# Extreme Seismic Hazards & Societal Implications

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## **Final Remarks**:

"Our Dream is the World without Disasters"

- Earthquakes do not kill people, but buildings (corruption, irresponsibility, ignorance …)

"If humans are building on inflammable material, over a short time the whole splendour of their edifices will be falling down by shaking. However, is this reason to blame providence for it?"
(*I. Kant, Das Erdbeben, 1756*)

*Kant (1724–1804)*

## **Final Remarks**:

"Our Dream is the World without Disasters"

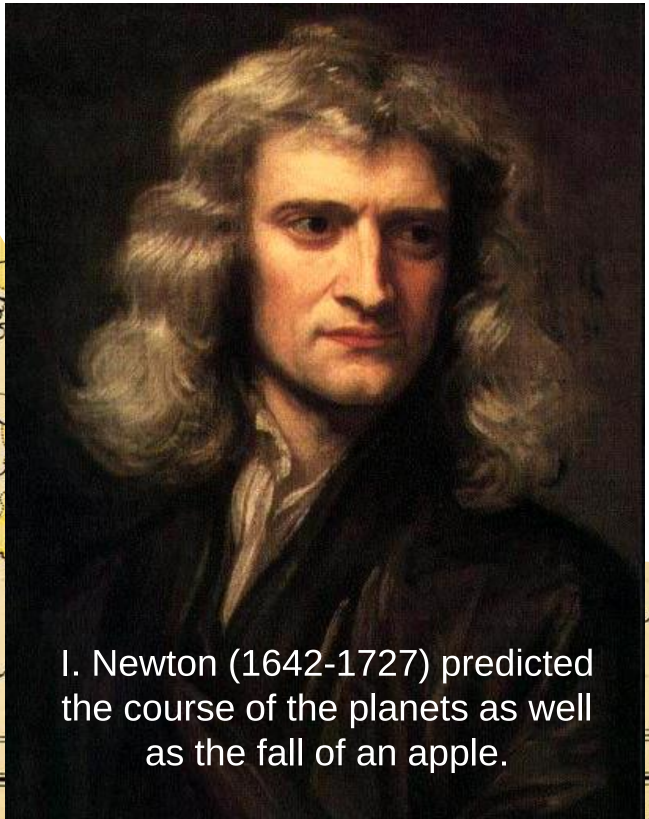
- Geohazards (earthquakes, volcanoes, tsunamis, landslides) cannot be reduced, but vulnerability!
- Reducing predictive uncertainties in geohazard research and enhancing modeling capabilities
- Dealing with multiple and/or sequential events
- Developing a trans-disciplinary link and research (example, forensic investigations of disasters)
- Developing links to policy-makers, media & insurance
- Enhancing science education and improving awareness on extreme hazards and disaster risk

## The Age of Enlightenment

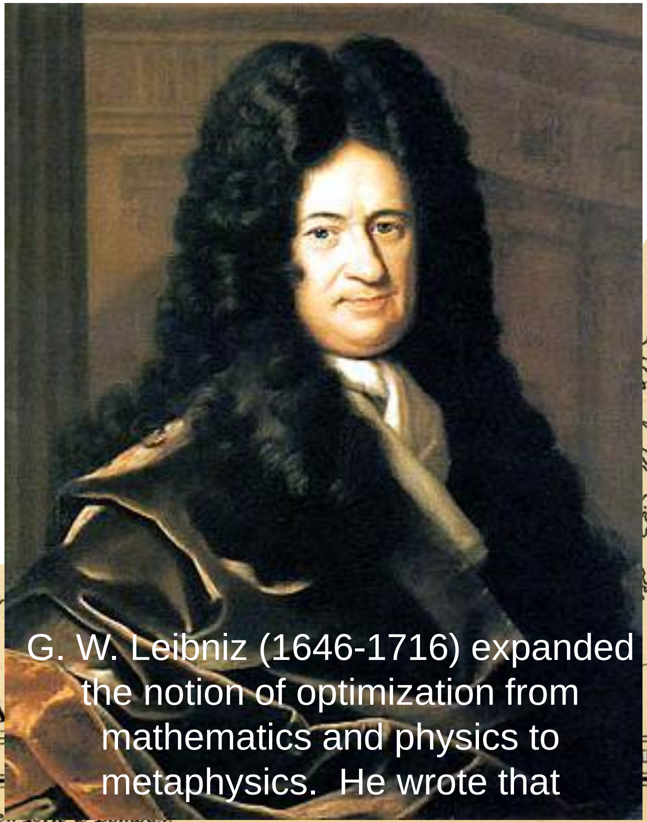
**The world appeared to become stable, calculable and predictable.**

