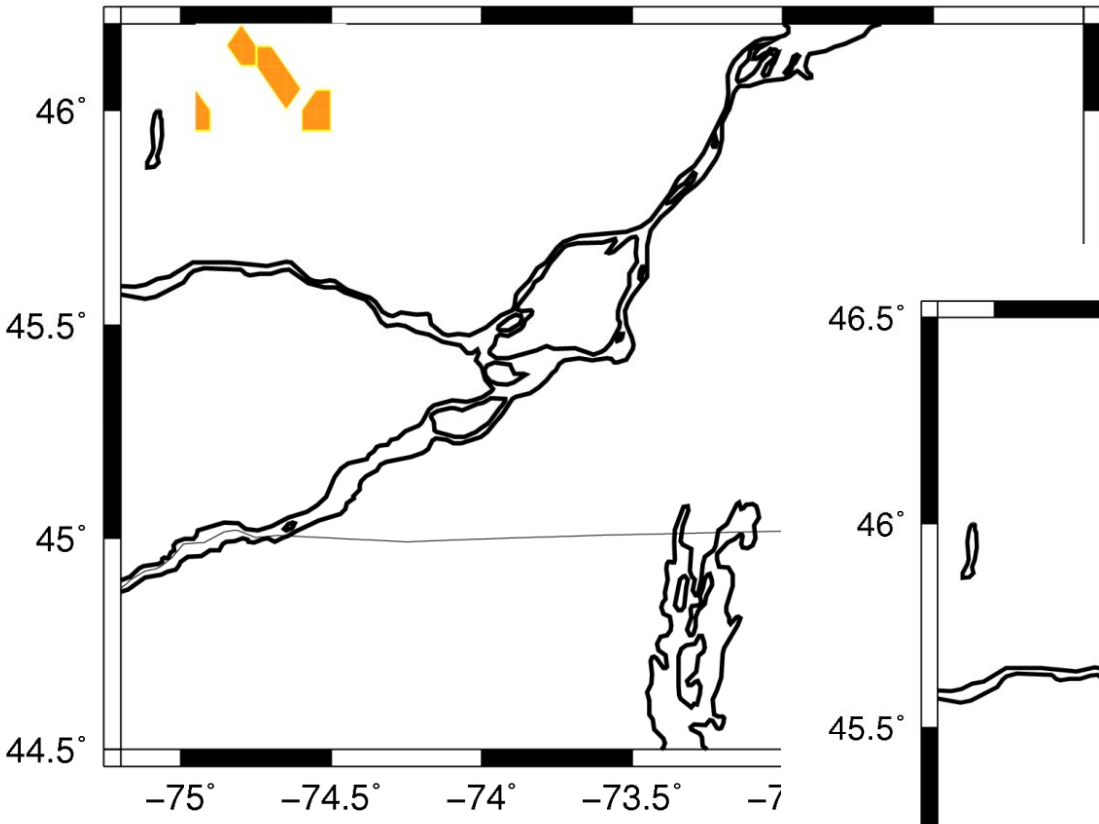
*Preliminary ShakeMap for 2002 **M**5.0 Au Sable Forks earthquake (www.shakemap.carleton.ca).*

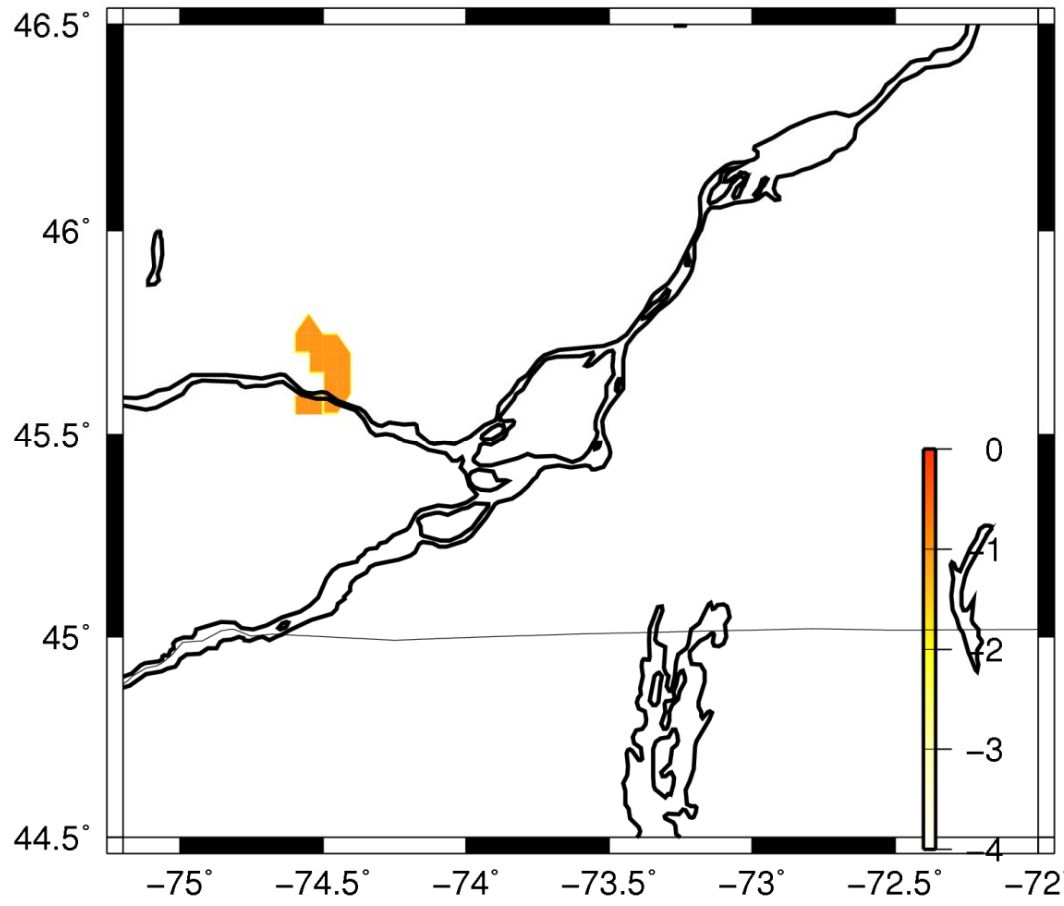
- Development of actual and theoretical ShakeMaps for urban areas of Canada (incorporating microzonation) to provide rapid earthquake information
- Scenario ShakeMaps to assist in emergency planning

