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Advanced School on Understanding and Prediction of Earthquakes and other Extreme Events in Complex Systems

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Understanding Extreme Seismic Hazards From Modeling and Prediction to Preventive Disaster Management

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Understanding Extreme Seismic Hazards

From Modeling and Prediction to Preventive Disaster Management

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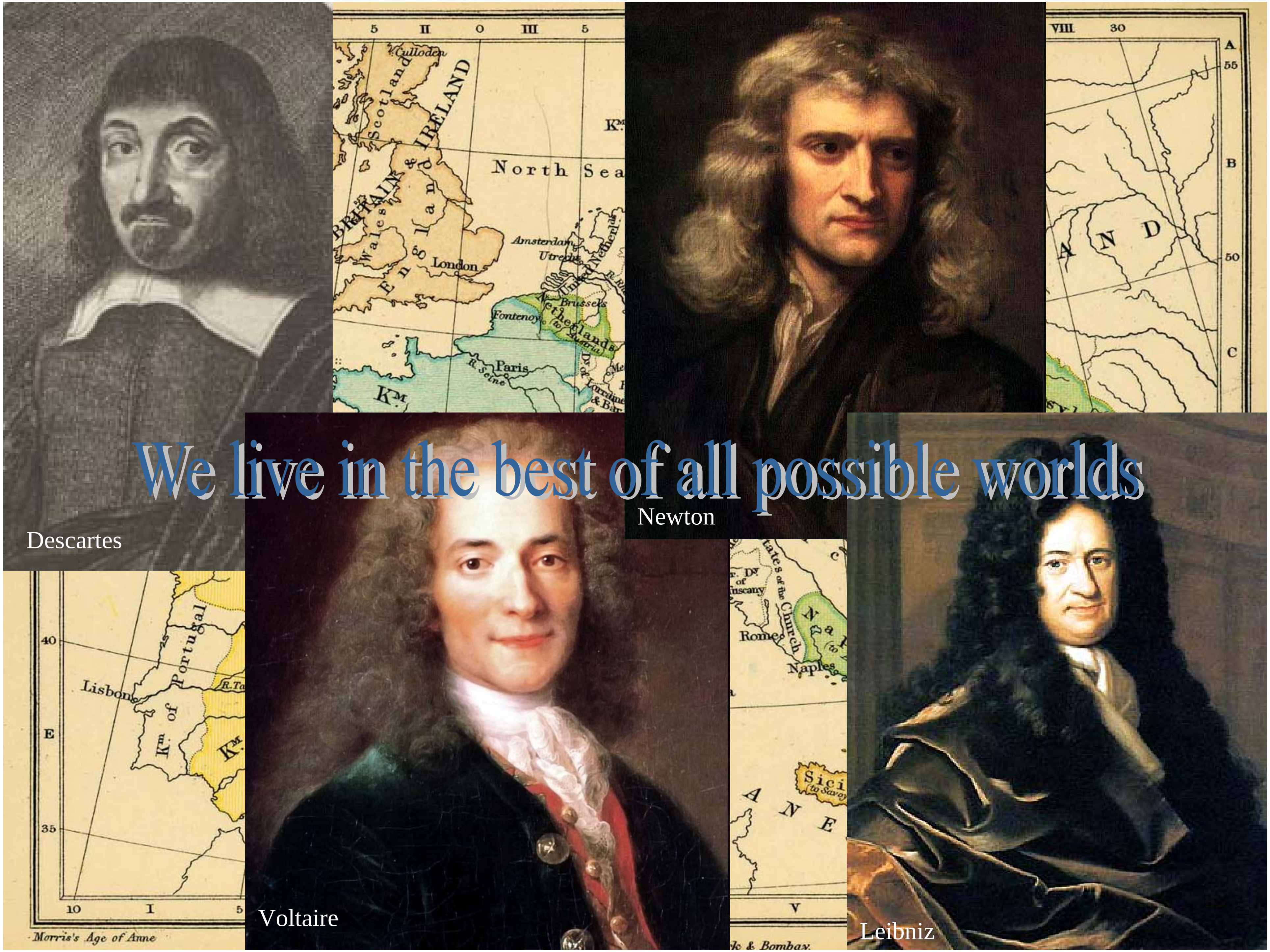

We live in the best of all possible worlds
Descartes
Newton
Voltaire
Leibniz
North Sea
IRELAND
Scotland
Wales
England
London
Amsterdam
Utrecht
Brussels
Fontenoy
Paris
R. Seine
Portugal
Lisbon
Rome
Naples
Church
Sici
to Savoy
Morris's Age of Anne

Lisbon, 1 November 1755

Marquês de Pombal

Portuguese artist

Extreme Seismic Events (ExSeiEvs)

ExSeiEv *is an earthquake's occurrence that with respect to other earthquakes is either notable, rare, unique, profound, or otherwise significant in terms of its impacts, effects, or outcomes*

(adapted from the general definition of extreme events by Extreme Events Workshop, Boulder, CO, 2000).

We shall distinguish two types of ExSeiEvs:

(I) an earthquake of the magnitude, which value is above a predefined threshold magnitude value near the upper end of the magnitude range of observed earthquakes; and

(II) an earthquake leading to extreme impact (disasters).

ExSeiEvs, like 1755 Lisbon, 1906 San Francisco, 1960 Chile, 2004 Aceh-Sumatra, 2008 Sichuan, 2011 East Japan earthquakes belongs to both types of extreme seismic events (high magnitude events and humanitarian disasters at the same time).

The 2010 M=8.8 Chile earthquake belongs to type I of extreme events.

The 2003 M=6.6 Bam earthquake or the 2010 M=7.0 Haiti earthquake can be characterized as type II ExSeiEvs.

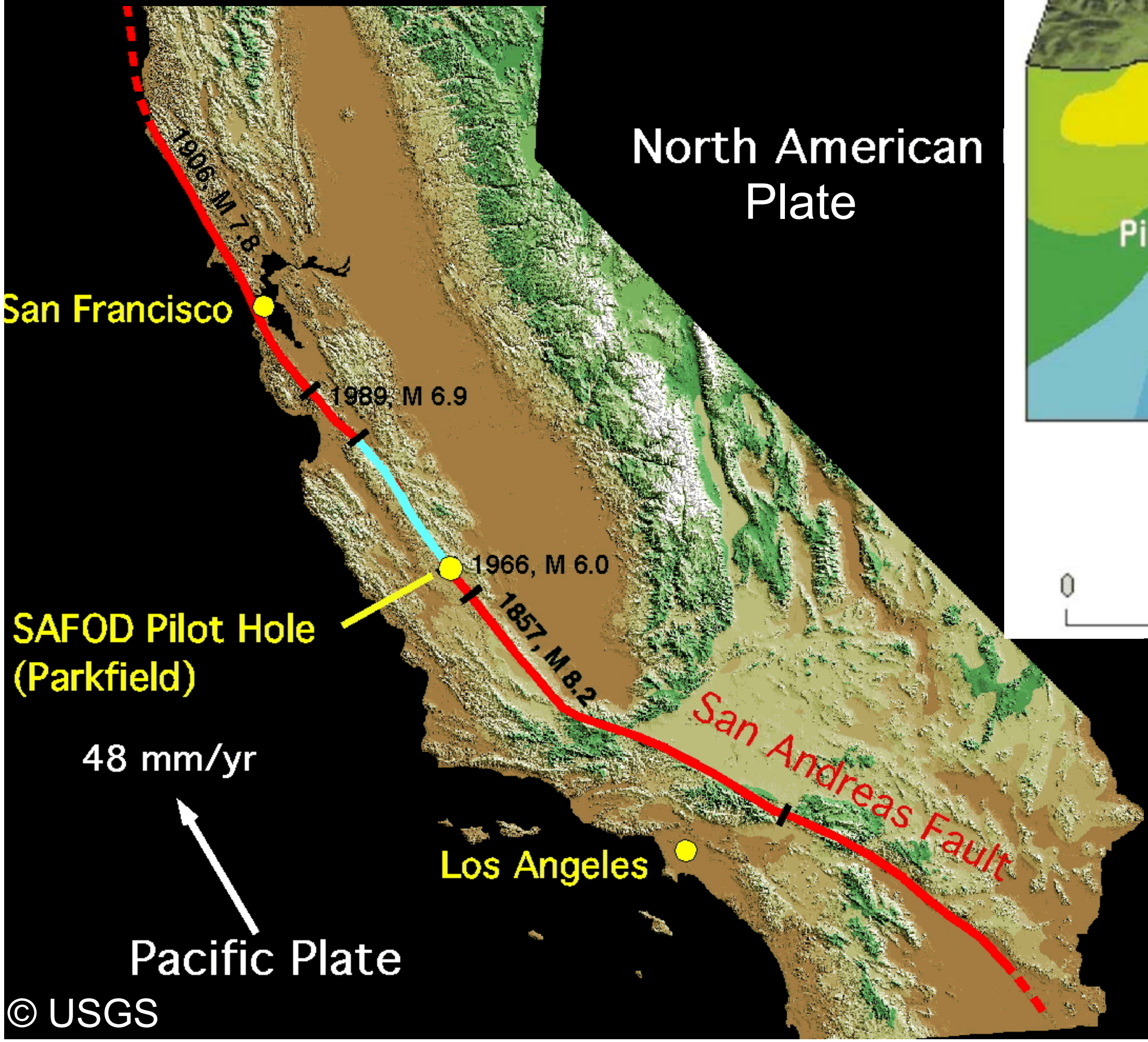
Extreme Seismic Events (ExSeiEv)

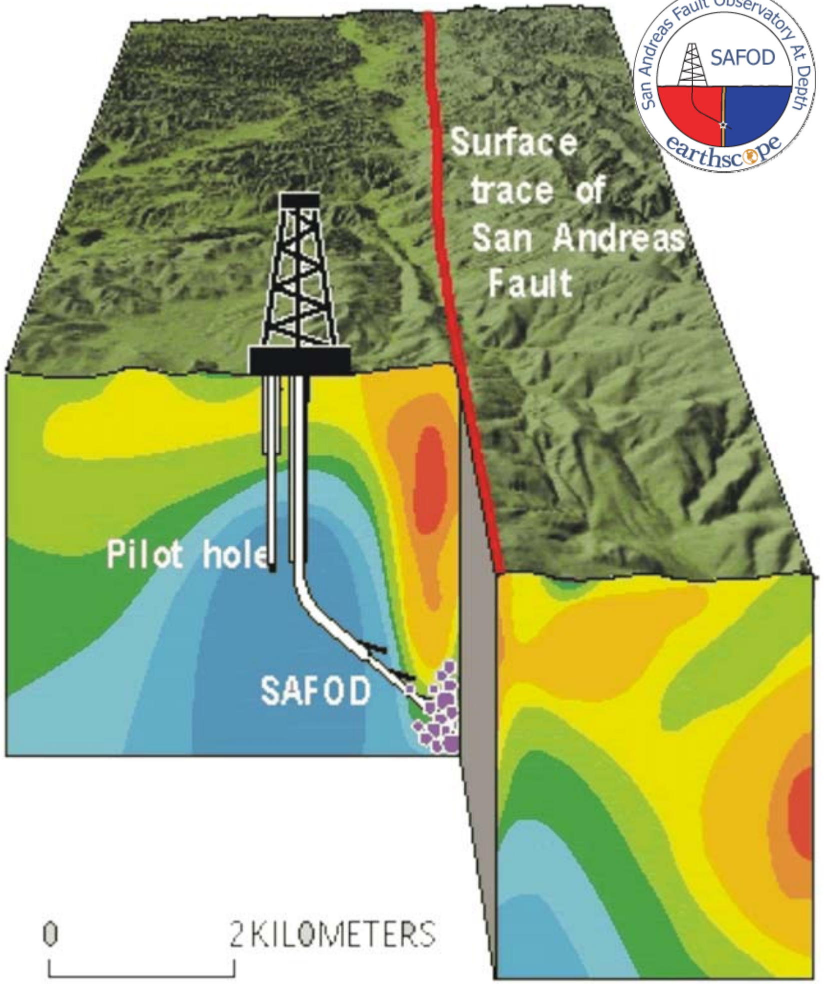
ExSeiEvs are key manifestations of lithosphere dynamics exhibiting a complex hierarchical nonlinear system behavior and evolving from stability to a catastrophe over space and time.

Chain of Tasks in Research on ExEvs

- Understanding of physical phenomena and dynamics of extreme events.
- From physical understanding of these events to modeling of extreme events.
- From modeling to earthquake hazard assessment and forecasting / prediction of the events.
- From sophisticated predictions to prompt information delivery to disaster management authorities to undertake preventive measures and to mitigate (if not fully prevent) earthquake or tsunami disasters.