**Two eminent scientists stand for this spirit of the 18th century.**

# We live in the best of all possible worlds



I. Newton (1642-1727) predicted the course of the planets as well as the fall of an apple.



G. W. Leibniz (1646-1716) expanded the notion of optimization from mathematics and physics to metaphysics. He wrote that

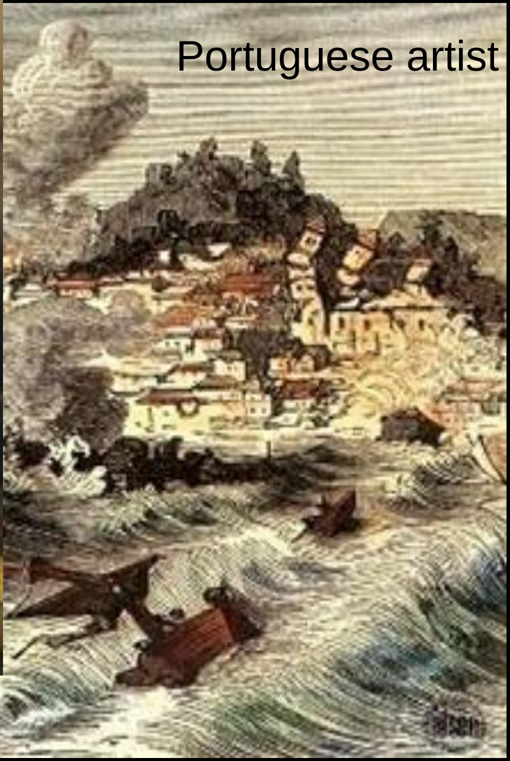
## The Notion of Risk

developed in Europe assumed that the future depends on human decisions rather than on providence with a chance to loose or to win.

P. Fermat and B. Pascal discuss about the modern concepts of probability and develop a theory **to control the incalculable future** (or to make **predictions with a quantifiable risk)**

Lisbon, 1 November 1755


Disaster Management Plan for Lisbon




Tohoku, 13 March 2011


National Geographic


250 years later

# Loss of Cover

(K. Fuchs)

**Loss of Faith**

**Loss of Safety**

**1 November 1755**

**11 March 2011**

# Extreme Seismic Events (ExSeiEv)

***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) A large magnitude and rare earthquake, and

(II) An earthquake leading to a disaster.

ExSeiEvs, like 1755 Lisbon, 1906 San Francisco, 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 1960 and 2010 Chile earthquakes 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.

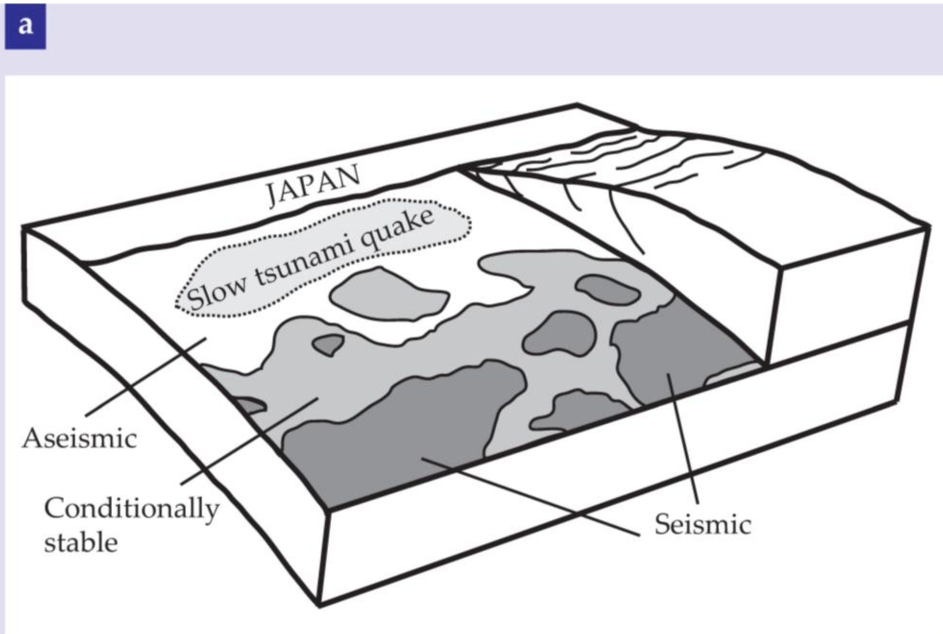
# Extreme Seismic EventS (ES2)

***ES2*** 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" Approach to Research on ES2 and Disaster Risk

- Understanding of physical phenomena and dynamics of extreme events.
- From physical understanding of these events *to* modeling of extreme events and hazard assessment.
- From modeling / hazard assessment *to* forecasting / prediction of ES2, and to the assessment of physical and social vulnerability, and exposure.
- From forecasting and sophisticated risk analysis *to* prompt information delivery to disaster management authorities in order to undertake preventive measures and to mitigate (if not fully prevent) earthquake / tsunami disasters.