Locations of potential earthquake locations near Montreal

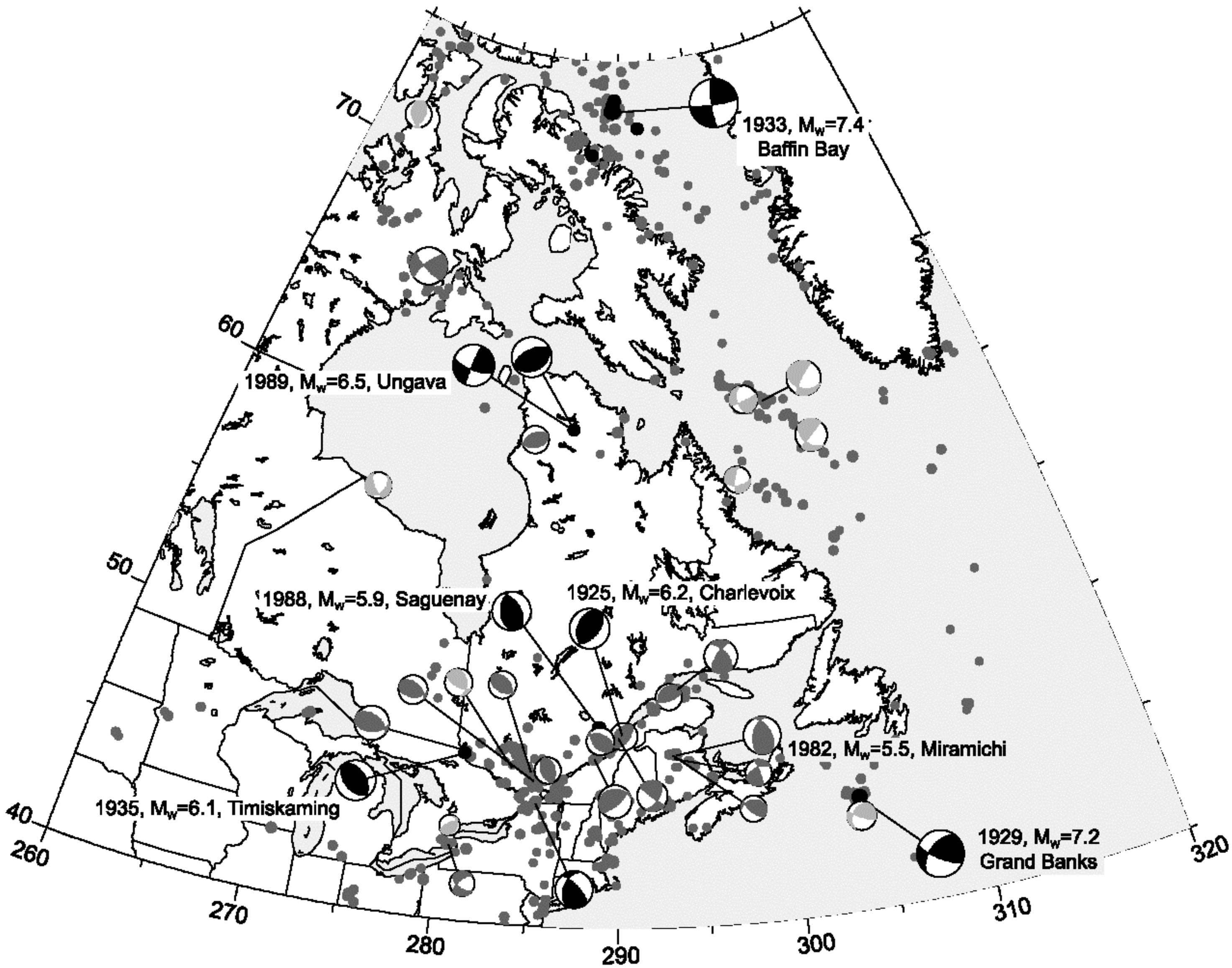


Convert these to likely rupture scenarios



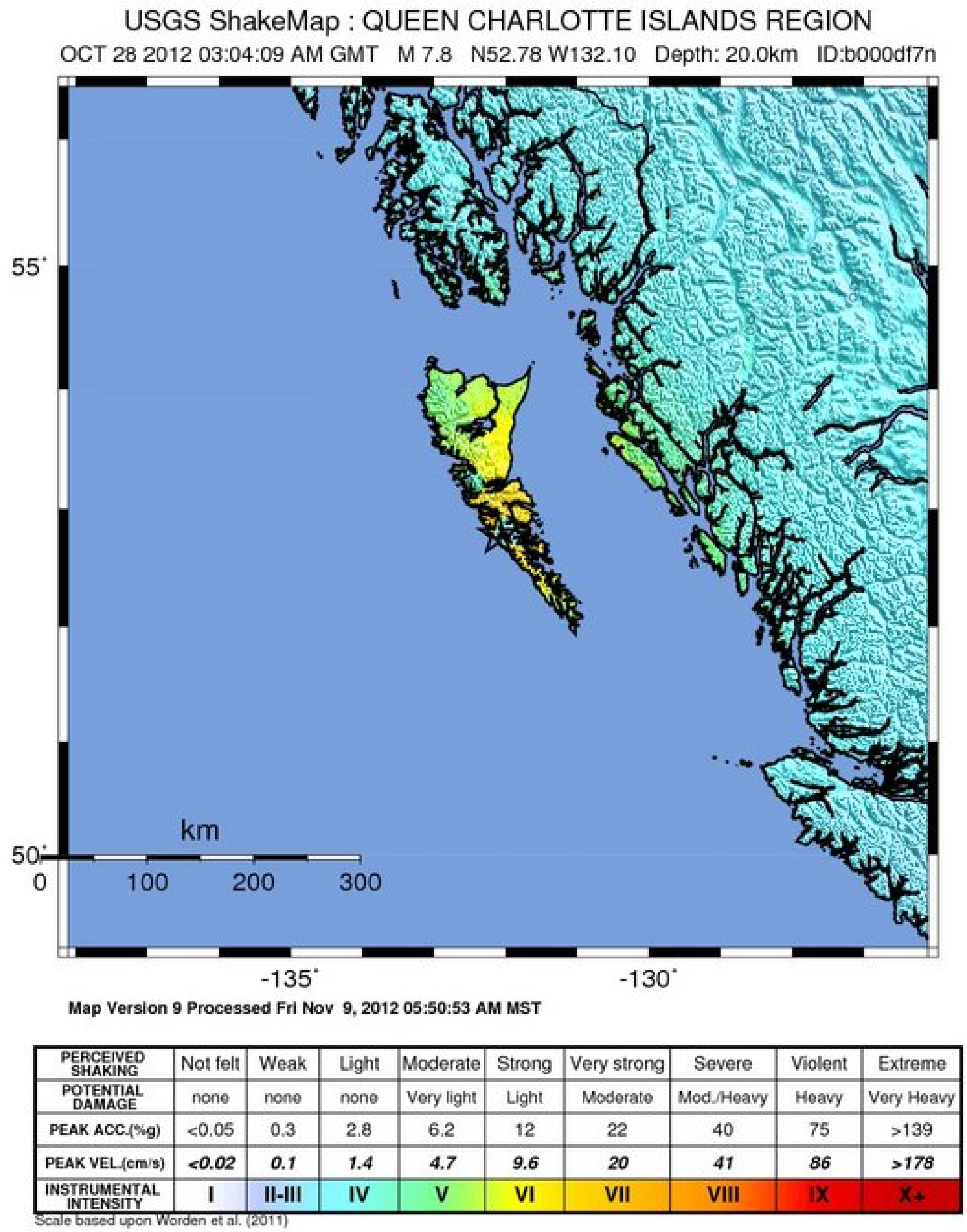


Historic events, Eastern Canada