Understanding of Earthquakes based on Physics of Fault Zones

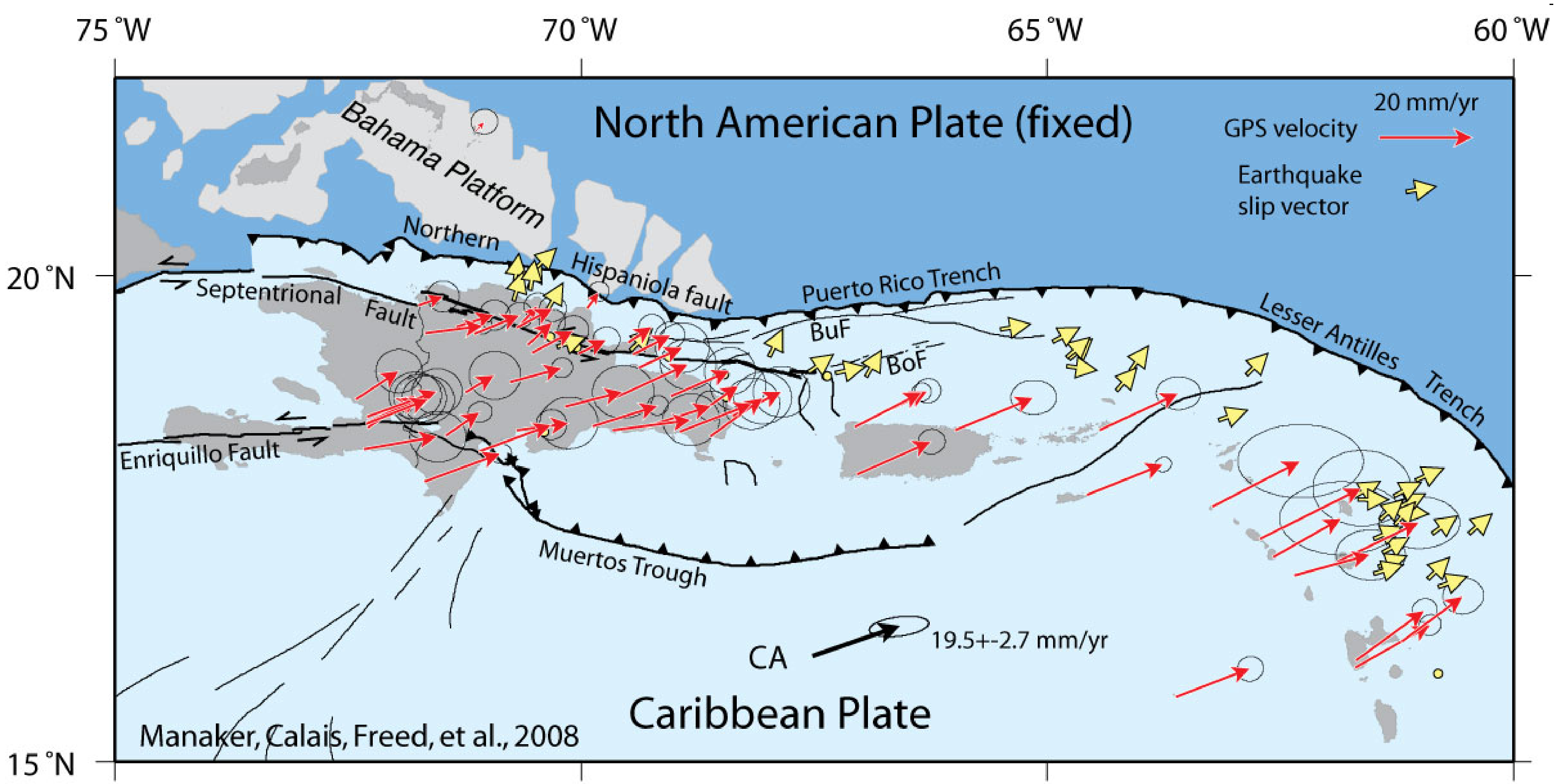




SAFOD project:

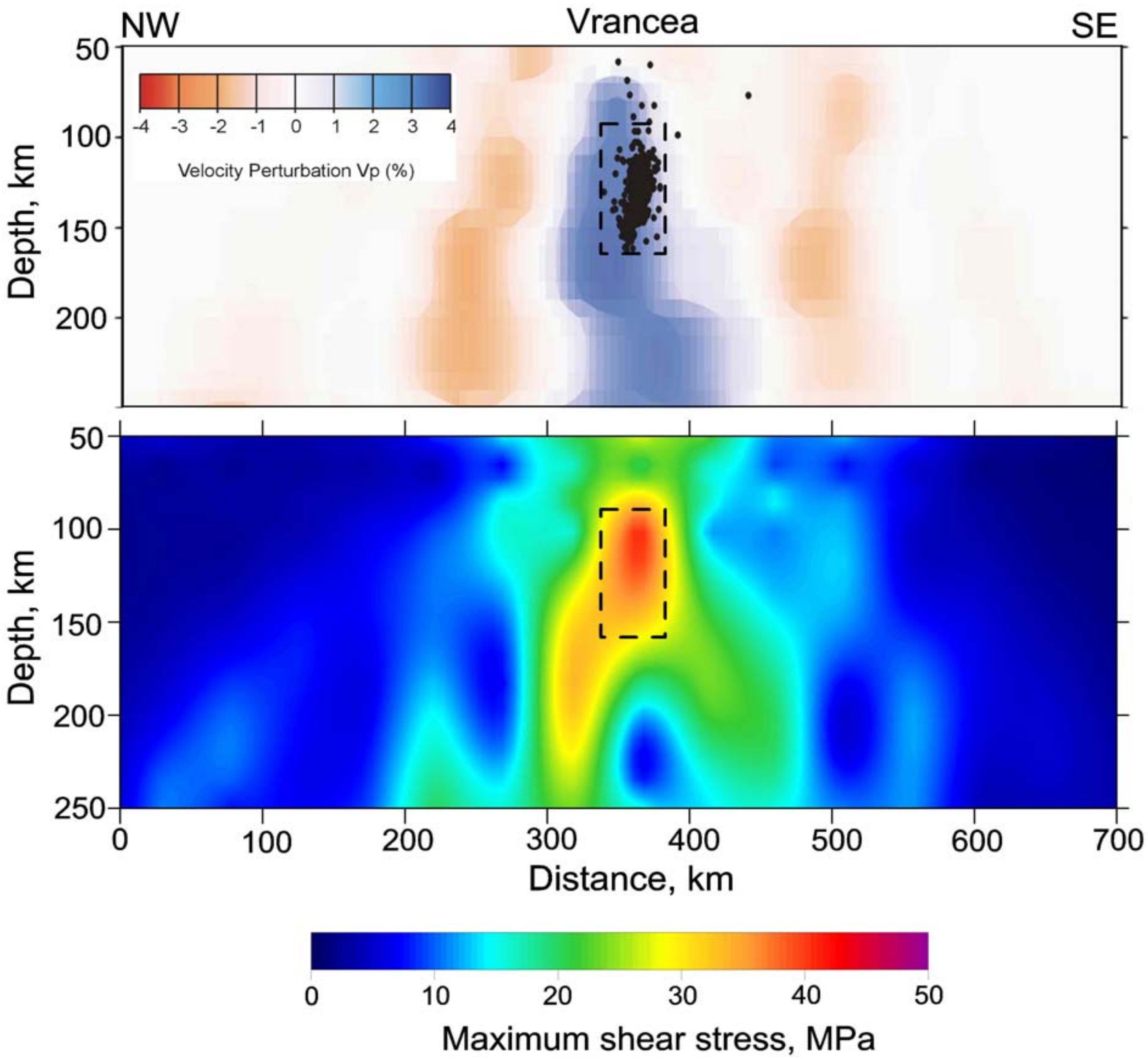
New information on fundamental theories of earthquake mechnaics and on how stress works in the lithosphere: stress generation and release

Understanding of Earthquake Preparation Processes Using GPS Geodesy



"… the Enriquillo fault in Haiti is currently capable of a Mw7.2 earthquake if the entire elastic strain accumulated since the last major earthquake was released in a single event today" (Manaker et al., 2008)

Understanding of Earthquake Preparation Processes Using Seismic Tomography & Stress Modeling

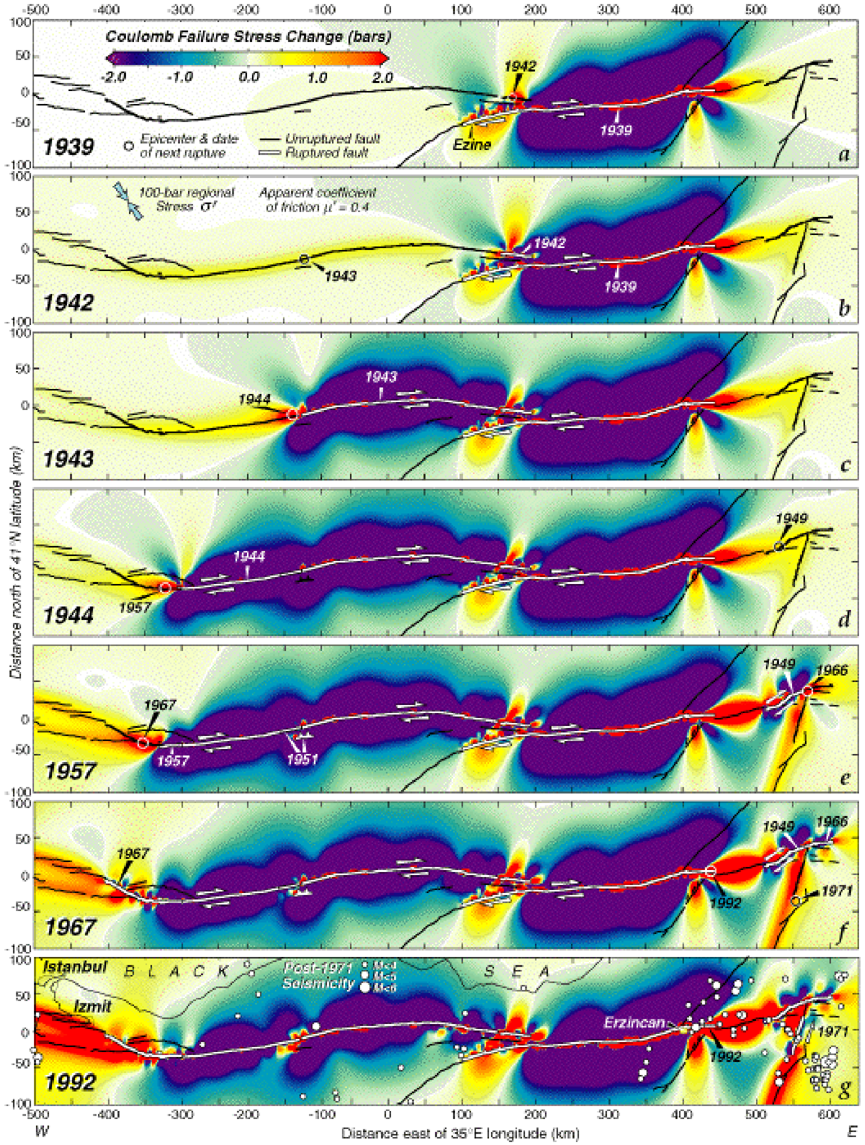


Ismail-Zadeh et al., 2005

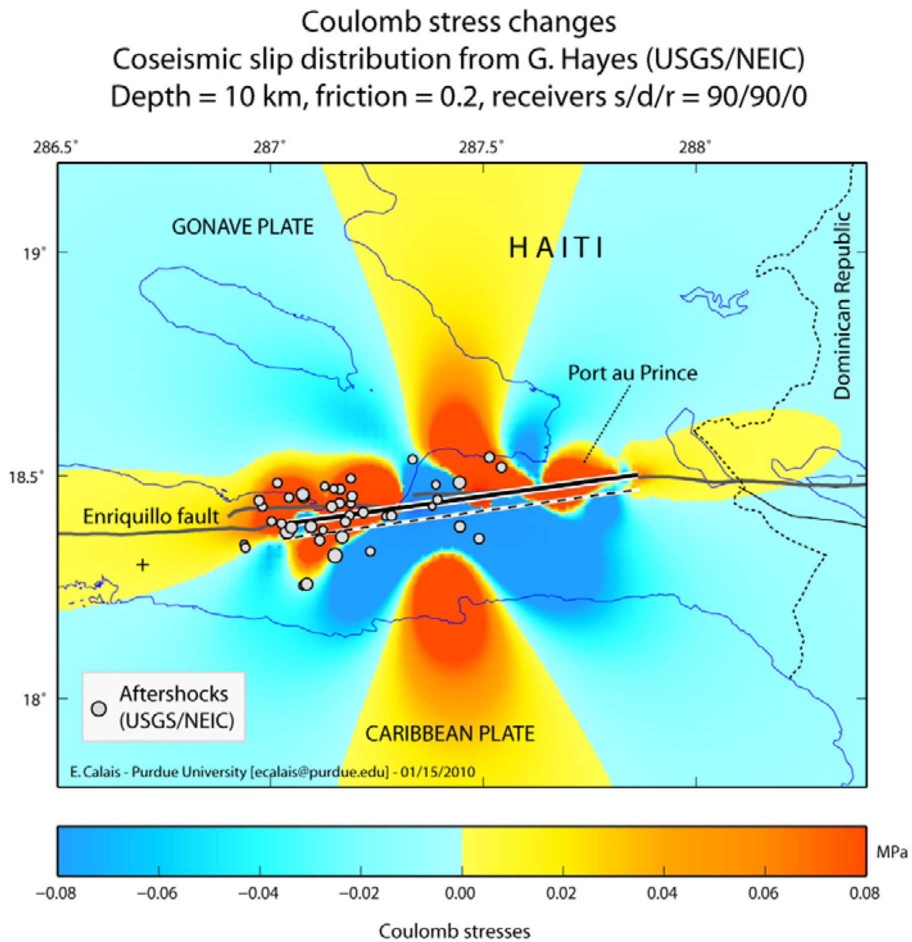
Understanding of Earthquake Preparation Processes

Using Stress Modeling

Coulomb-stress change evaluation



Stein et al.,1997



Understanding of Earthquake Preparation Processes Using Earthquake Modeling

Simulation of realistic earthquake catalogs for an earthquake-prone region is of a great importance. The catalogs of synthetic events over a large time window can assist in interpreting the seismic cycle behavior and/or in predicting a future extreme event, as the available observations cover only a short time interval. If a segment of the catalog of modeled events approximates the observed seismic sequence with a sufficient accuracy, the part of the catalog immediately following this segment might be used to predict the future seismicity and to forecast extreme events.