# Understanding of Large Earthquake Occurence Using Physics of Rupture



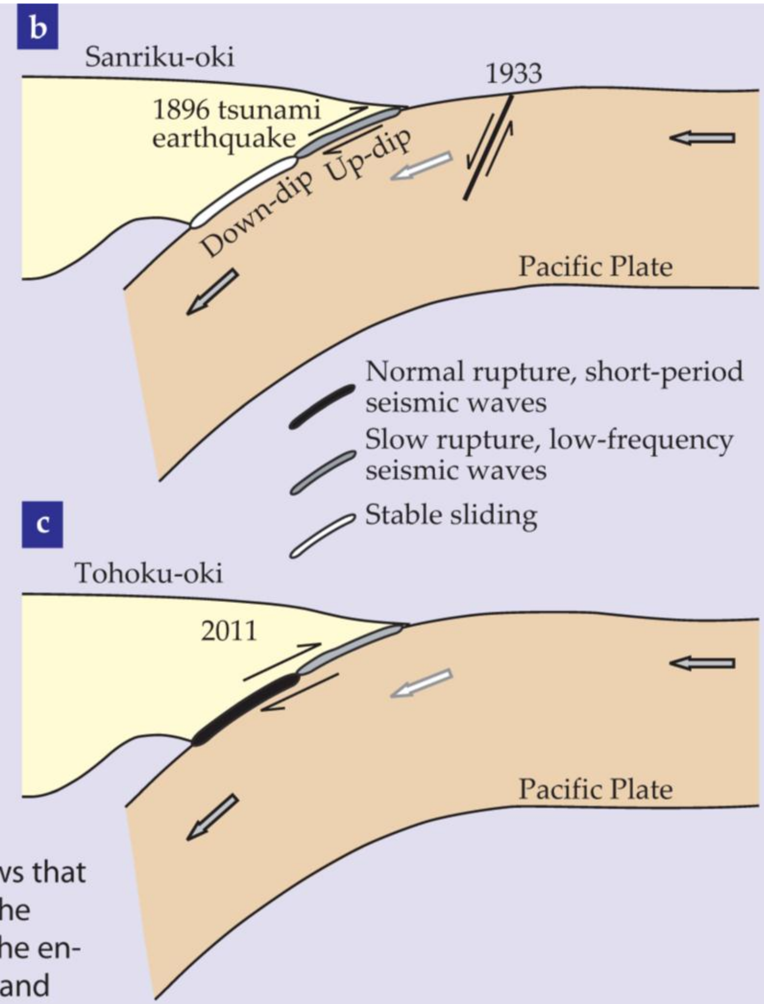
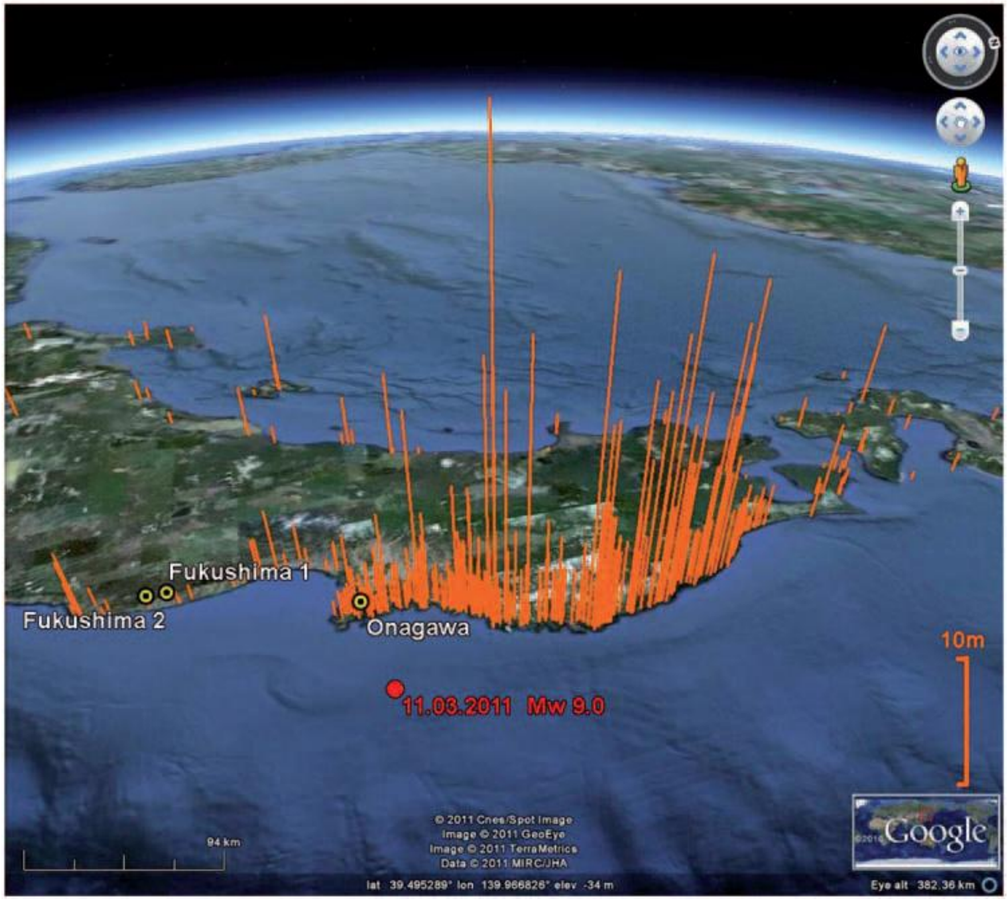