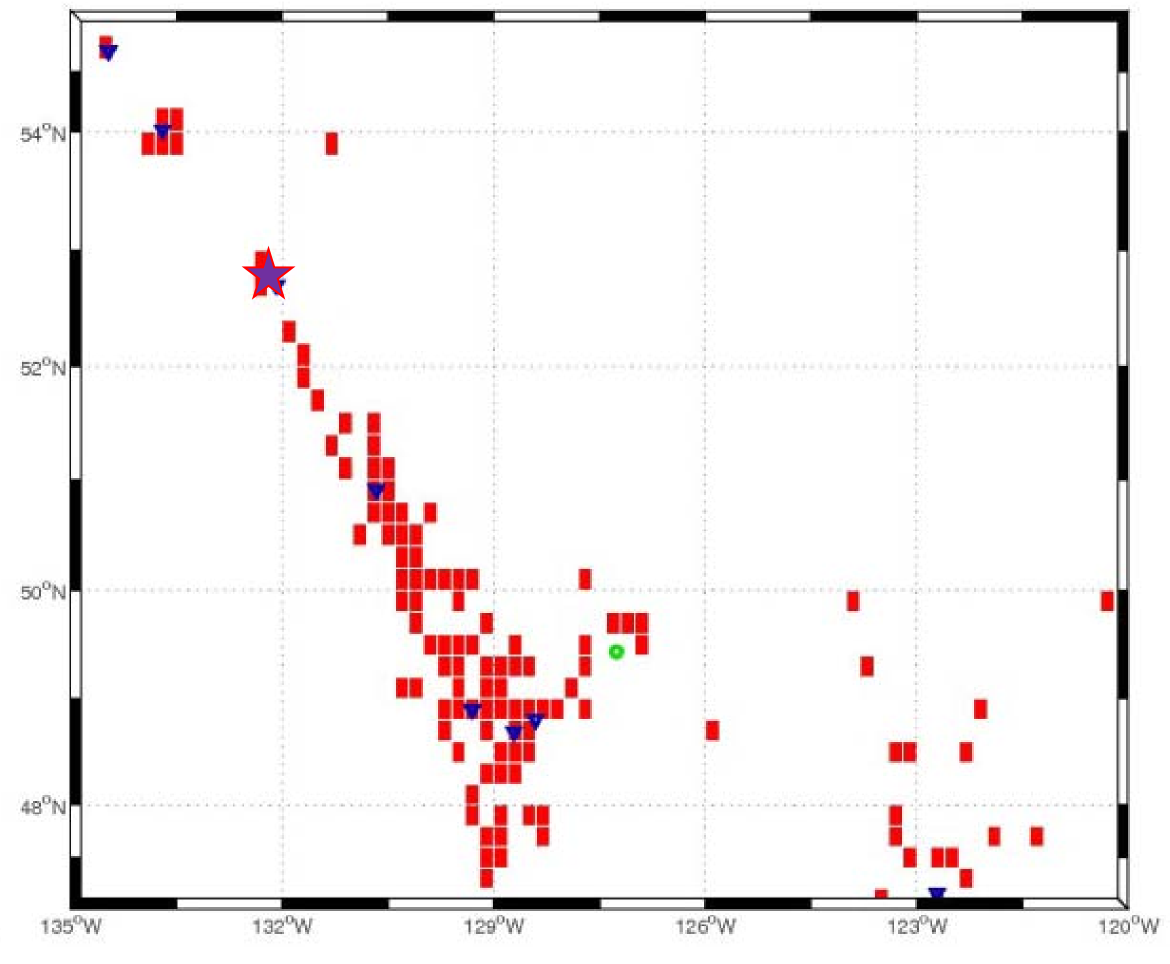
Mazzotti et al., 2005a

Queen Charlotte Island, Oct. 28, 2012 M ~ 7.7

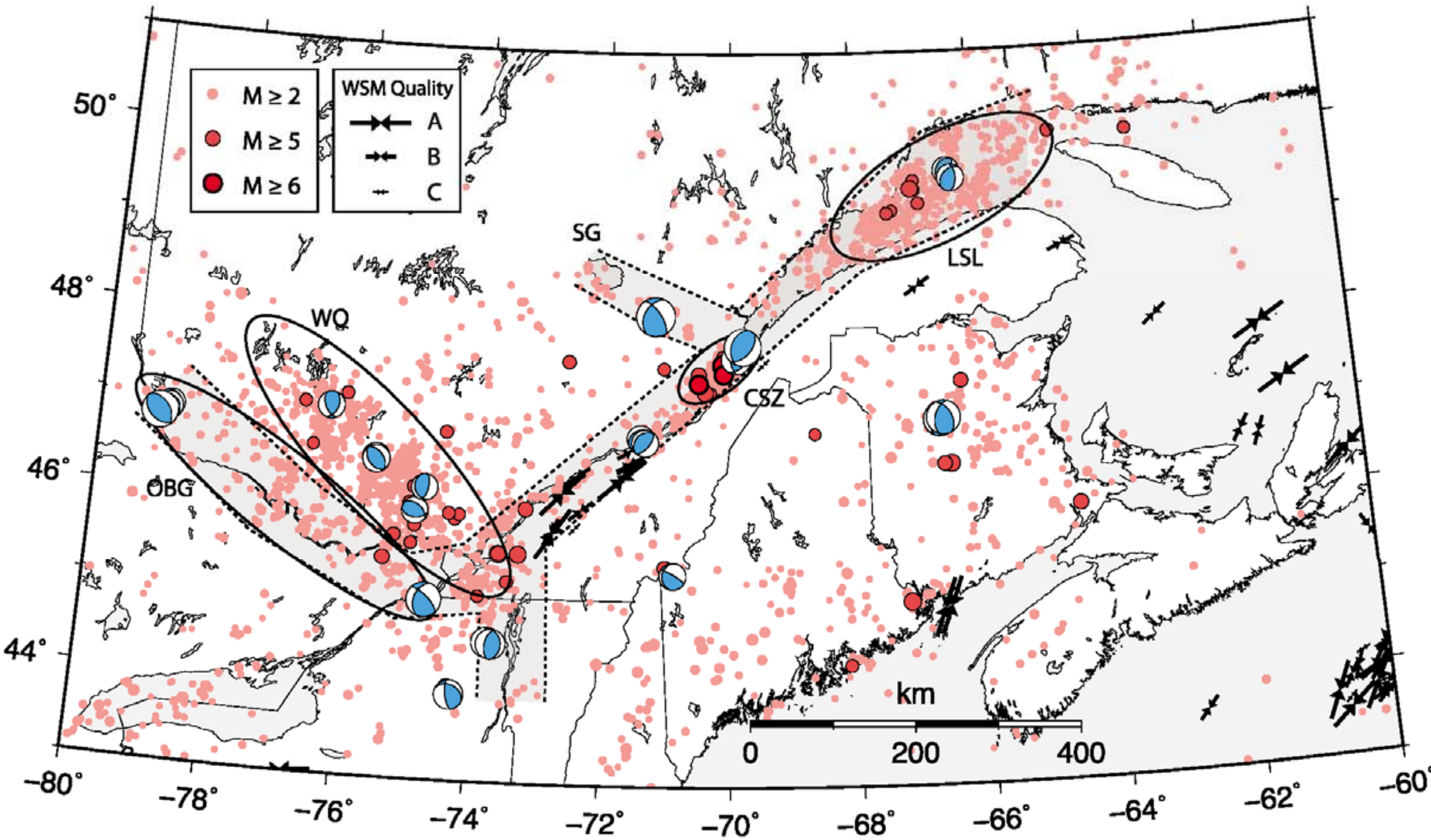


Queen Charlotte Island, Oct. 28, 2012
M ~ 7.7

PI Forecast, 2004