Catalogs of modeled seismic events allow to analyze

–Spatial-temporal correlation between earthquakes

–Earthquake clustering

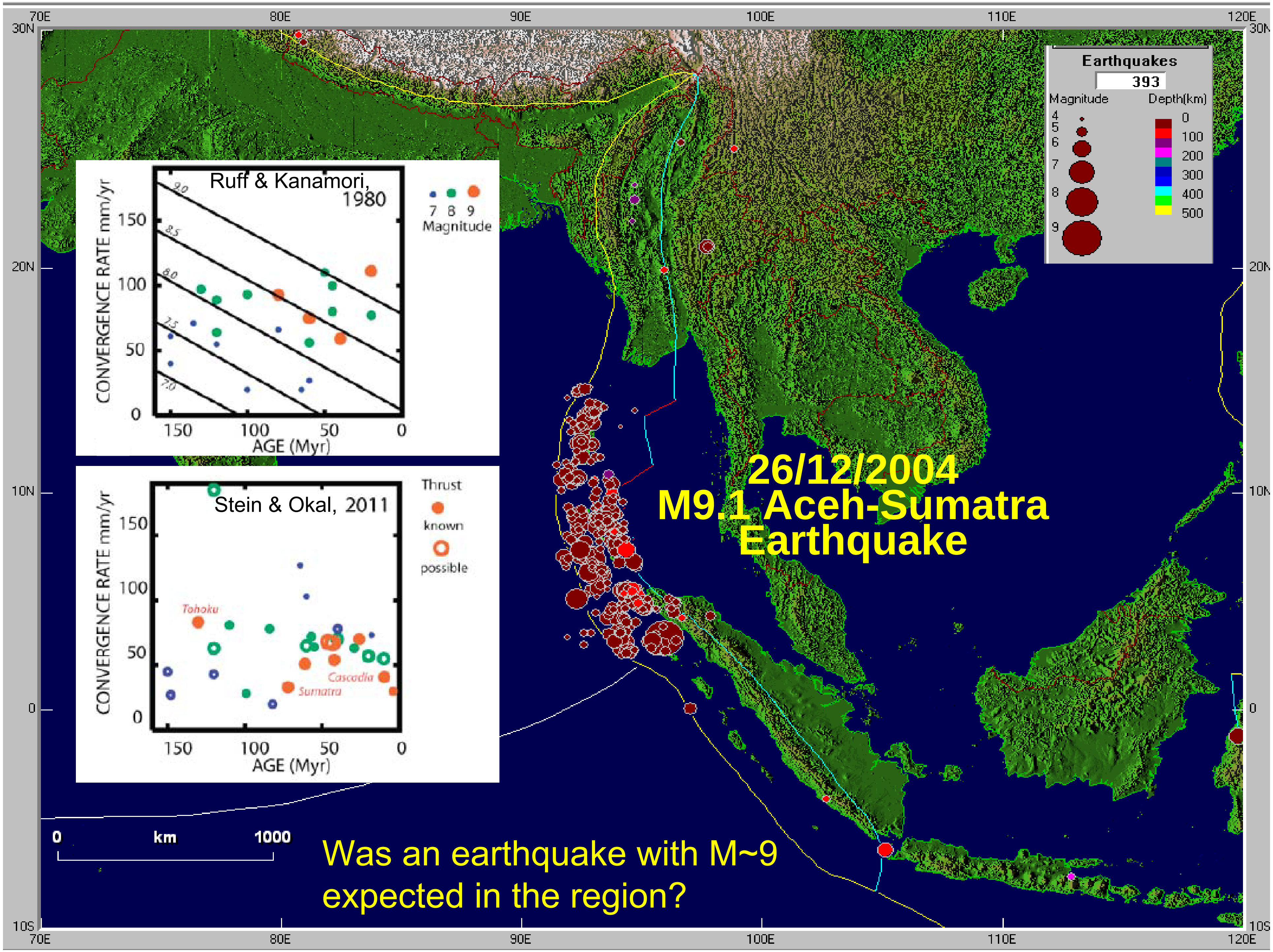
–Occurrence of large seismic events

–Long-range interaction between the events

–Fault slip rates

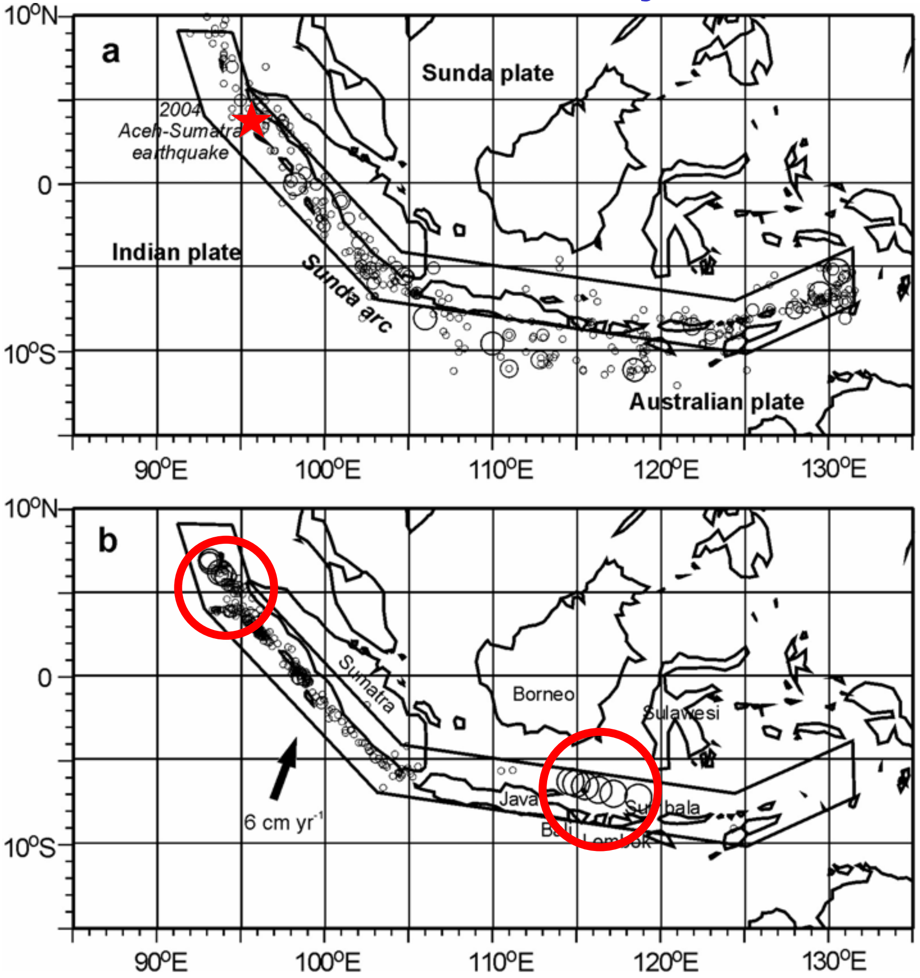
–Mechanism of earthquakes

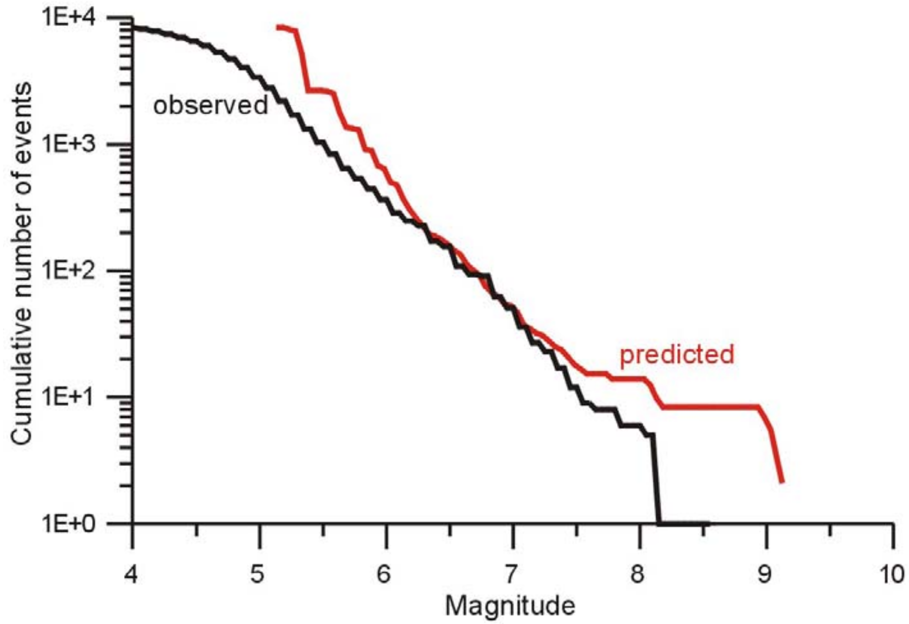
–Seismic moment release


26/12/2004
M9.1 Aceh-Sumatra
Earthquake
Was an earthquake with M~9
expected in the region?
Ruff & Kanamori, 1980
CONVERGENCE RATE mm/yr
AGE (Myr)
7 8 9
Magnitude
Stein & Okal, 2011
Thrust
known
possible
Tohoku
Cascadia
Sumatra
Earthquakes
393
Magnitude
Depth(km)
0
km
1000
70E
80E
90E
100E
110E
120E
30N
20N
10N
0
10S