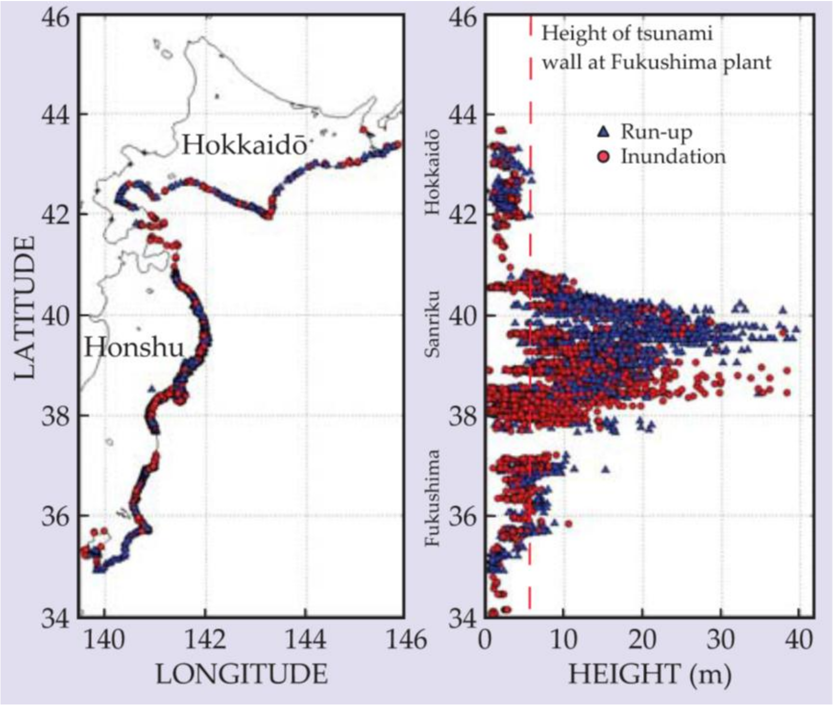

**Figure 2. A frictionally complex fault. (a)** The megathrust off the coast of Japan comprises regions that slip seismically, regions that slip aseismically, slow-rupturing regions that experience large slip at shallow depths generating tsunami earthquakes, and conditionally stable regions that slip aseismically unless adjacent slips drive them to slide seismically. **(b)** Cross-sectional schematic of the Sanriku-oki region shows that the great 1896 and 1933 earthquakes ruptured at shallow depths, but the deeper part of the megathrust appears to be aseismic. **(c)** By contrast, the entire megathrust in the Tohoku-oki region failed—both shallow "up-dip" and deeper "down-dip" parts of the cross section. The faster-sliding down-dip rupture generated high levels of short-period radiation, while the slower-sliding up-dip rupture generated low levels of short-period radiation.

Lay and Kanamori, 2011

# Understanding of Large Earthquake Occurence Using Tsunami Data Analysis

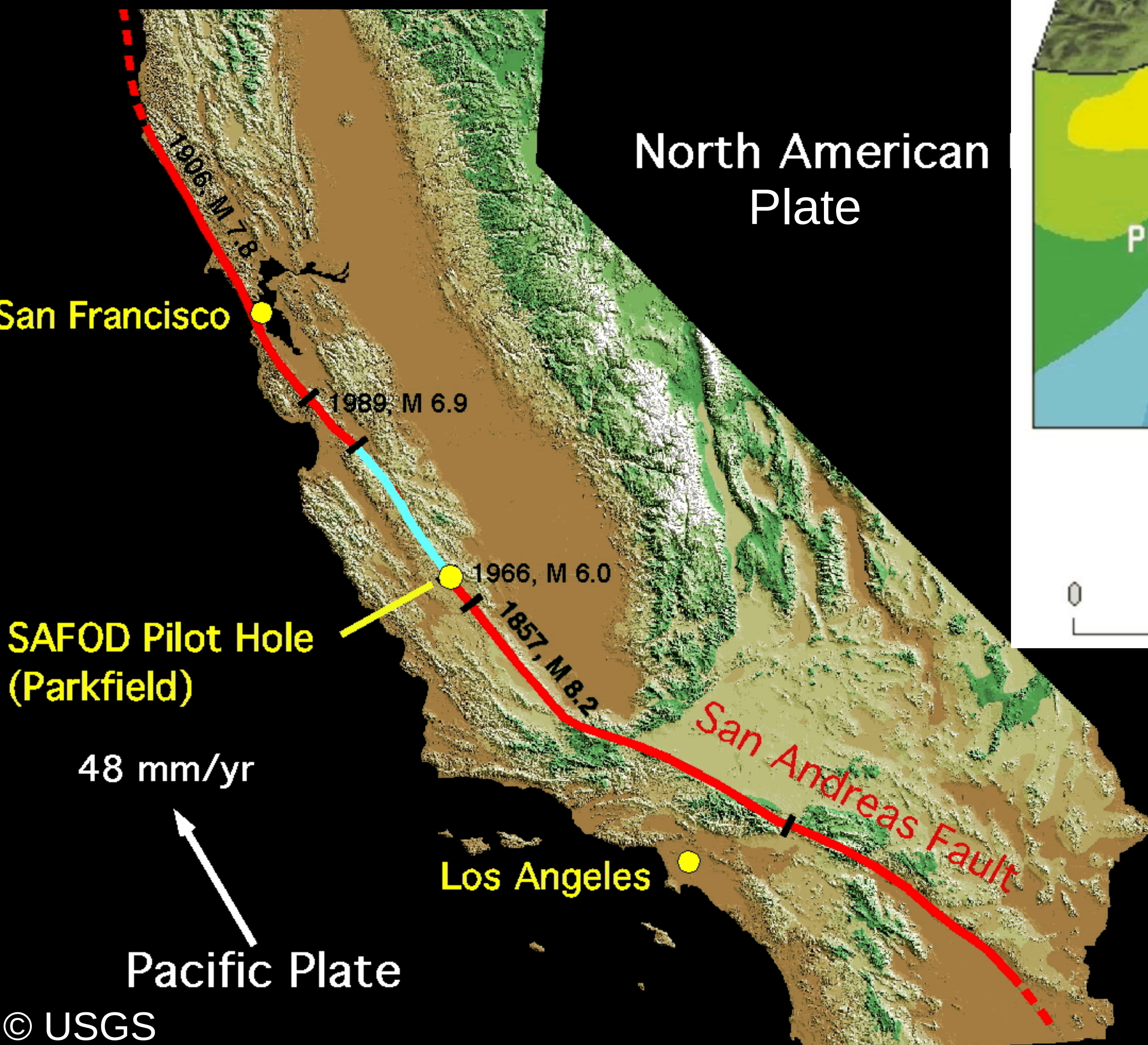



A map of reported historical tsunami run-ups along the Tohoku coast for the time period from AD 800 until 1965 (Noeggerath et al., 2011).