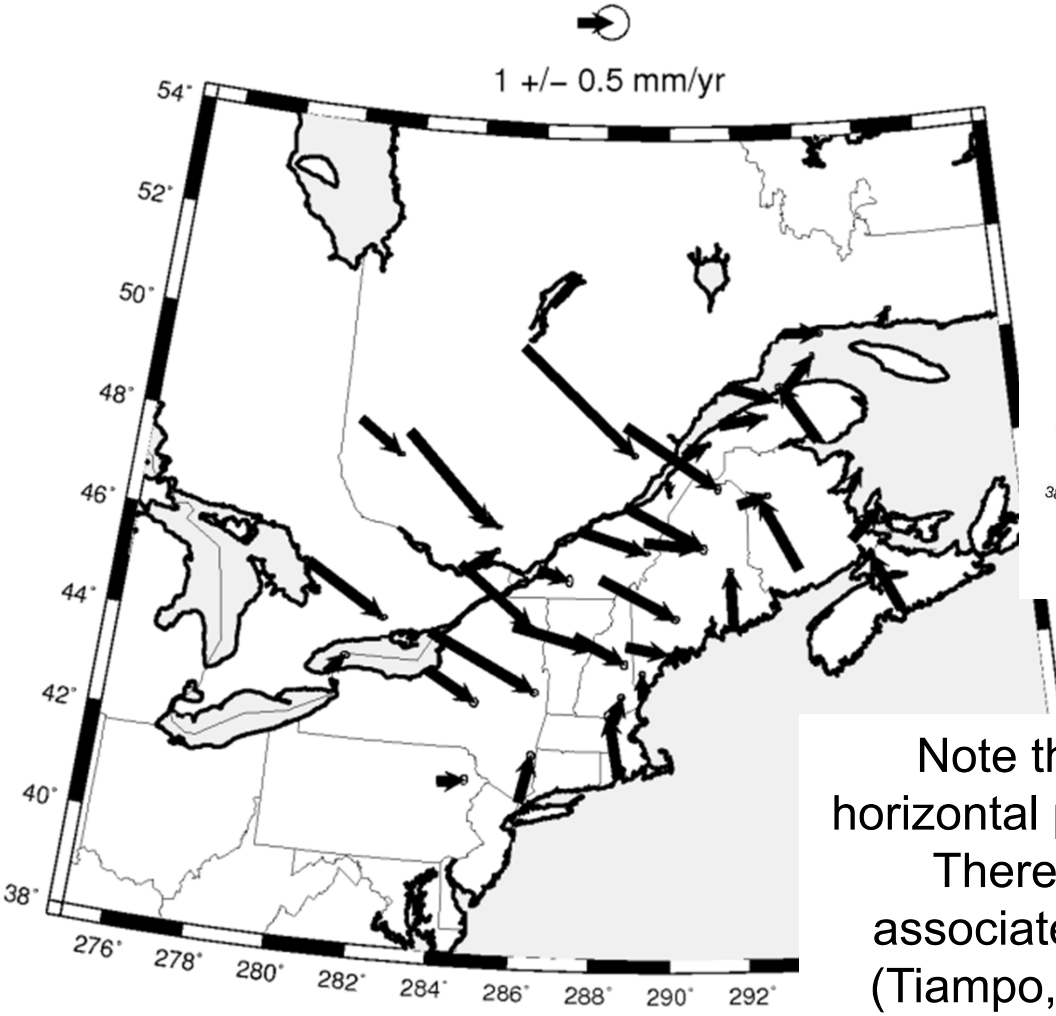


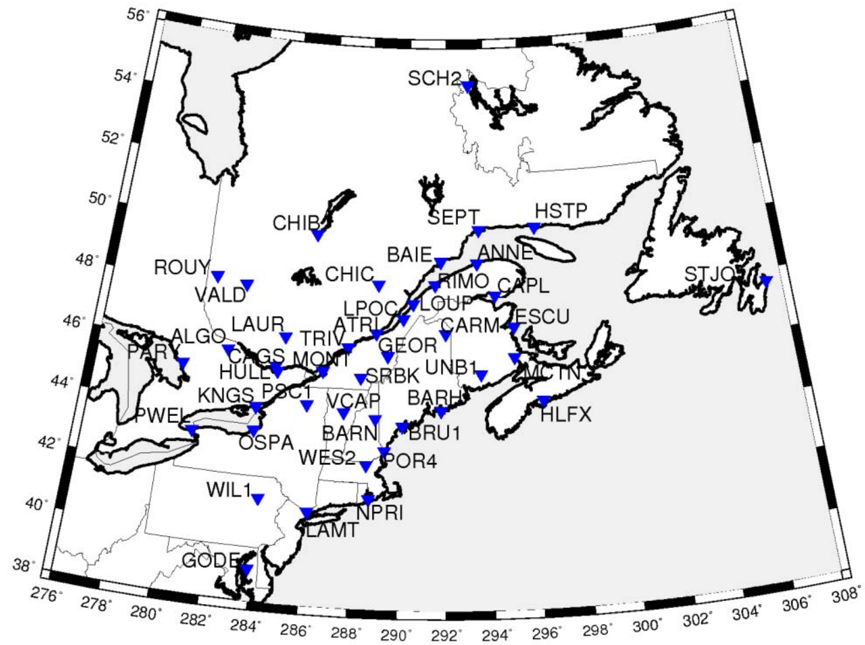
Eastern Canadian seismicity



Composite catalog; M ≥ 2 (1985), selected
focal mechanisms, M ≥ 4.3 (Baird et al., 2010)

GPS velocities, Eastern Canada