Sunda Arc – BAFD model

Observed seismicity, M>6

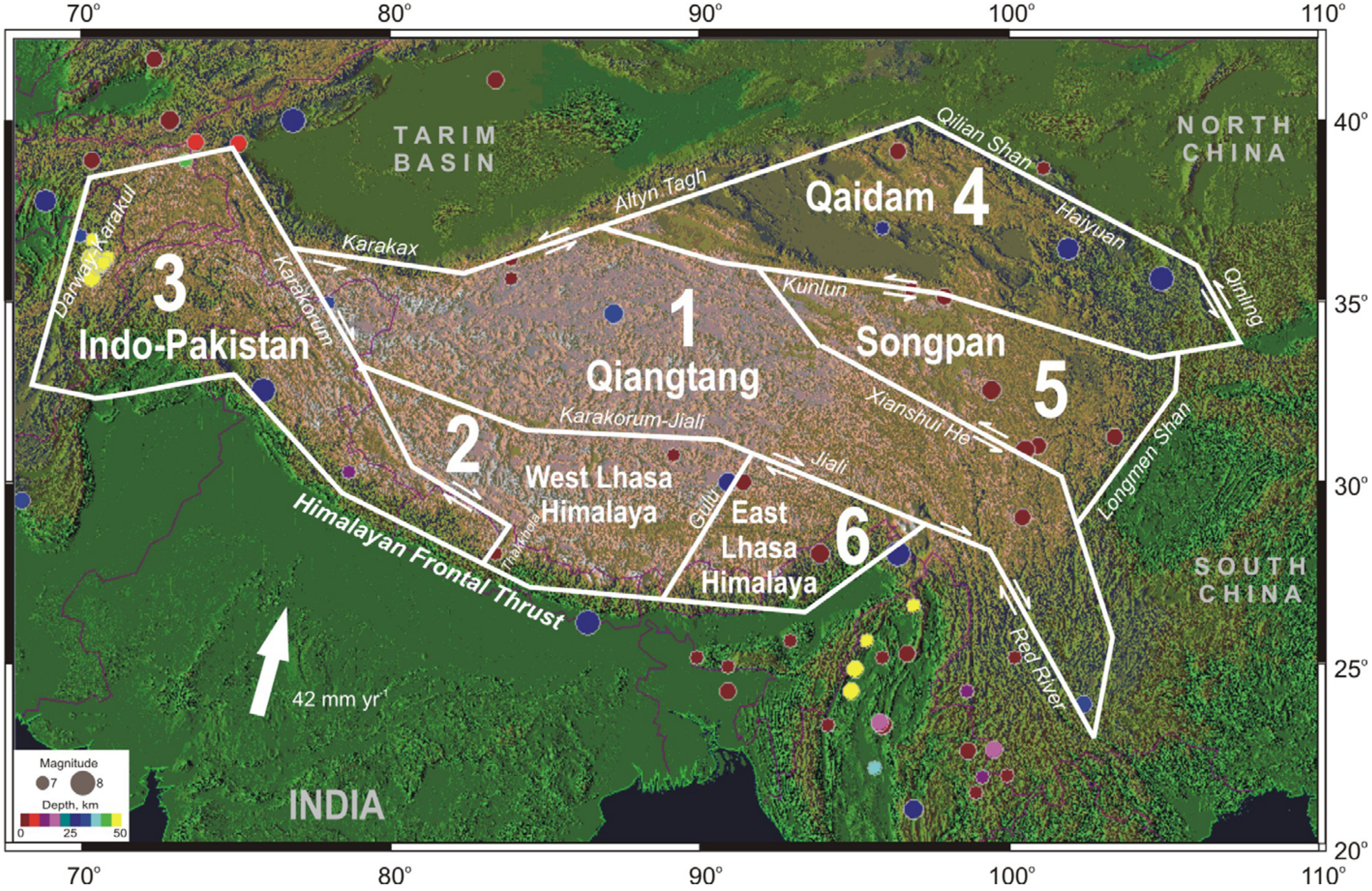




Synthetic seismicity, M>7

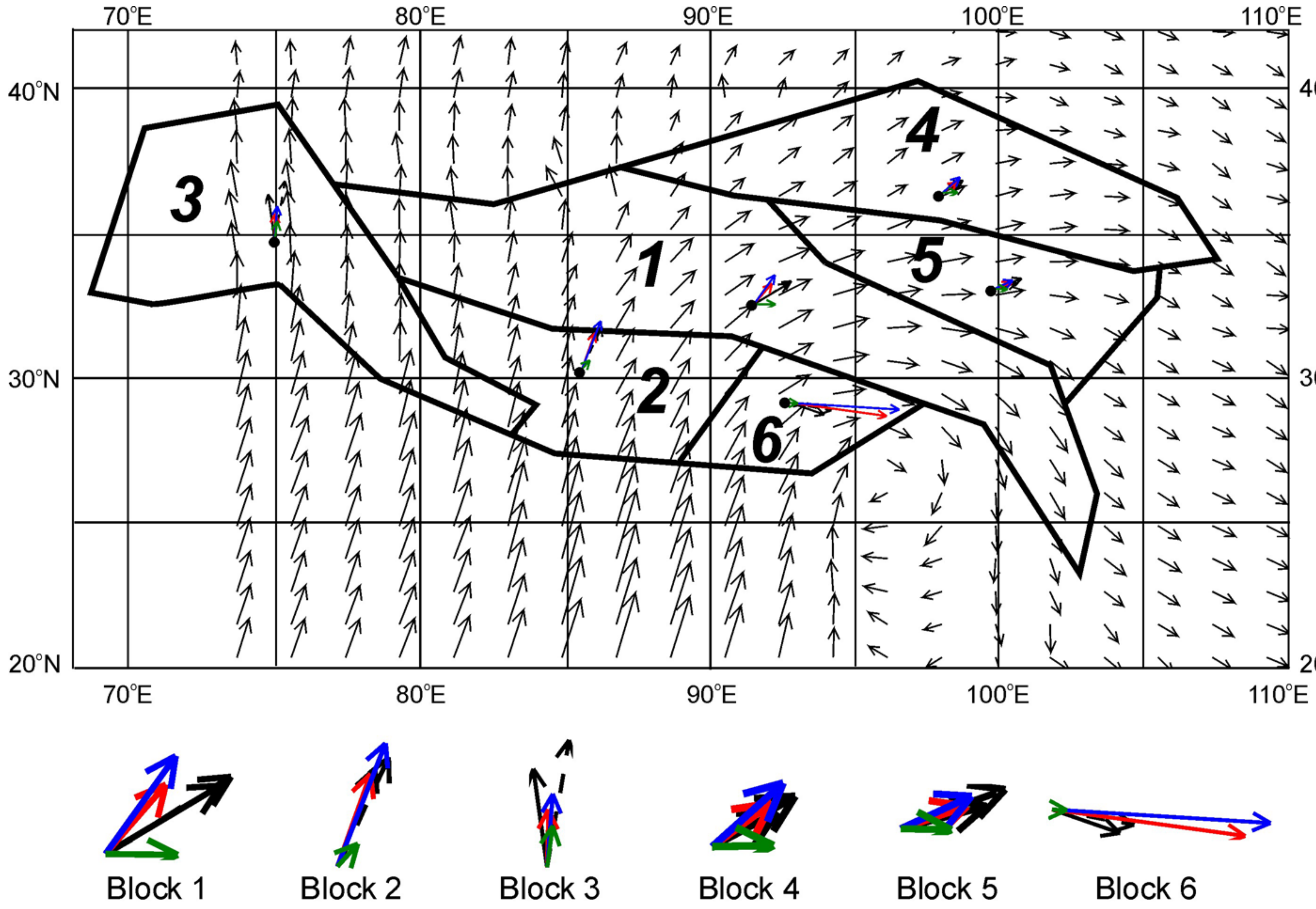
(Soloviev and Ismail-Zadeh, 2003)

Tibetan Plateau - BAFD Model

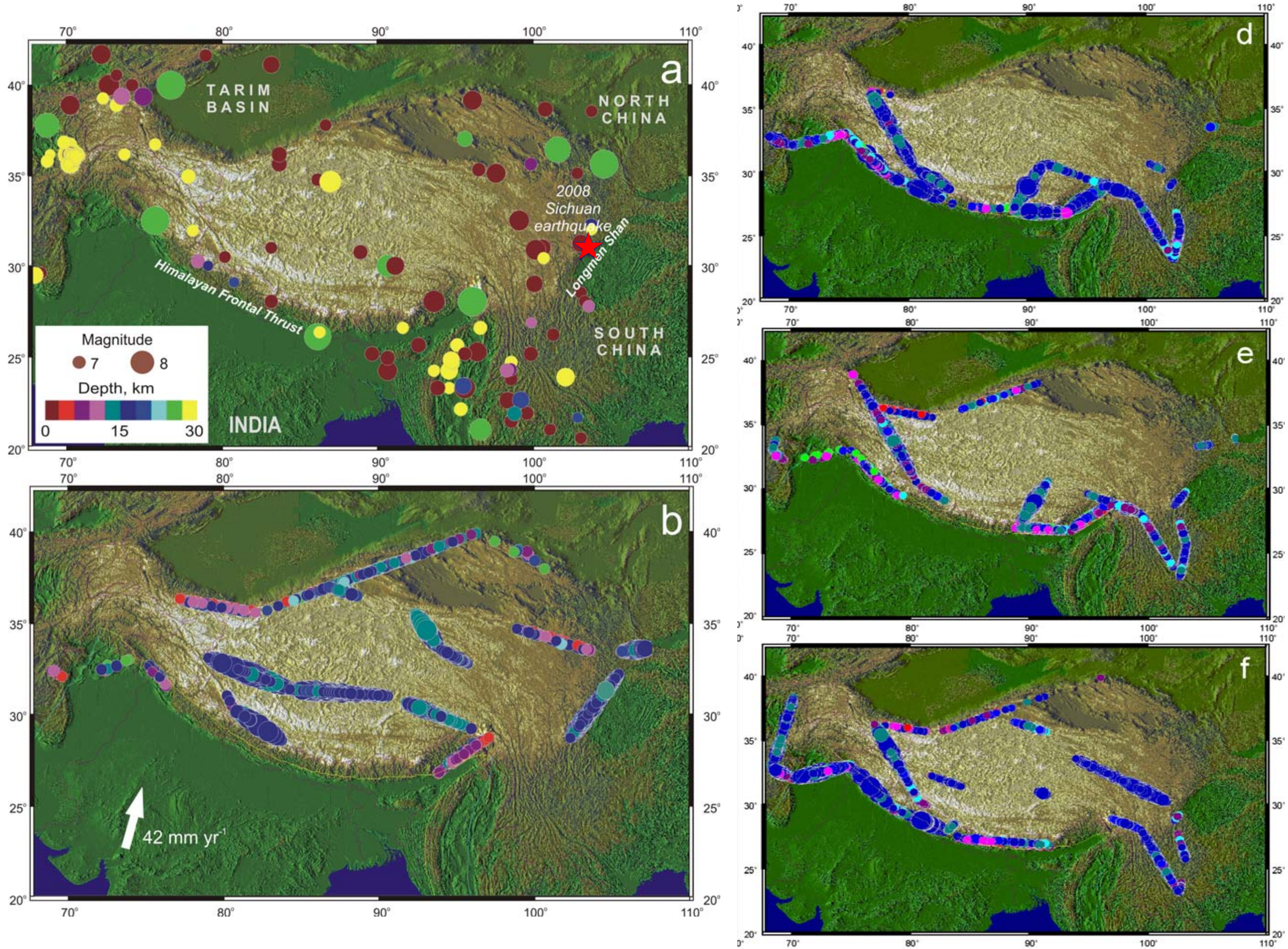


(Ismail-Zadeh et al., 2007)

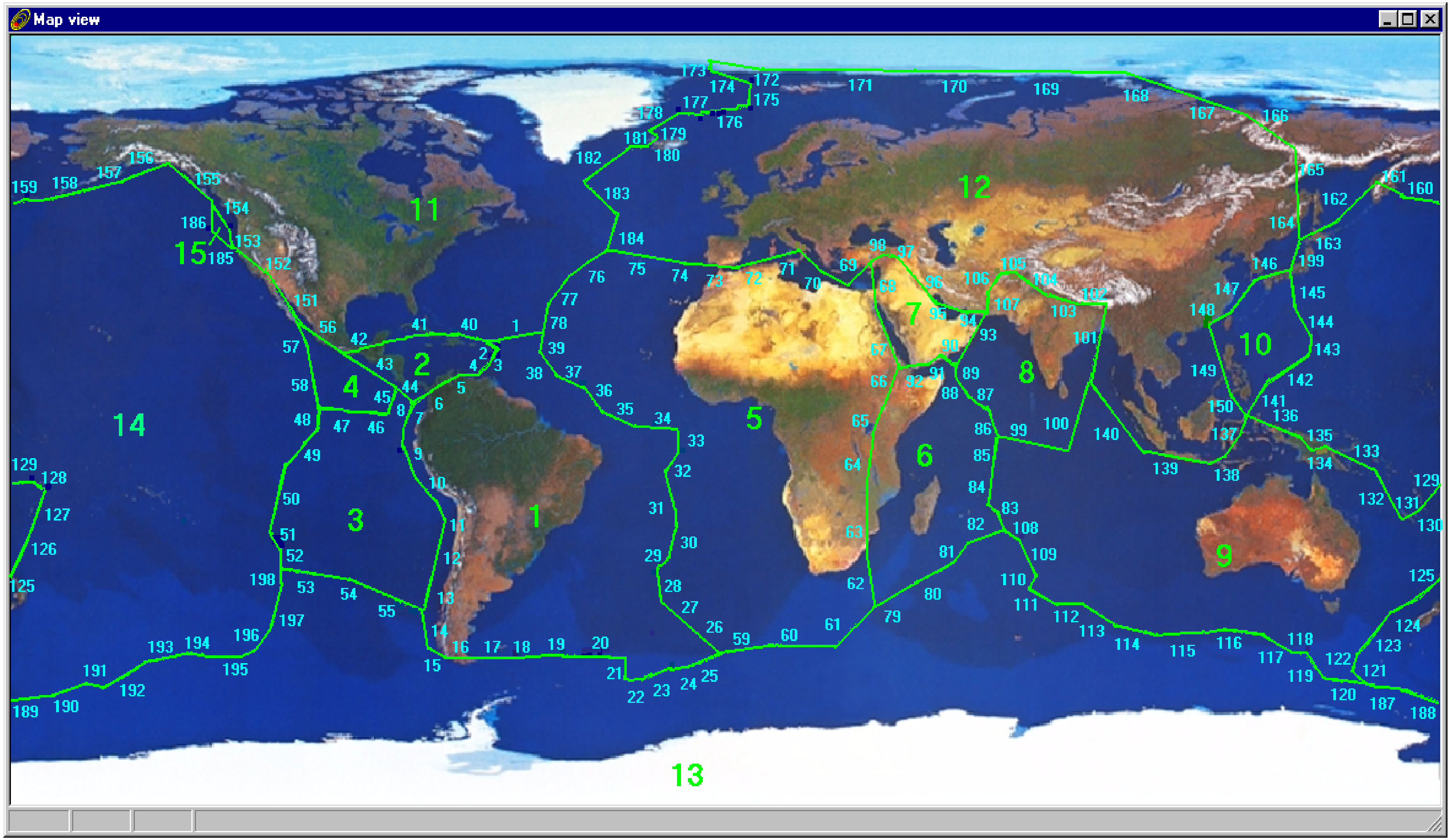
Block Movements vs. Geodetic Measurements