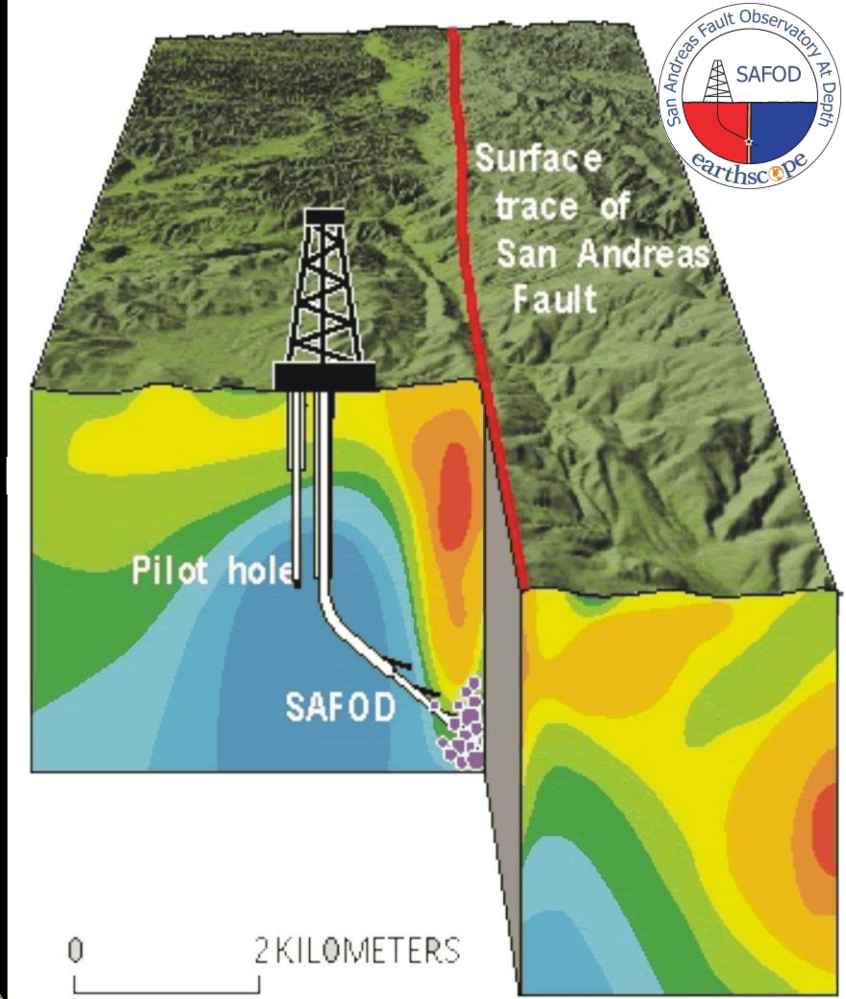



A map of the Honshu and Hokkaido islands and the relative locations and heights of the 2011 tsunami inundation (red) and the tsunami run-up (blue) (Lay and Kanamori, 2011).