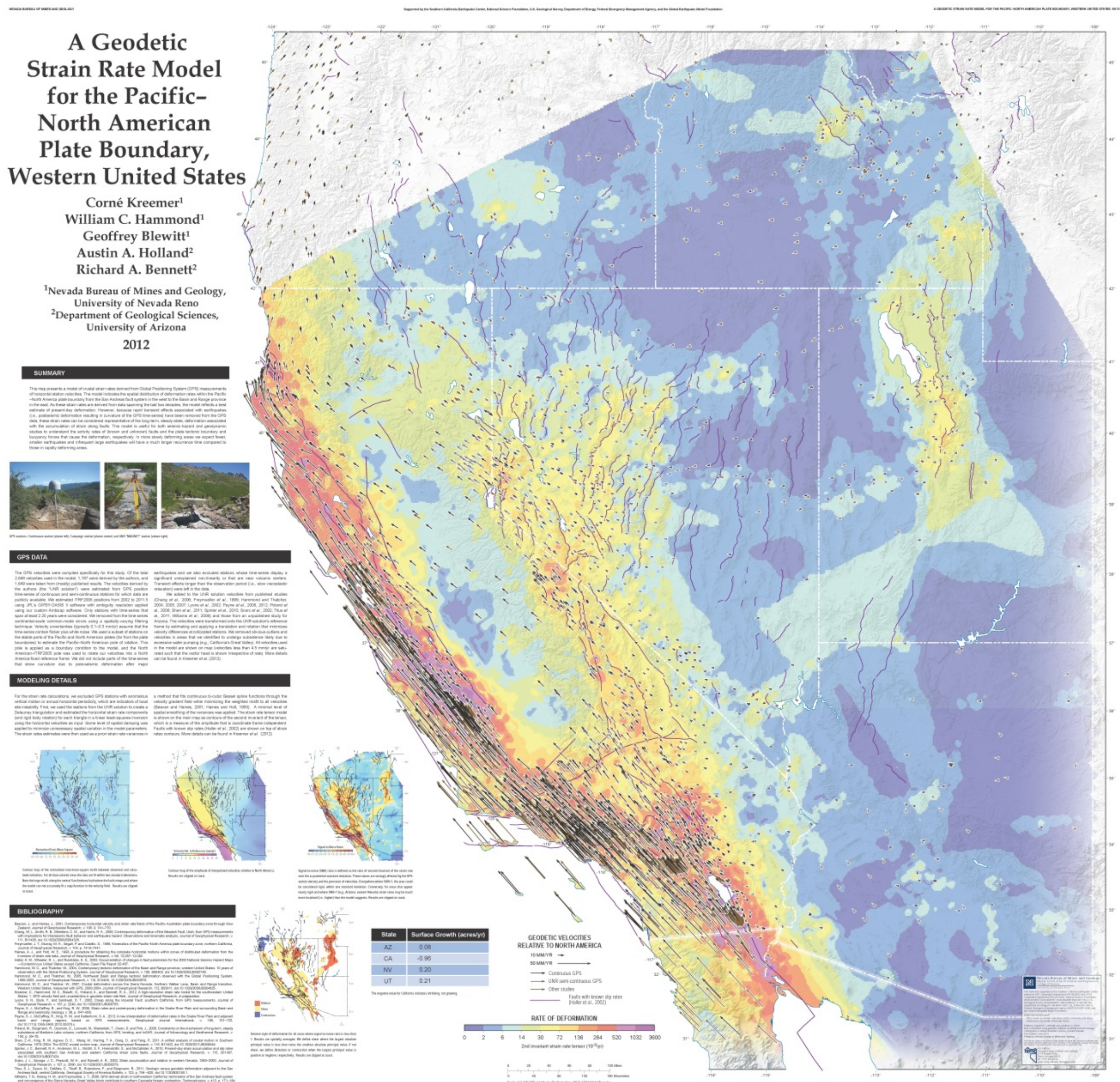




Note that this is predominantly horizontal post-glacial rebound (PGR). There is no detectable signal associated with regional seismicity (Tiampo, Mazzotti & James, 2011).