Tibetan Plateau - BAFD Model Results



Lithosphere Block Structure in BAFD Model

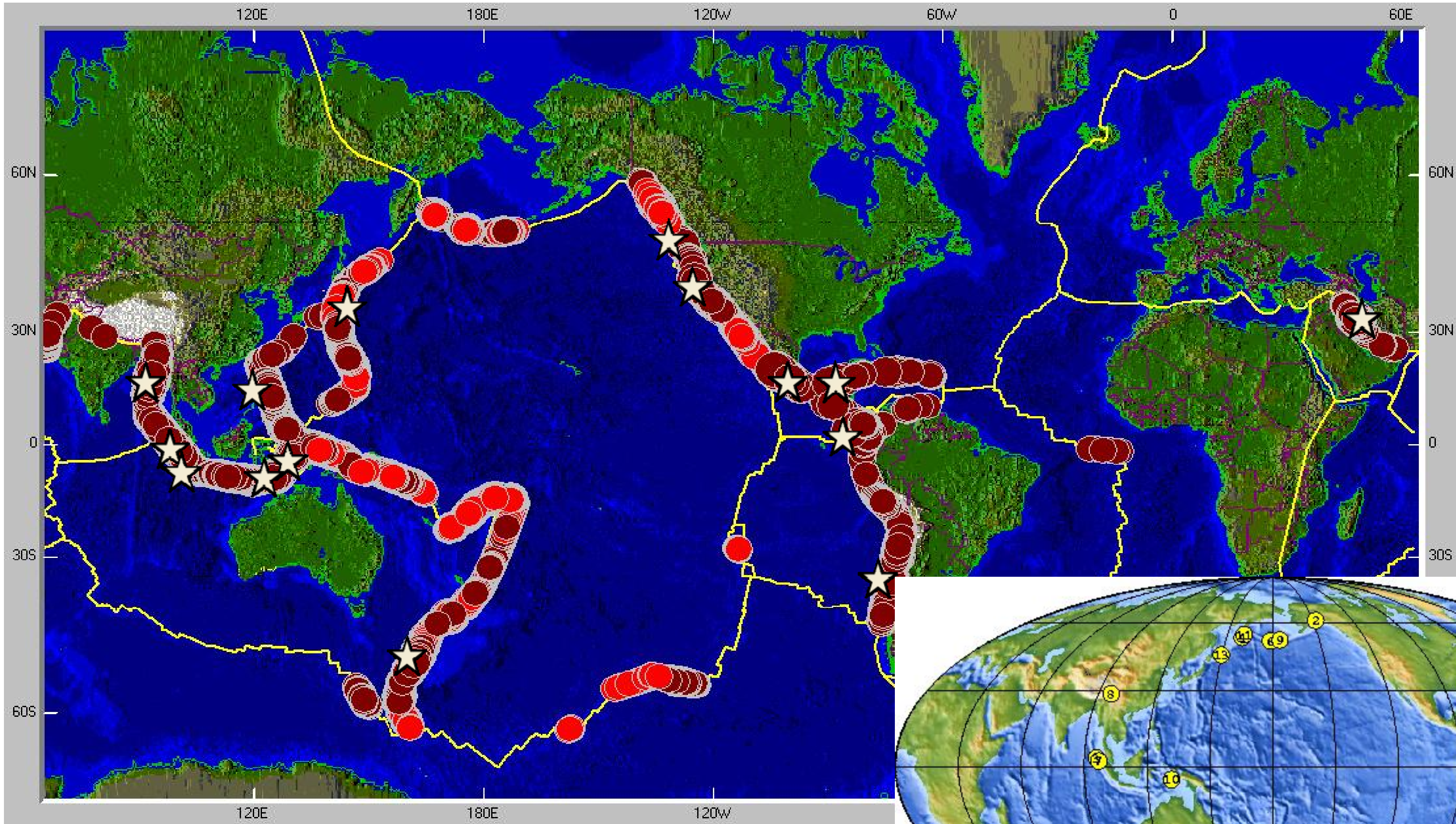


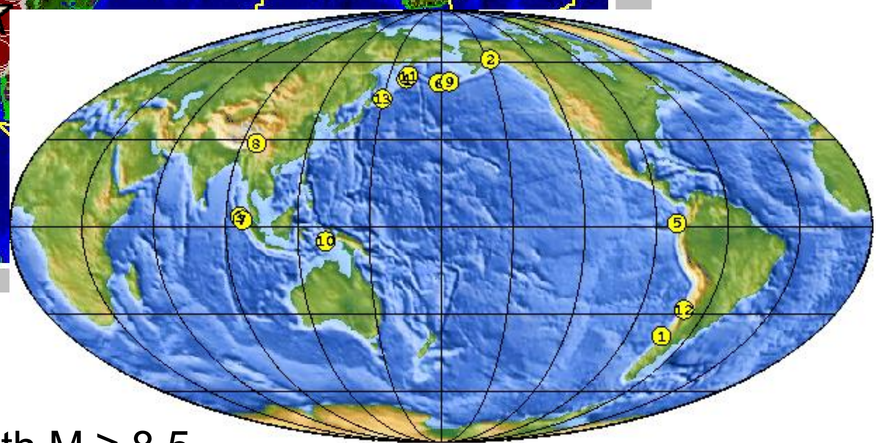
A movement of the BAFD model is induced by asthenospheric flow.
The HS3-NUVEL-1 (Gripp and Gordon, 2002) is used to generate the flow.

Synthetic Seismicity

case 5.1, events with M ≥ 8.0

15 extreme modeled events are marked by star





Earthquakes with M ≥ 8.5

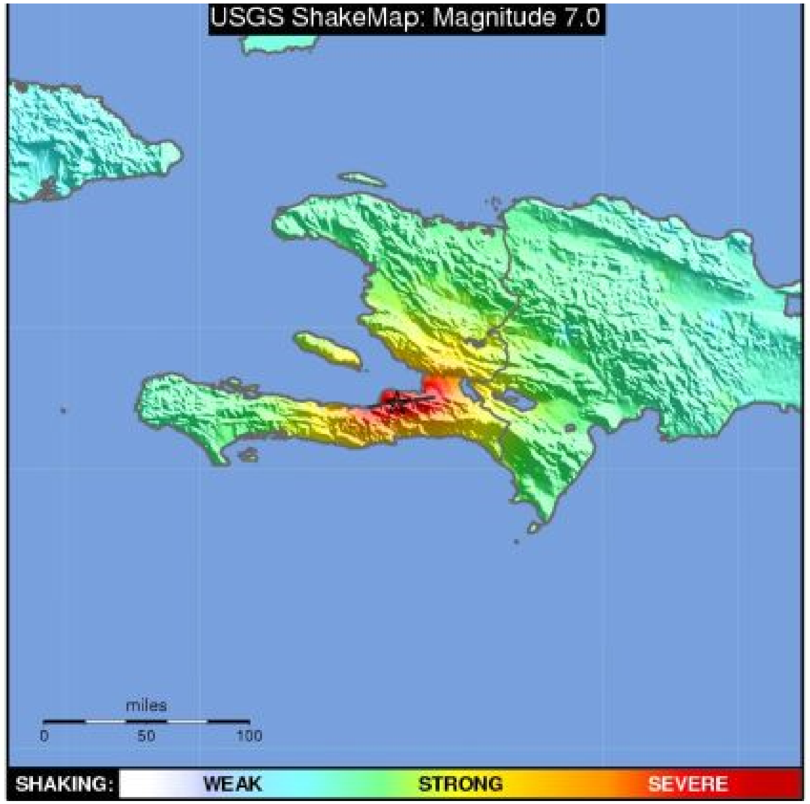
USGS National Earthquake Information Center

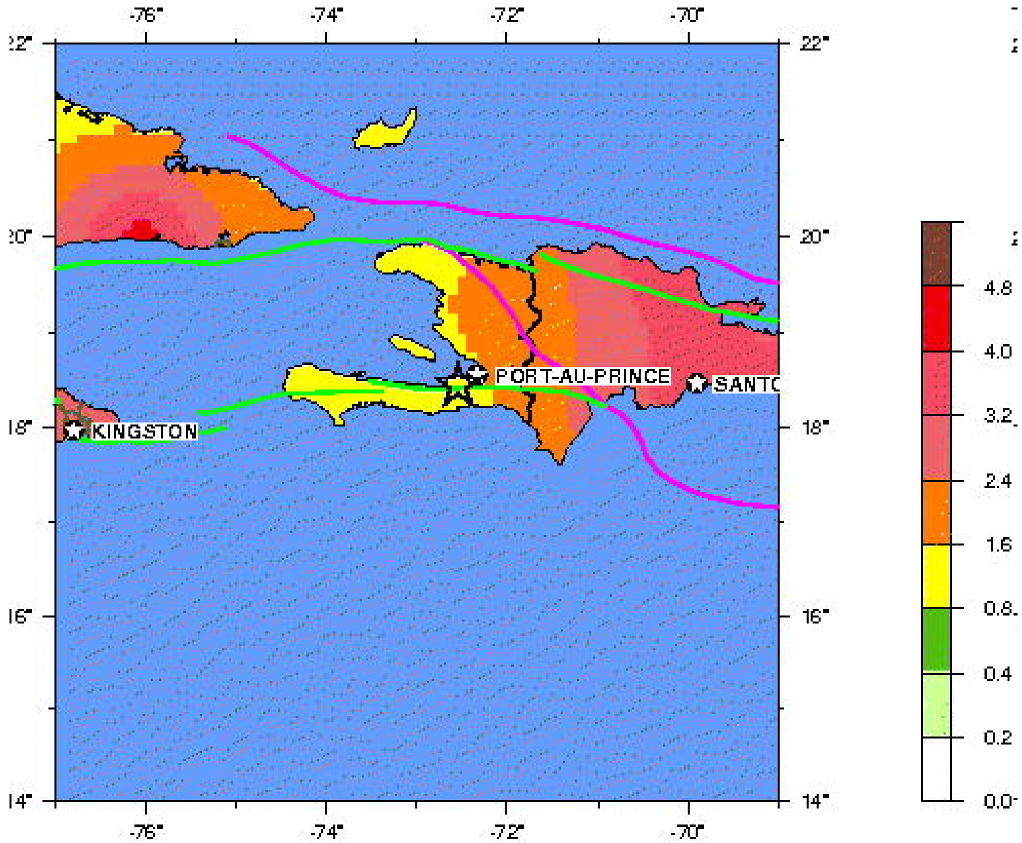
Rosenberg et al., 2010

Can Probabilistic Seismic Hazard Assessment used Nowadays Forecast Extreme Seismicity?

Can PSH Assessment “Forecasts” ExSeiEvs?

2010 Haiti Earthquake





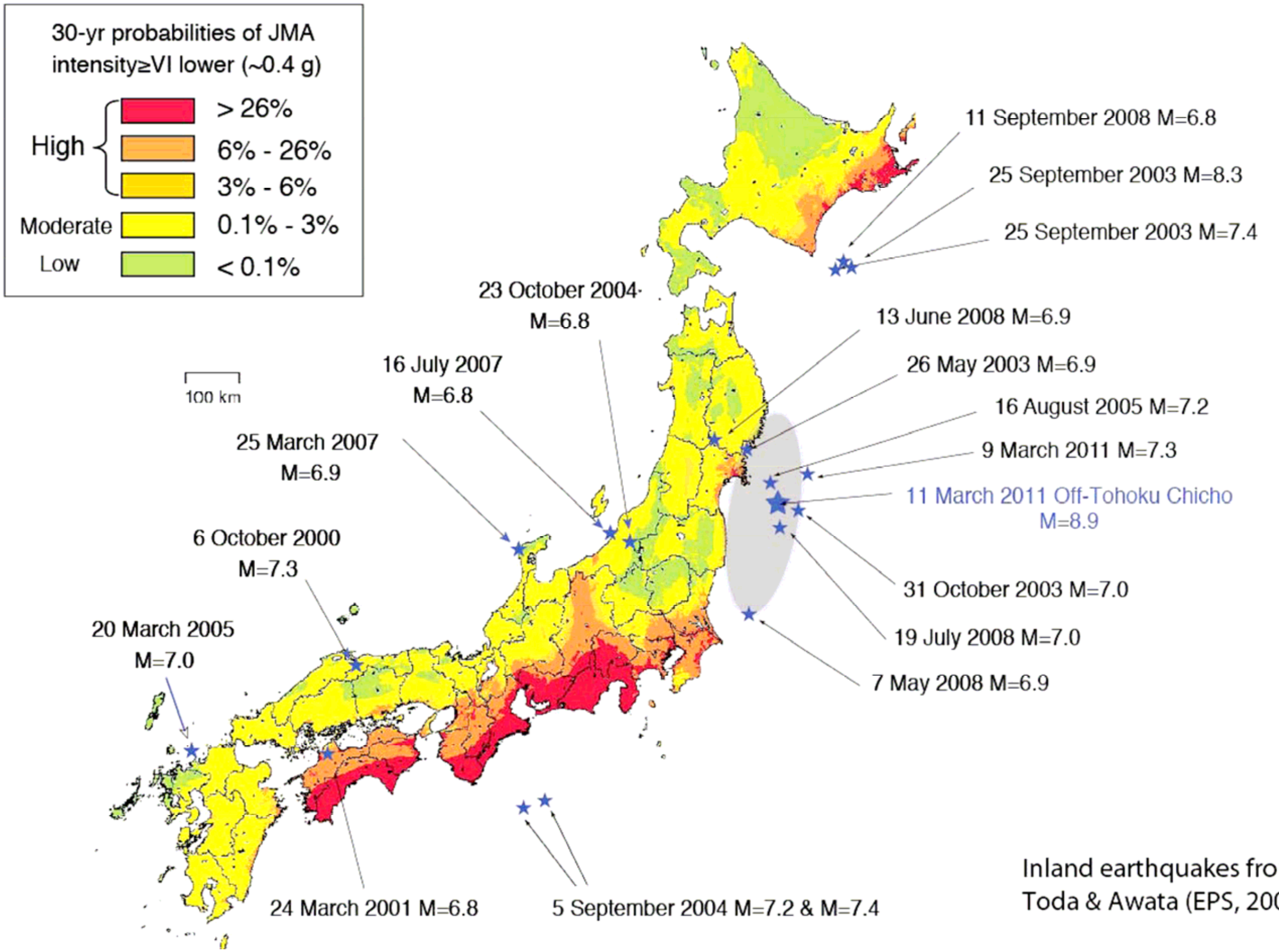
USGS

Observed shaking

Predicted PGA by PSHA

Can PSH Assessment "Forecasts" ExSeiEvs?