# Understanding of Earthquakes Preparation Processes based on Physics of Fault Zones



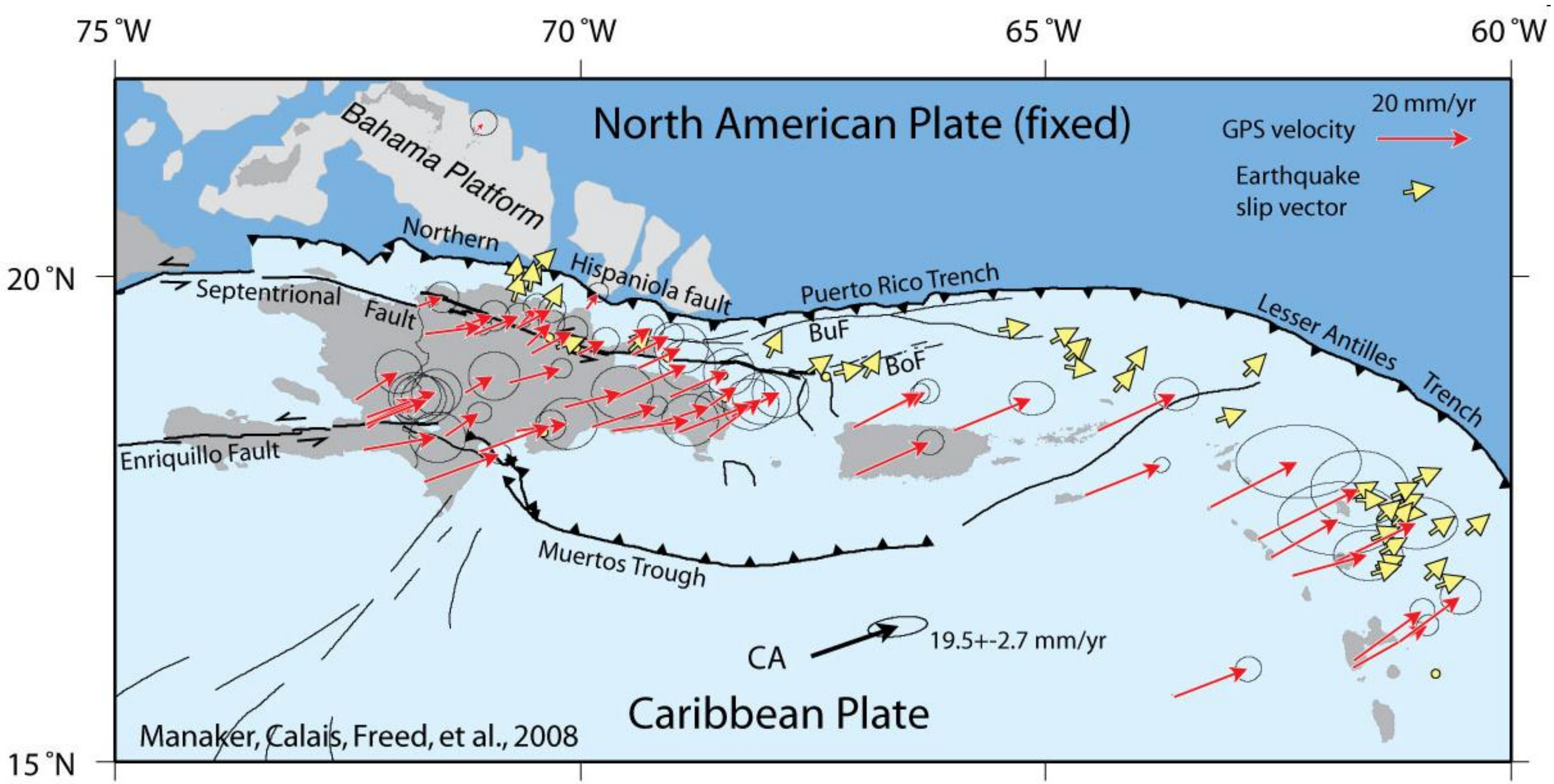



SAFOD project:

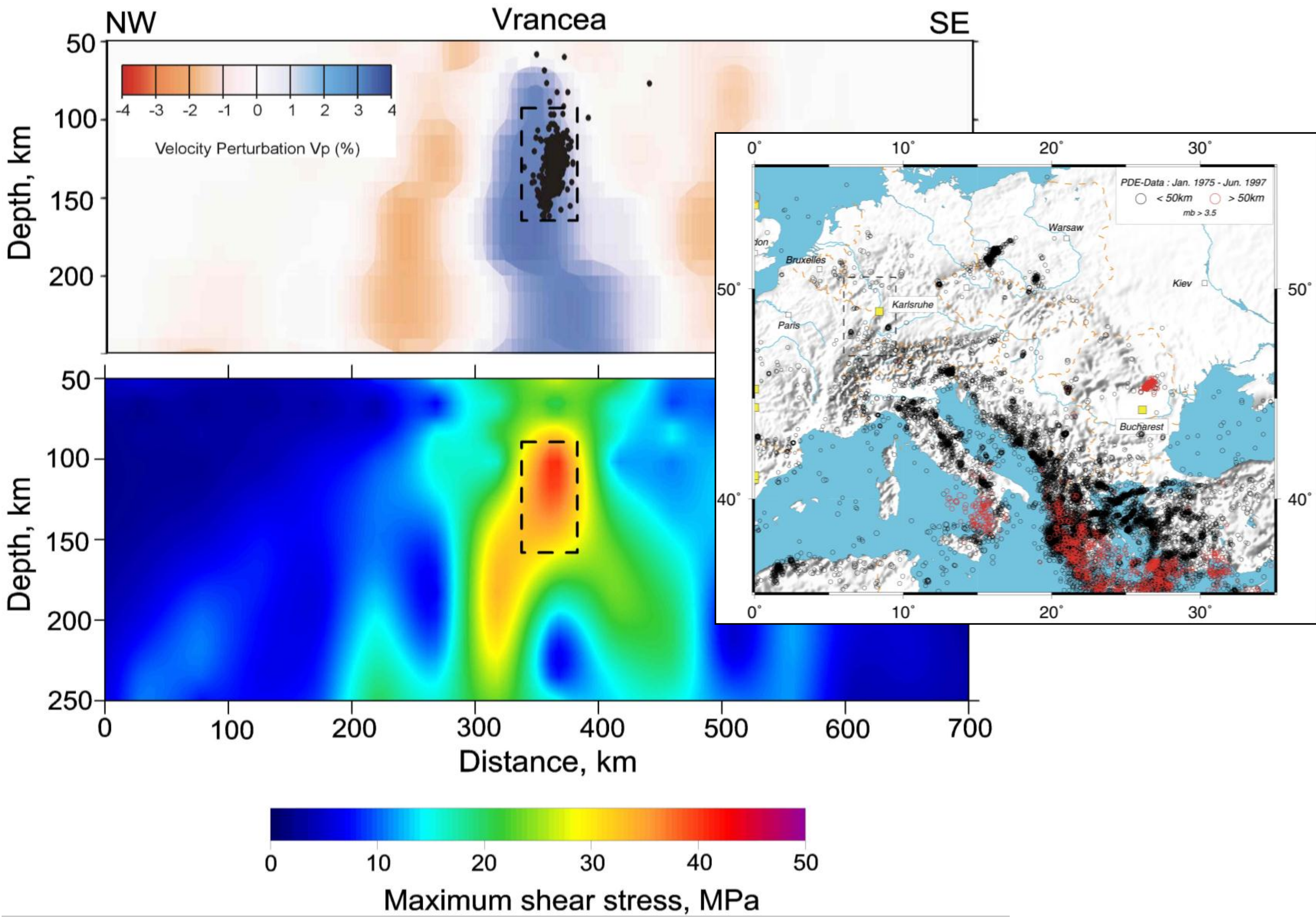
New information on fundamental theories of earthquake mechnaics and on how stress works in the lithosphere: stress generation and release