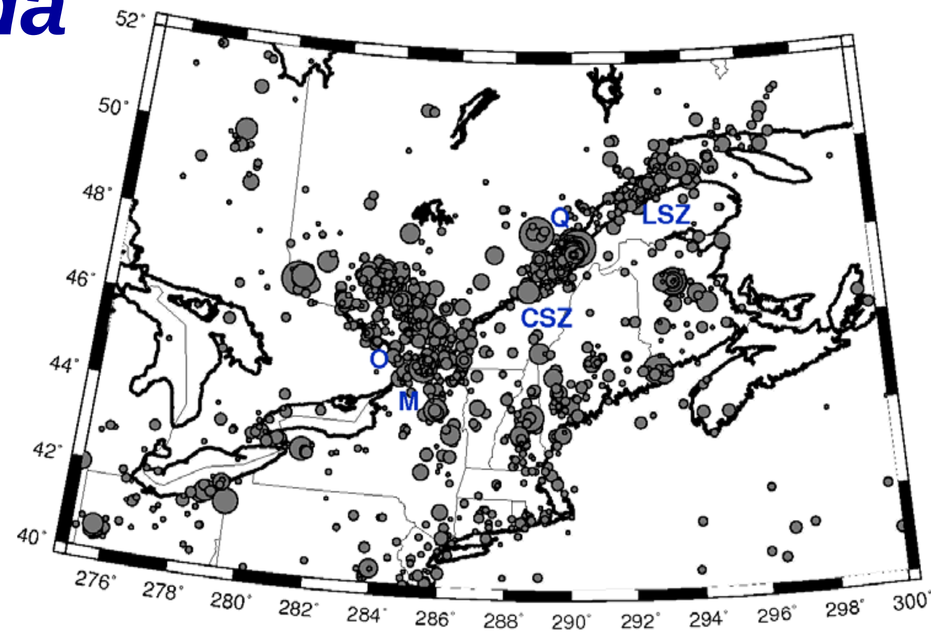
Horizontal velocities, 2000-2006.