How well has the 2005 Japanese National Seismic Hazard Map forecast the last decade of earthquakes?



Inland earthquakes from Toda & Awata (EPS, 2007)

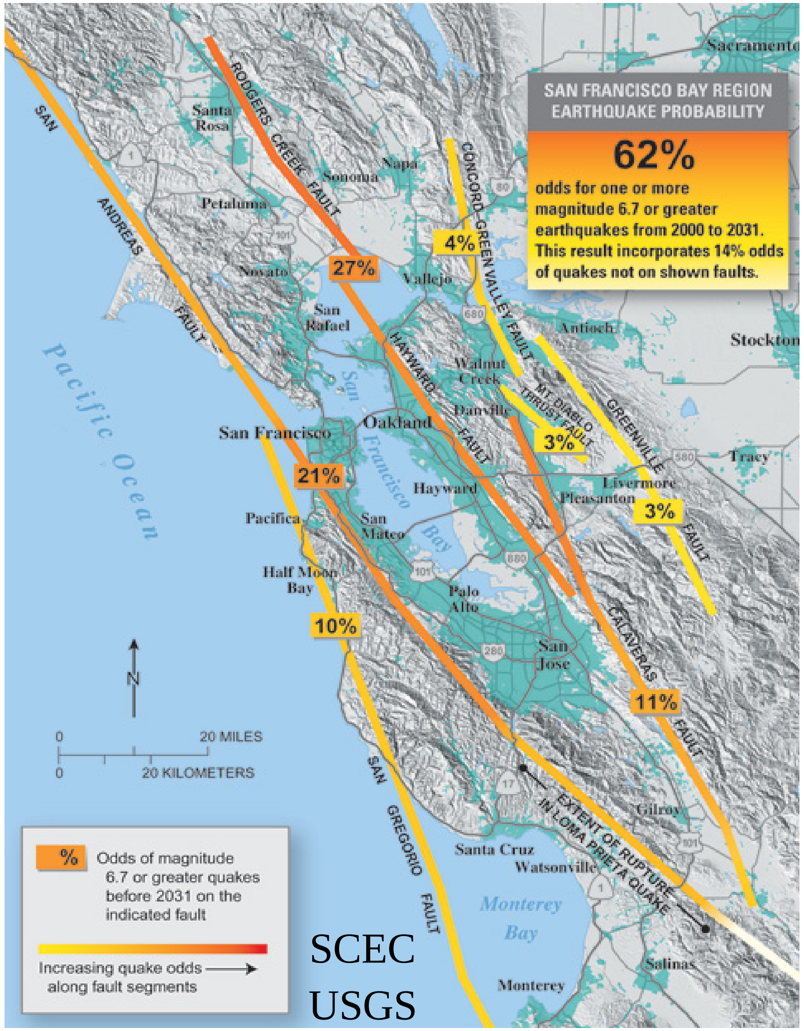
Predicting ExSeiEvs

Natural disasters became *“a threat to civilization survival”*. Prediction of extreme seismic events is necessary for *protection of population, economy, and environment*, and it opens a possibility to reduce the damage by escalation of disaster preparedness.

Classification of earthquake predictions

Temporal, in years		Spatial, in source zone size L	
Long-term	10	Long-range	Up to 100 L
Intermediate-term	1	Middle-range	5-10 L
Short-term	0.01-0.1	Narrow	2-3 L
Immediate	0.001	Exact	1 L

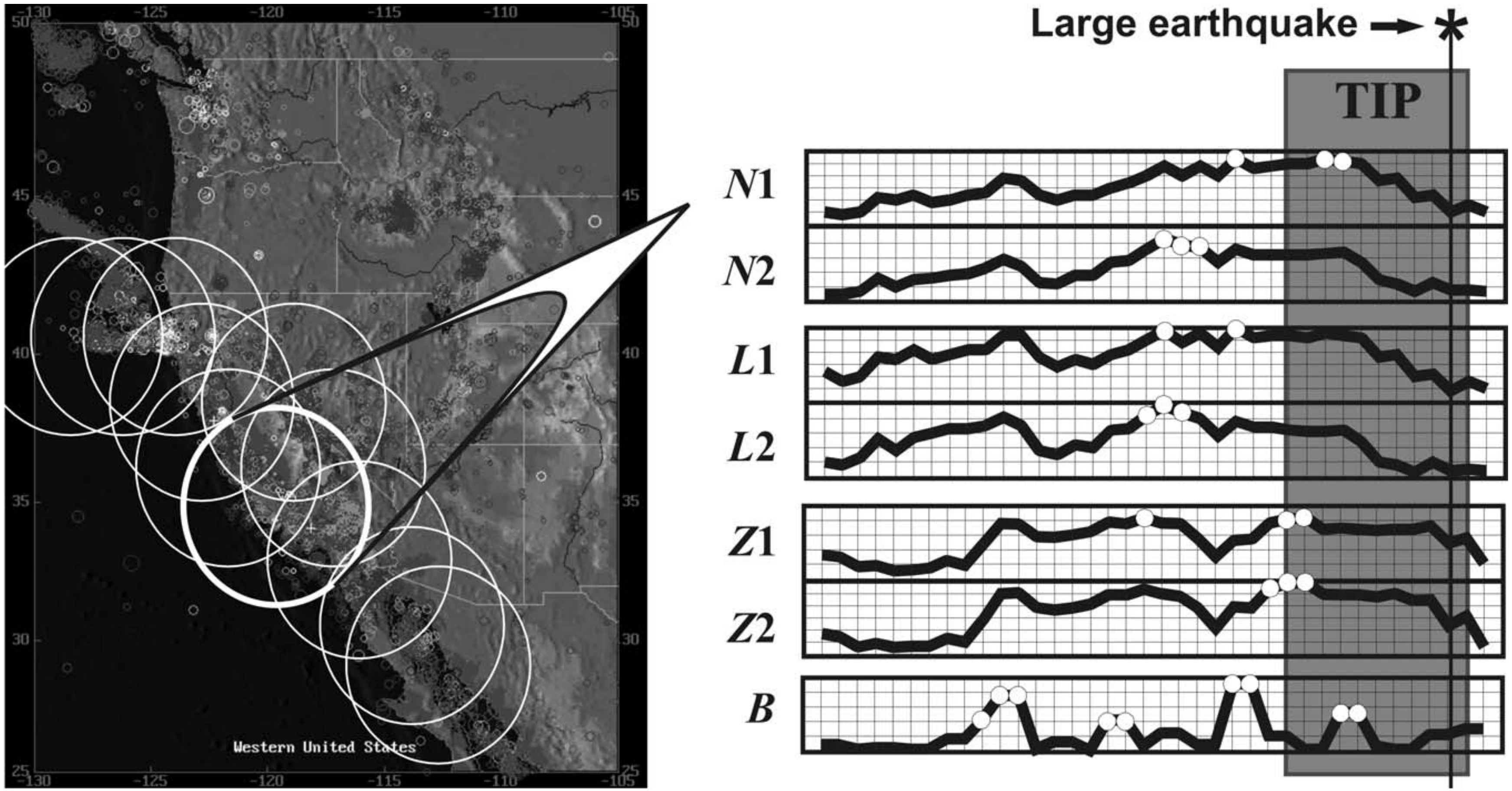
Note: Spatial accuracy of predictions depends on the source size L of target earthquakes.



Long-term earthquake prediction

Predicting ExSeiEvs

Intermediate-term earthquake prediction

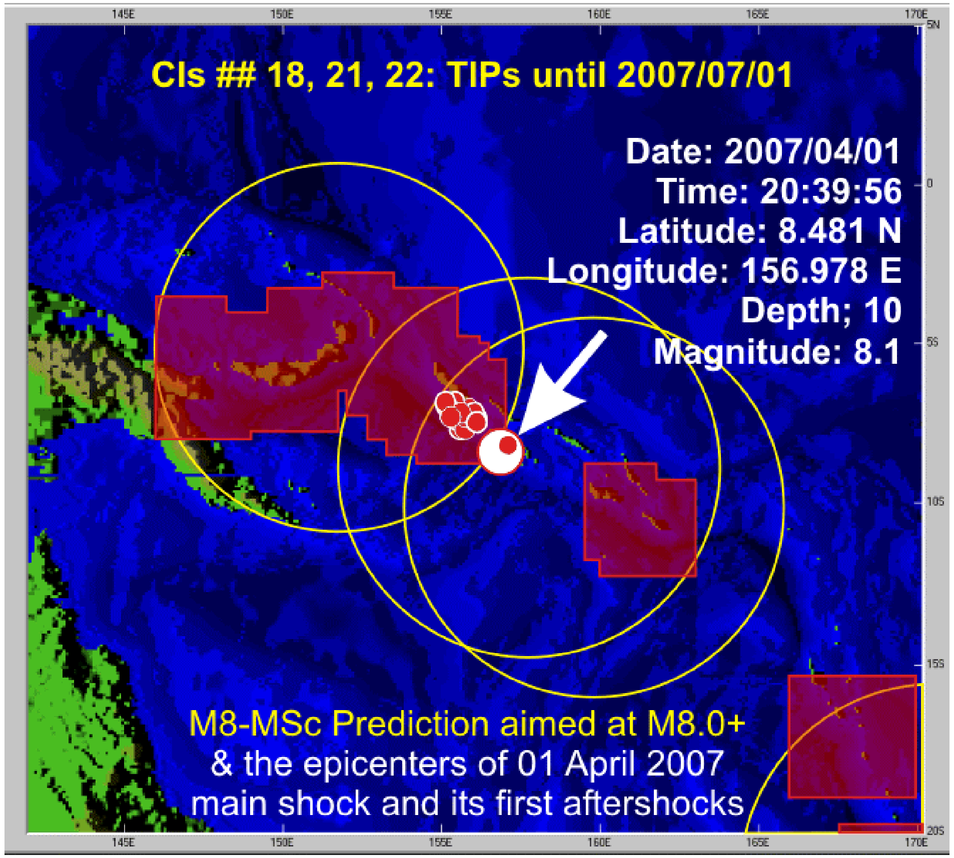


N the number of earthquakes of magnitude ***M**** or greater; ***N**** the annual number of earthquakes
L the deviation of ***N*** from longer-term trend; ***Z*** estimated as the ratio of the average source diameter to the average distance between sources; ***B*** the maximum number of aftershocks.
Each of the functions *N*, *L*, and *Z* is calculated twice with $M^* = M_{min}(N^*)$ for N^* = *N*1 and N^* = *N*2.