# 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)

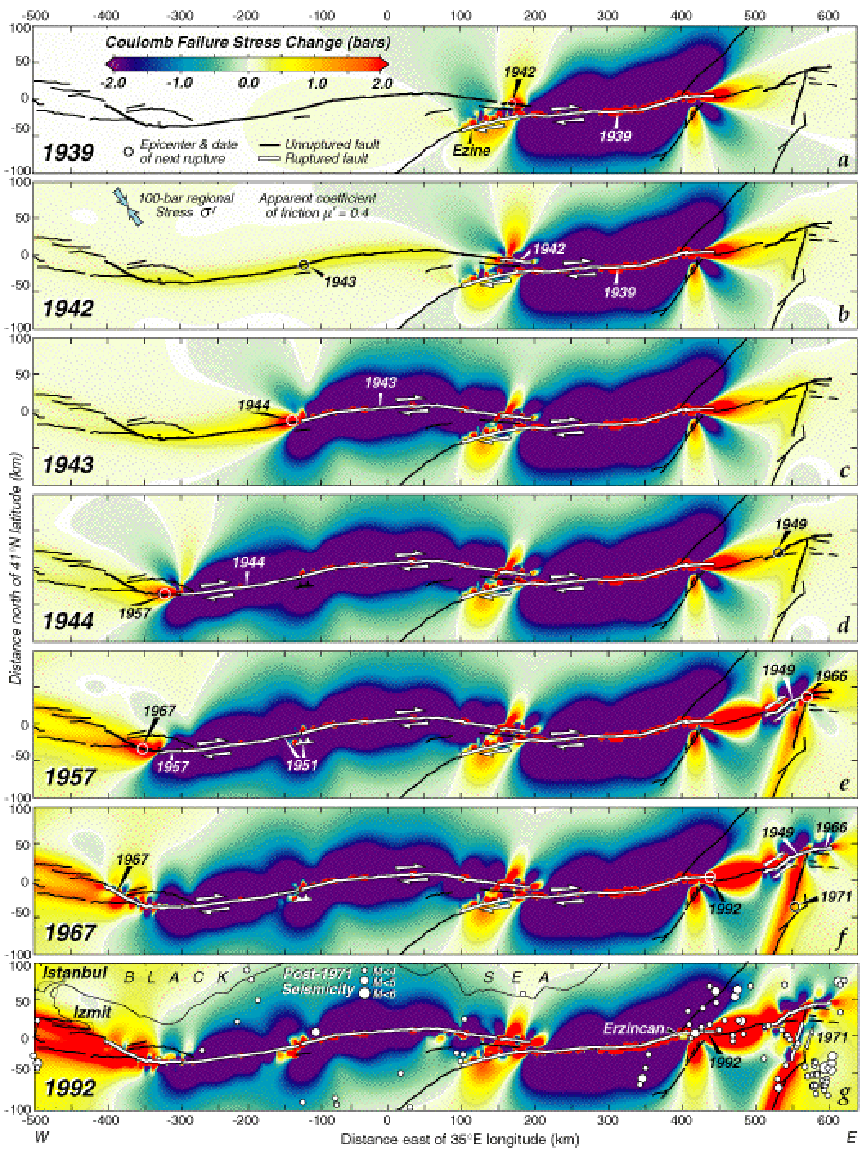
# Understanding of Strong Earthquake Preparation Processes - Stress Modeling