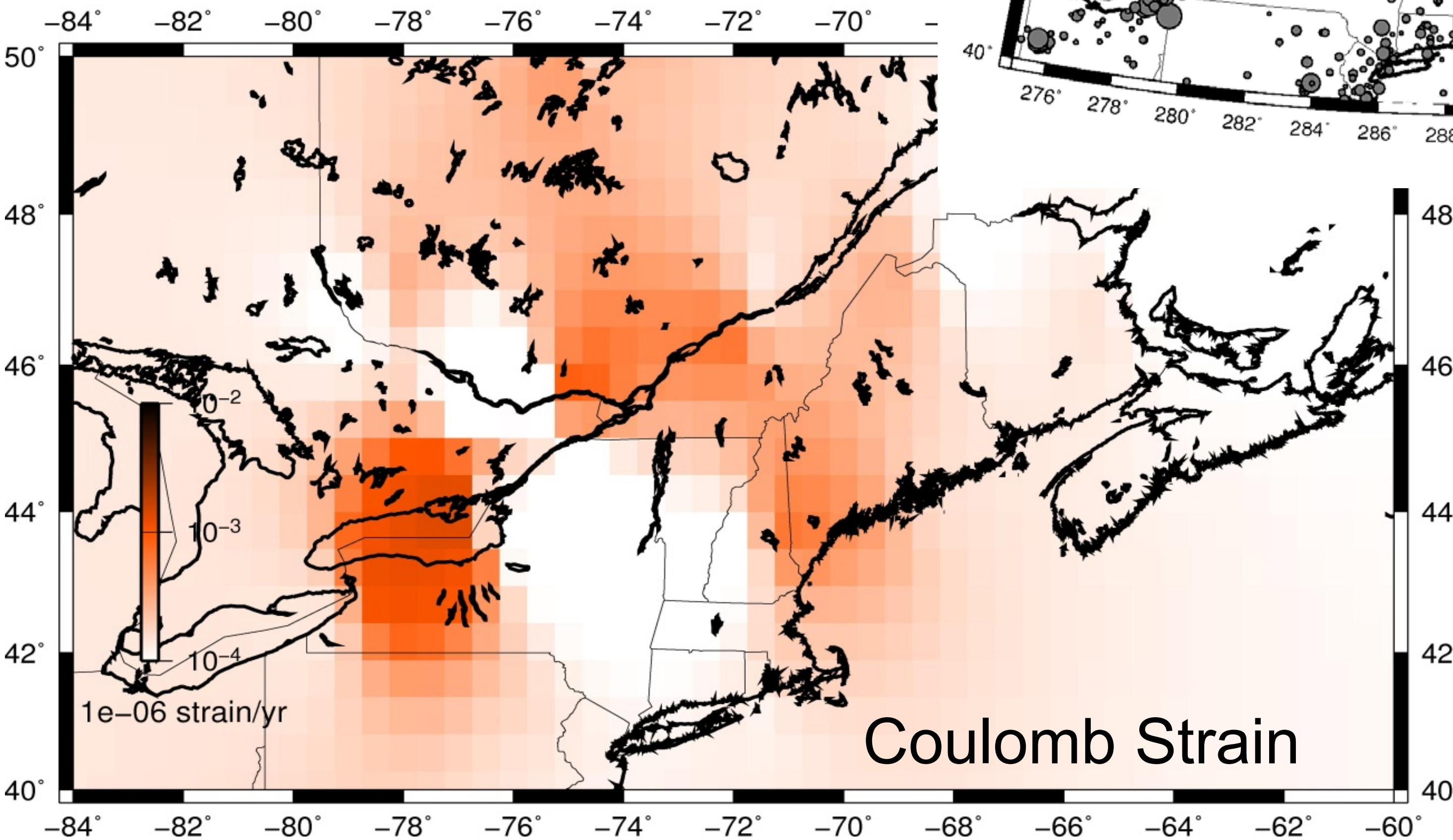
GPS velocities and strain maps



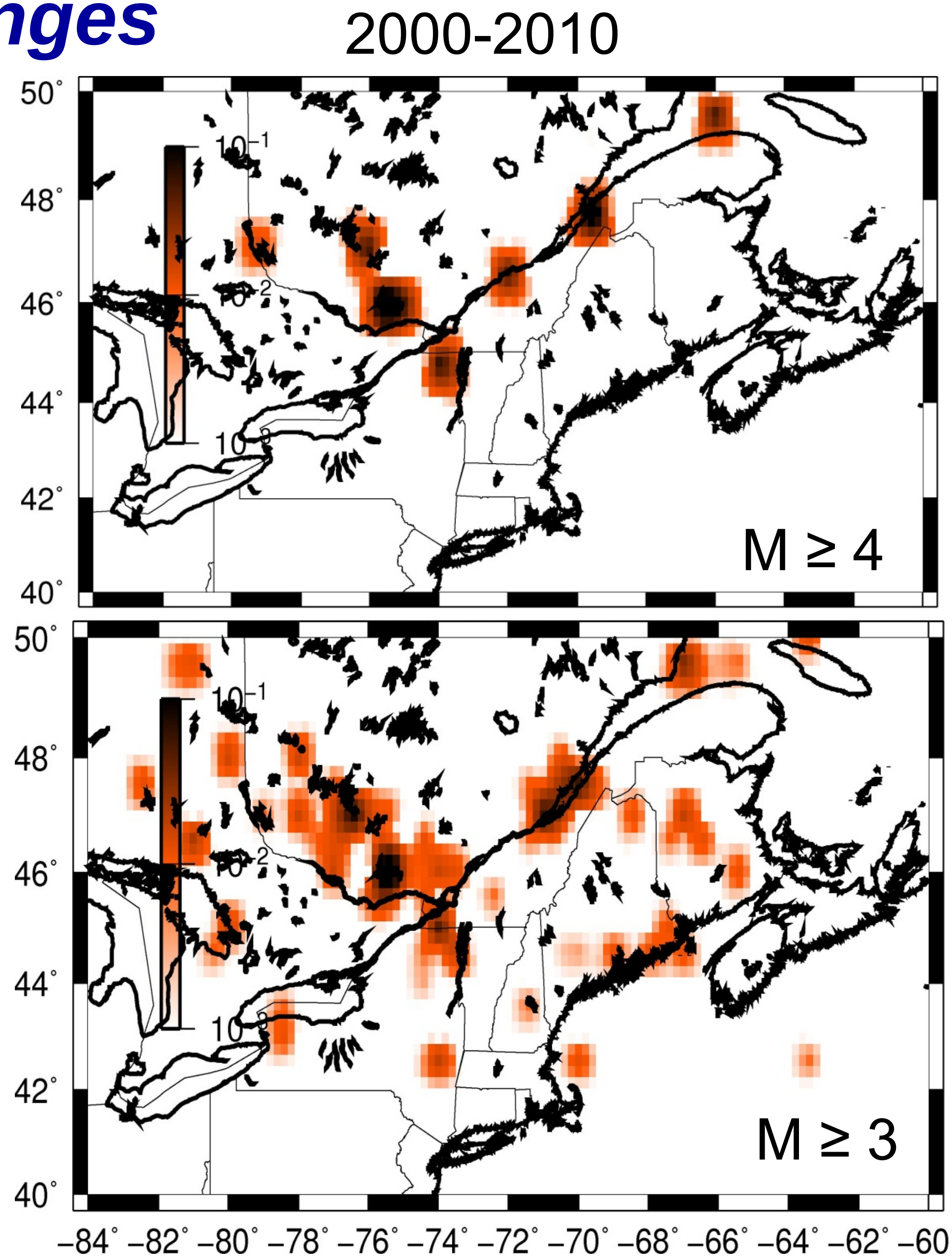
Kreemer et al. 2012

Strain in eastern Canada

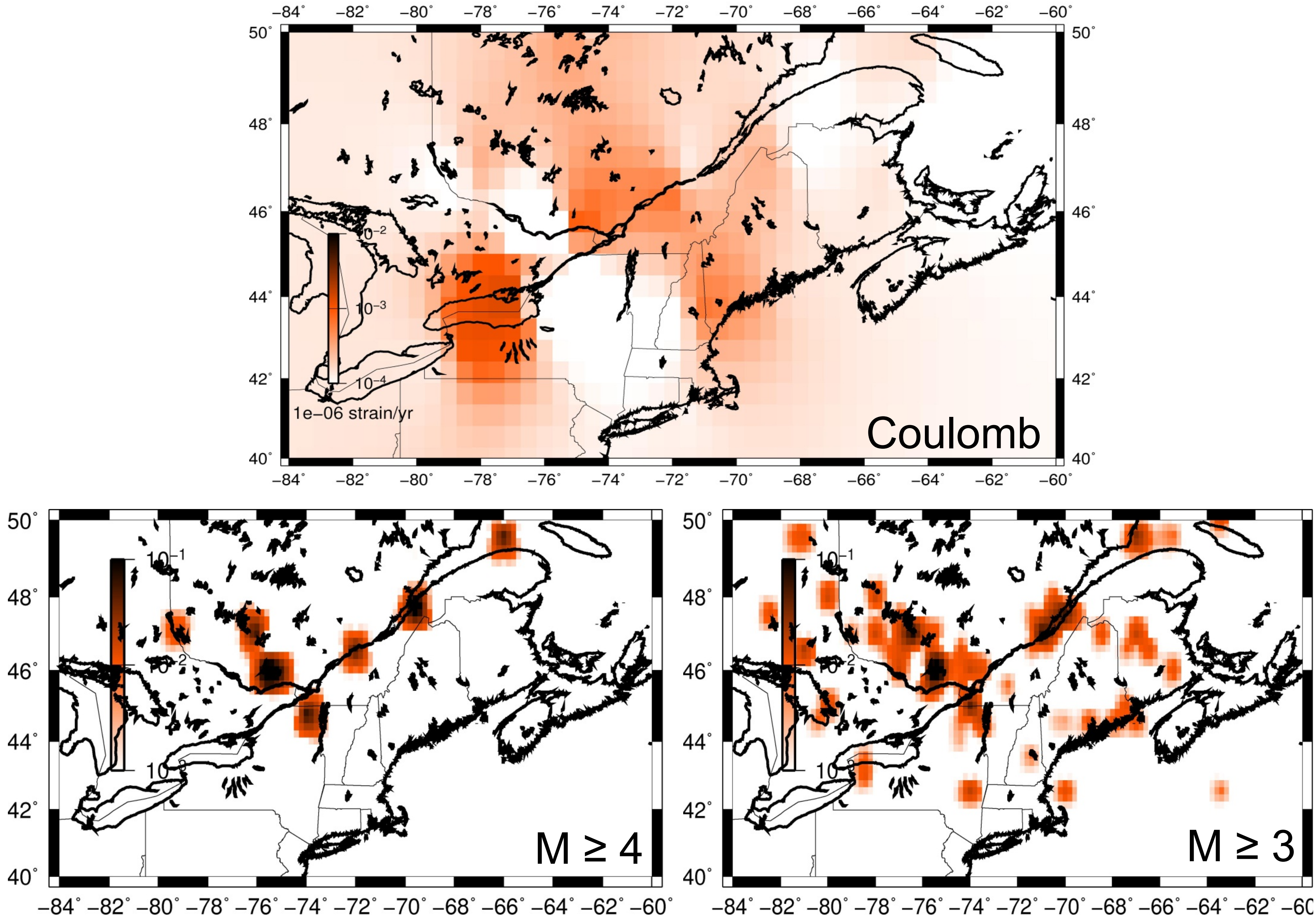




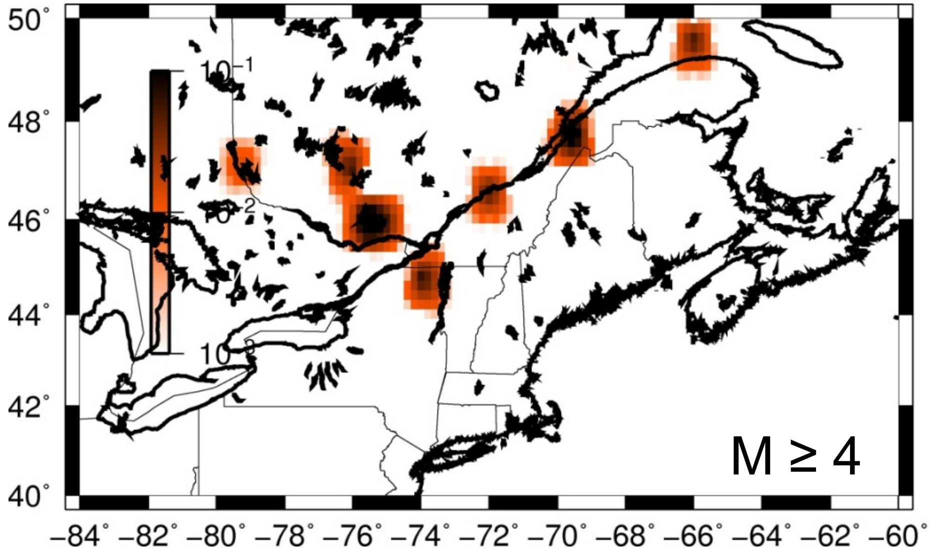
Seismicity rate changes

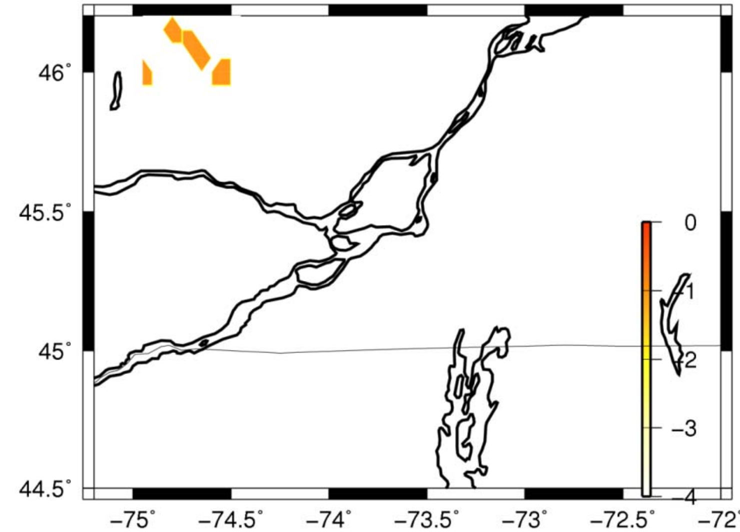


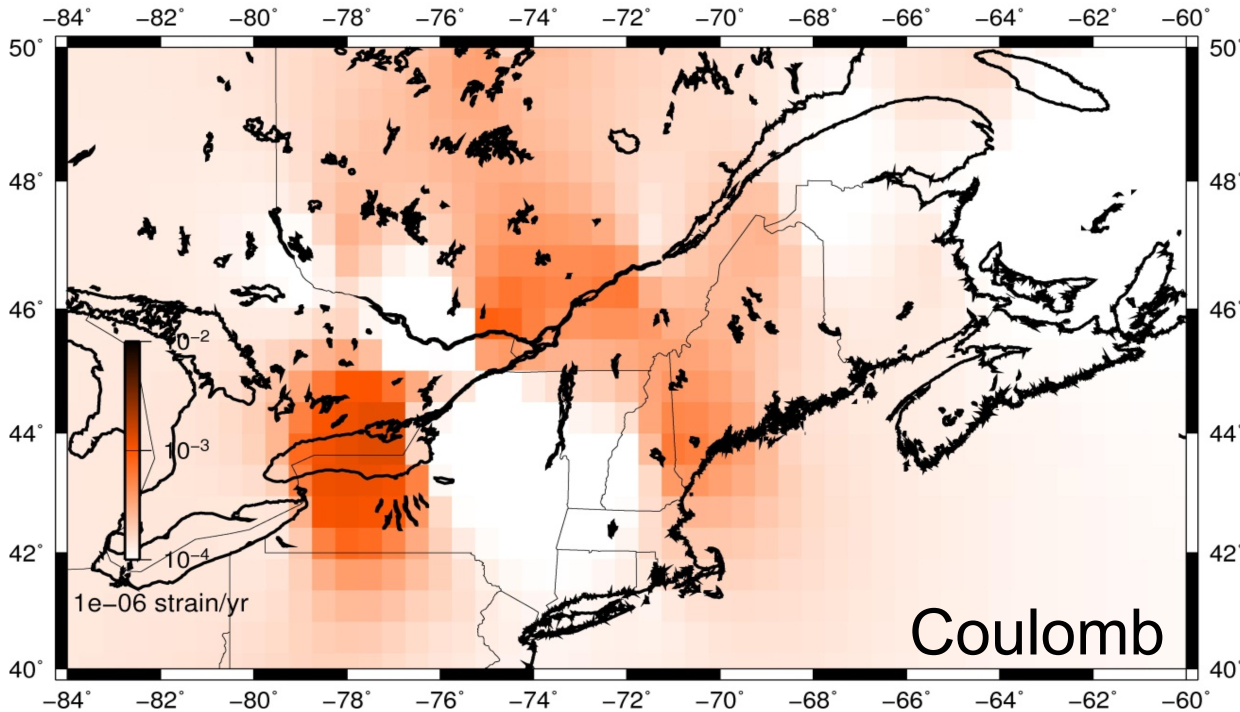
Seismicity and strain in eastern Canada



Seismicity and strain in eastern Canada







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.
- Earthquake forecasting can be successful – we can forecast large events in both eastern and western Canada.
- Rupture scenarios and ground shaking maps can be created from likely locations of future events identified by seismicity data.
- These same locations can be related to areas of high strain (deformation) derived from GPS data.
- However, our recent work suggests that deformation does map into increases into seismicity changes, and those seismicity changes can be related to locations of potential earthquake sites.