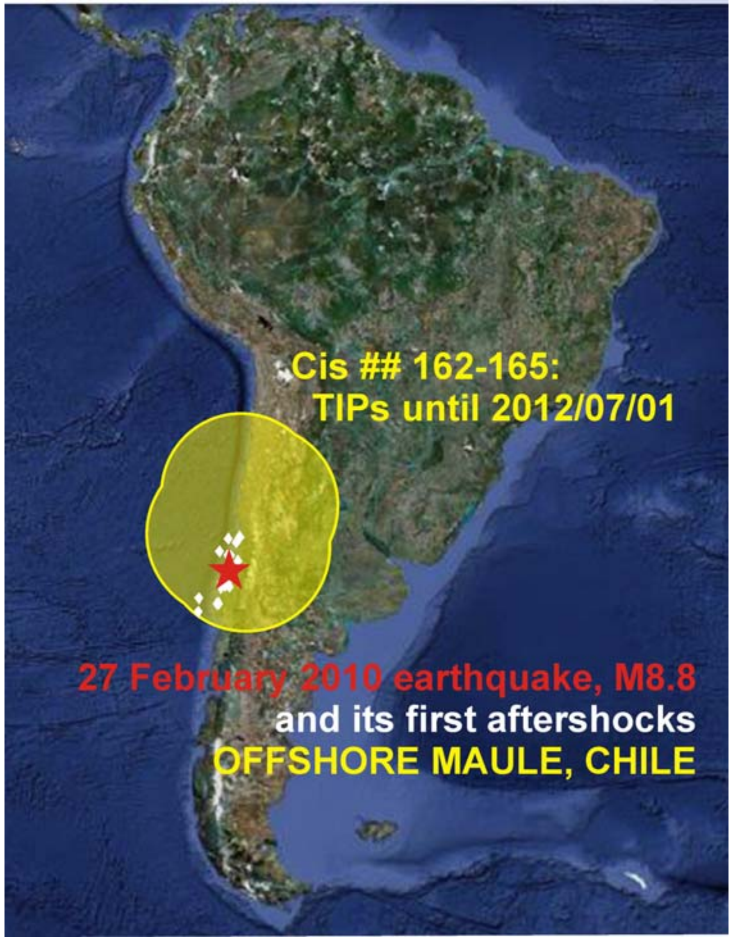
Predicting ExSeiEvs

Intermediate-term earthquake prediction

2007 Solomon Islands Earthquake



2010 Chile Earthquake

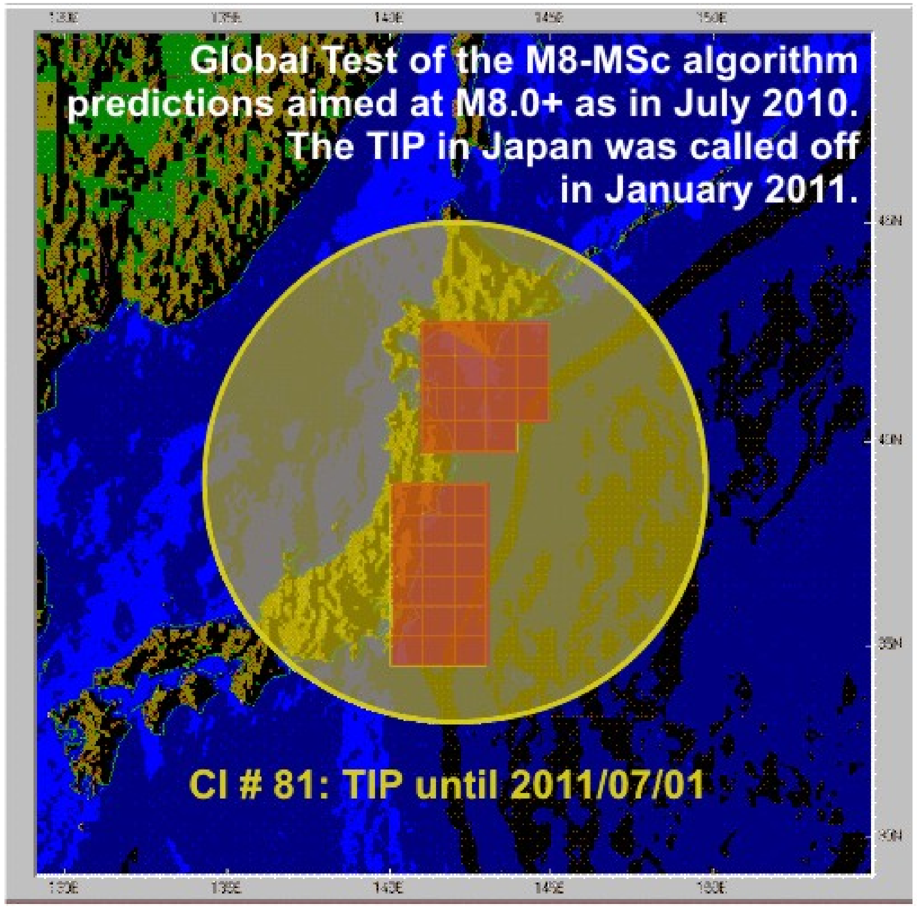


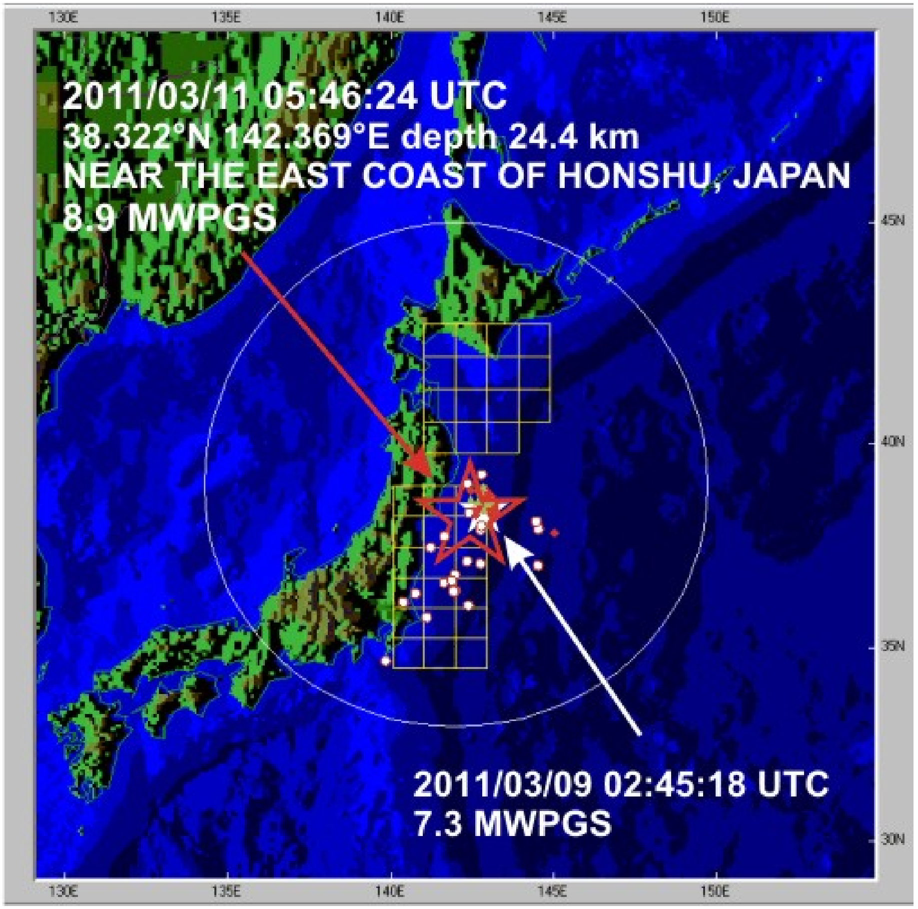
(courtesy of V. Kossobokov)

Predicting ExSeiEvs

Intermediate-term earthquake prediction

2011 East Japan Earthquake





(courtesy of V. Kossobokov)

Predicting ExSeiEvs

Intermediate-term earthquake prediction

Performance of the M8 earthquake prediction algorithm

<table>
<tr><th rowspan="3">Test period</th><th colspan="3">Large earthquakes</th><th colspan="2" rowspan="2">Alarms, %</th><th colspan="2" rowspan="2">Confidence level, %</th></tr>
<tr><th colspan="2">Predicted by</th><th rowspan="2">Total</th></tr>
<tr><th>M8</th><th>M8-MSc</th><th>M8</th><th>M8-MSc</th><th>M8</th><th>M8-MSc</th></tr>
<tr><td>1985-2009</td><td>13</td><td>10</td><td>18</td><td>32.93</td><td>16.78</td><td>99.93</td><td>99.98</td></tr>
</table>

Final Remarks:

Preparedness to Extreme Seismic Hazards

Questions:

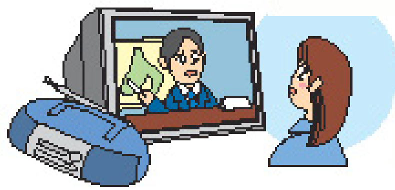
- How the huge knowledge in science of ExEvs can assist in mitigation or prevention of tragic consequences of the events?
- What should scientists do to convince disaster management authorities to mitigate or possibly even to prevent humanitarian disasters caused by earthquakes?

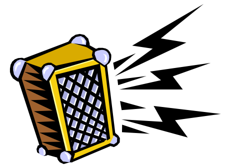
Some answers:

- We (geoscientists) should encorage inter-, multi- and trans-disciplinary studies related to geohazards and disaster risk analysis.
- We should enhance our modeling and forecasting abilities.
- We should measure scientific achievements by the reduction in disaster risk and actual damages, rather than just by the accounting the knowledge accumulated.
- We should delivery an accurate information about potential ExEvs (and the probability of their occurences) to disaster management authorities.
- We should educate the society living with risk and increase the awareness of population about ExEvs.

Public Awareness

Without having the scientific awareness raised, no political and governmental actions are possible. Here there is a large room for geoscientists to take responsibility.





Safe Evacuation Route

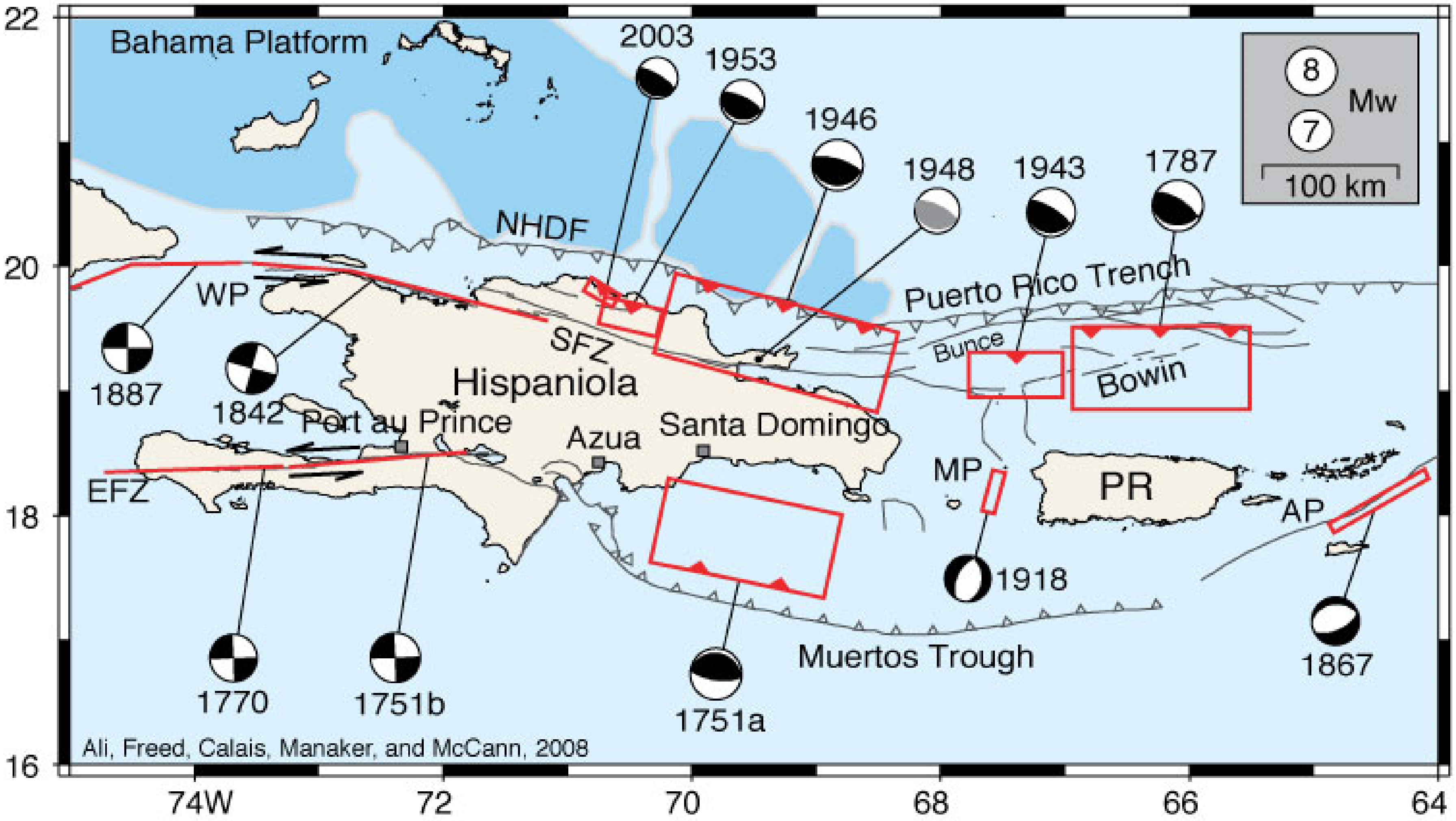
Understanding of Hazardous Areas

Early Warning

Safe Evacuation

Appropriate Risk Awareness of Local Communities

Scientific Awareness



Public Education

Geoscientists should promote *e*-education through the Internet

Dunbar (2007)

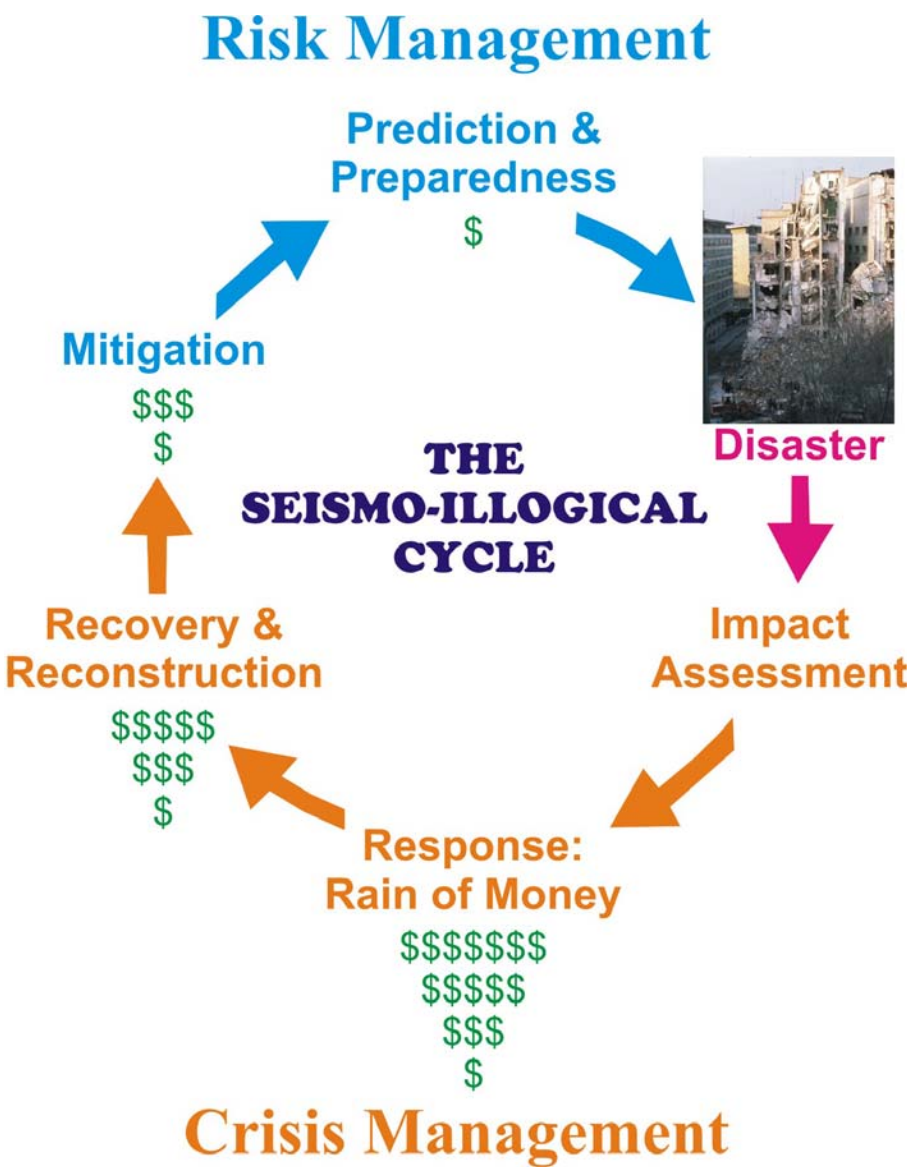
Economics of Disaster Risk Management

"If about 5 to 10% of the funds, necessary for recovery and rehabilitation after a disaster, would be spent to mitigate an anticipated earthquake, it could in effect save lives, constructions, and other resources."

(Ismail-Zadeh, OECD Workshop, 2006)

"The tendency to reduce the funding for preventive disaster management of natural catastrophes rarely follows the rules of responsible stewardship for future generations, neither in developing countries nor in highly developed economies"

(Ismail-Zadeh and Takeuchi, 2007)



Final Remarks:

“Our Dream is the World without Natural Disasters”

- Earthquakes do not kill people, but buildings and corruption
- Geohazards cannot be reduced, but vulnerability

- Reducing predictive uncertainties in geohazard research
- Dealing with multiple and/or sequential events
- Developing a trans-disciplinary link and research

- Enhancing links to policy-makers, media & insurance
- Enhancing science education and improving awareness on extreme hazards and disaster risk

Buildings kill ...

Port-au-Prince, Haiti, 2010.

Corruption kills?

(Ambraseys and Bilham, 2011)

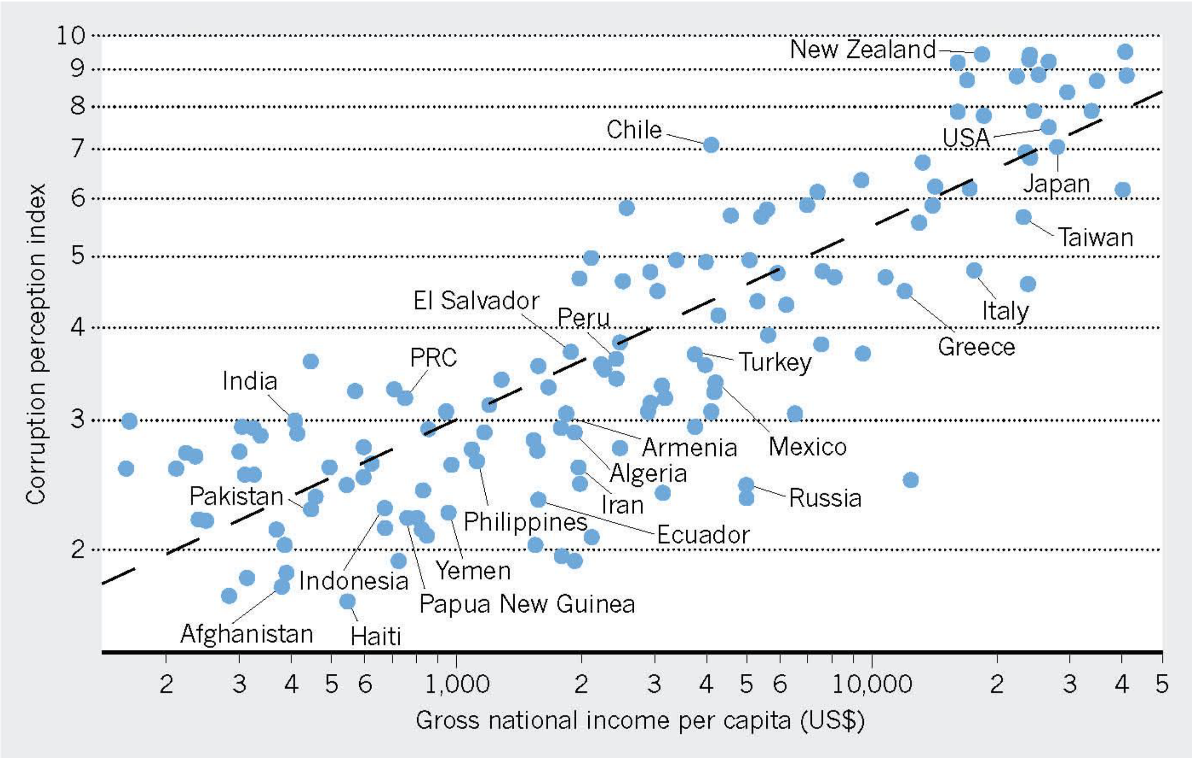


Figure 2 | Cash and corruption. The poorest countries are the most corrupt, but some are more corrupt than others. A weighted regression line (dashed) divides nations that are perceived as more corrupt (below the line) than might be expected from the average income per capita from those that are less corrupt (above the line). Named countries have lost citizens in building collapse caused by earthquakes since 1980.

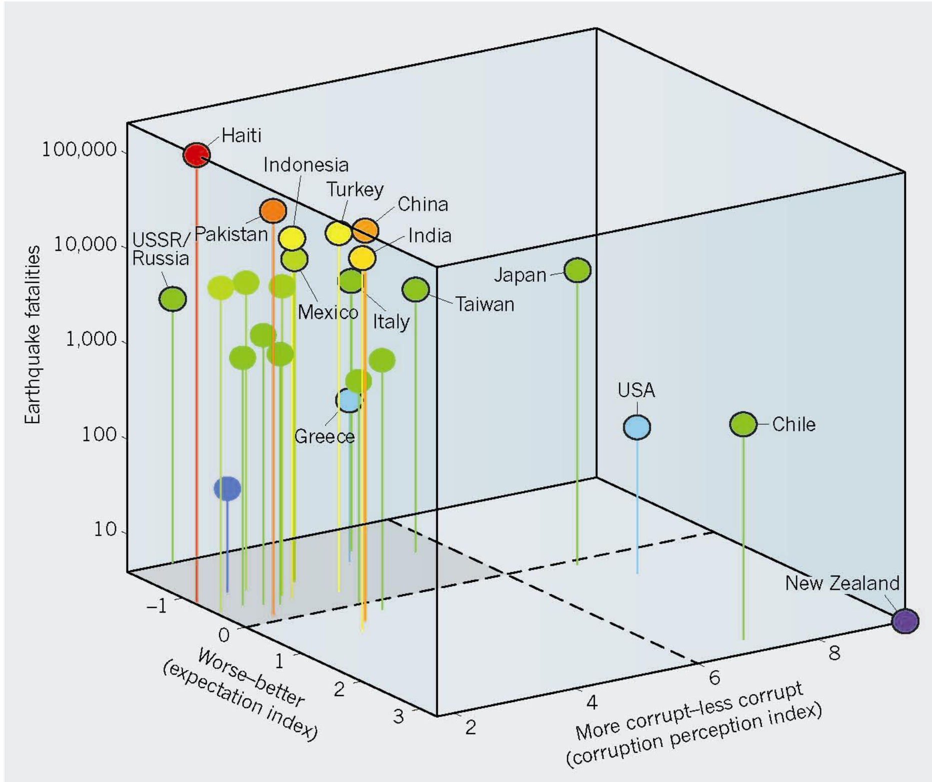


Figure 3 | Corruption's toll. Corruption versus the level of corruption that might be expected from per capita income. Of all earthquake fatalities attributable to building collapse in the past three decades, 82.6% occur in societies that are anomalously corrupt (left-hand corner of the plot).

Final Remarks:

"Our Dream is the World without Natural Disasters"

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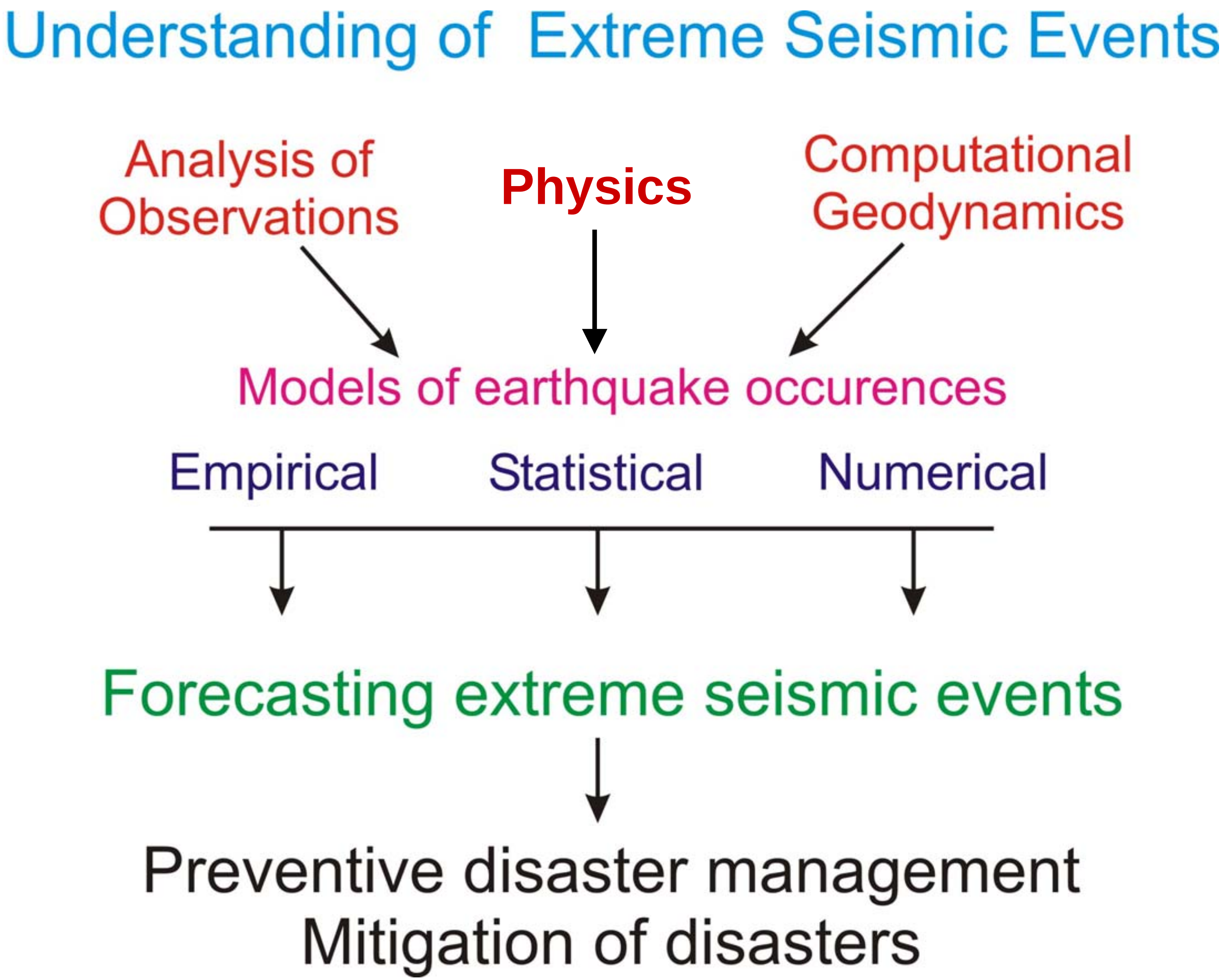
Conclusion



(via preparedness, education and awareness)