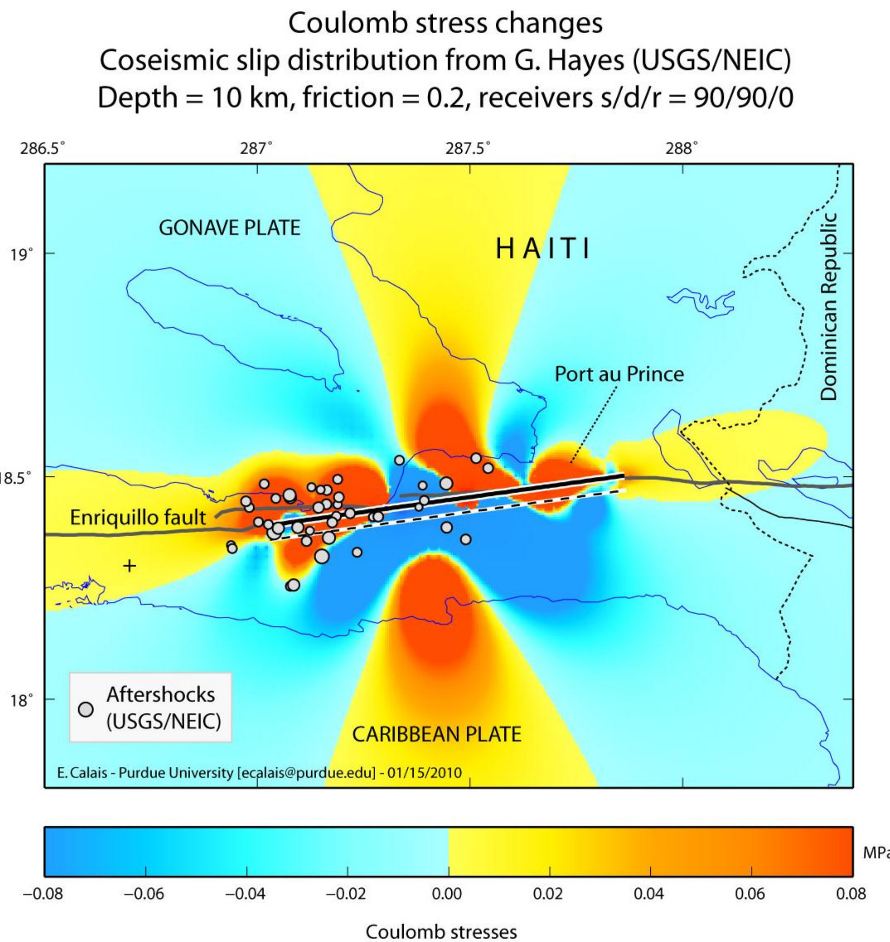

Ismail-Zadeh et al., 2005, PEPI

# Understanding of Strong Earthquake Preparation Processes – Stress Modeling

Coulomb-stress change evaluation




Stein et al.,1997



# Understanding of ExSeiEvs Dynamics Using Earthquake Modeling

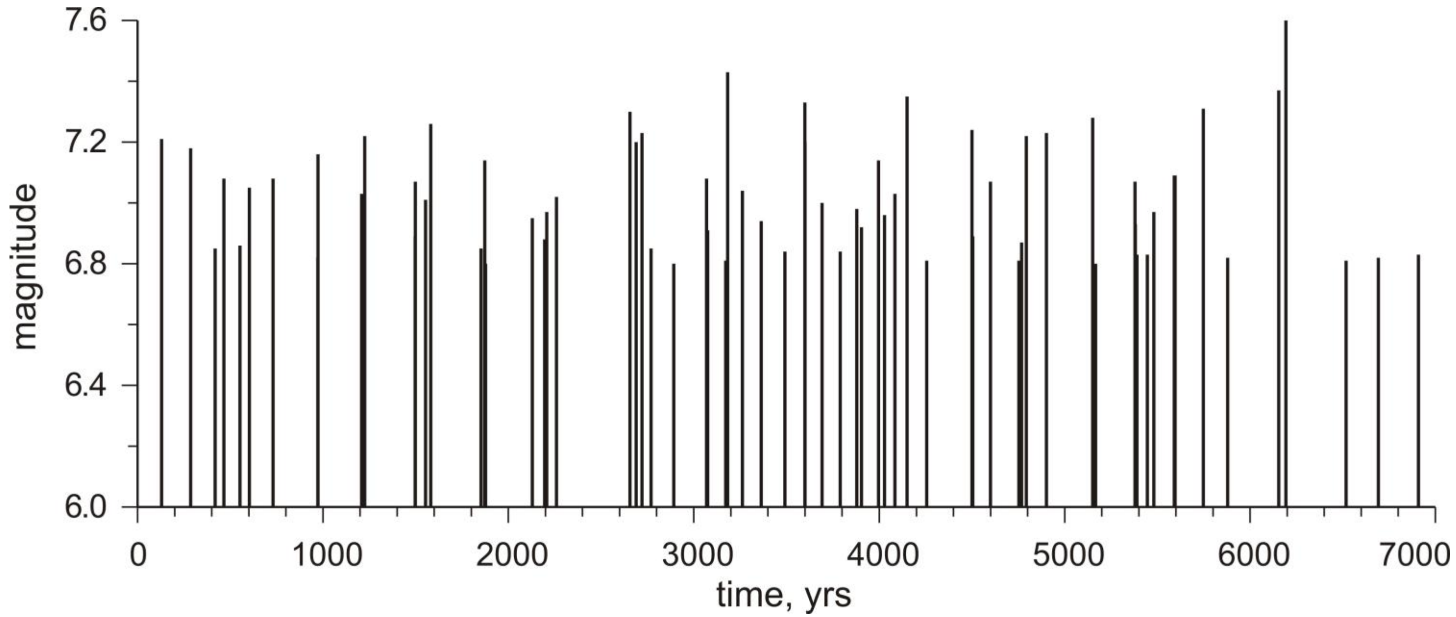
Simulation of realistic earthquake catalogs for an earthquake-prone region is of a great importance. The catalogs of synthetic events over a large time window can assist in interpreting the seismic cycle behavior and/or in predicting a future extreme event, as the available observations cover only a 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 analyse and to forecast extreme events.

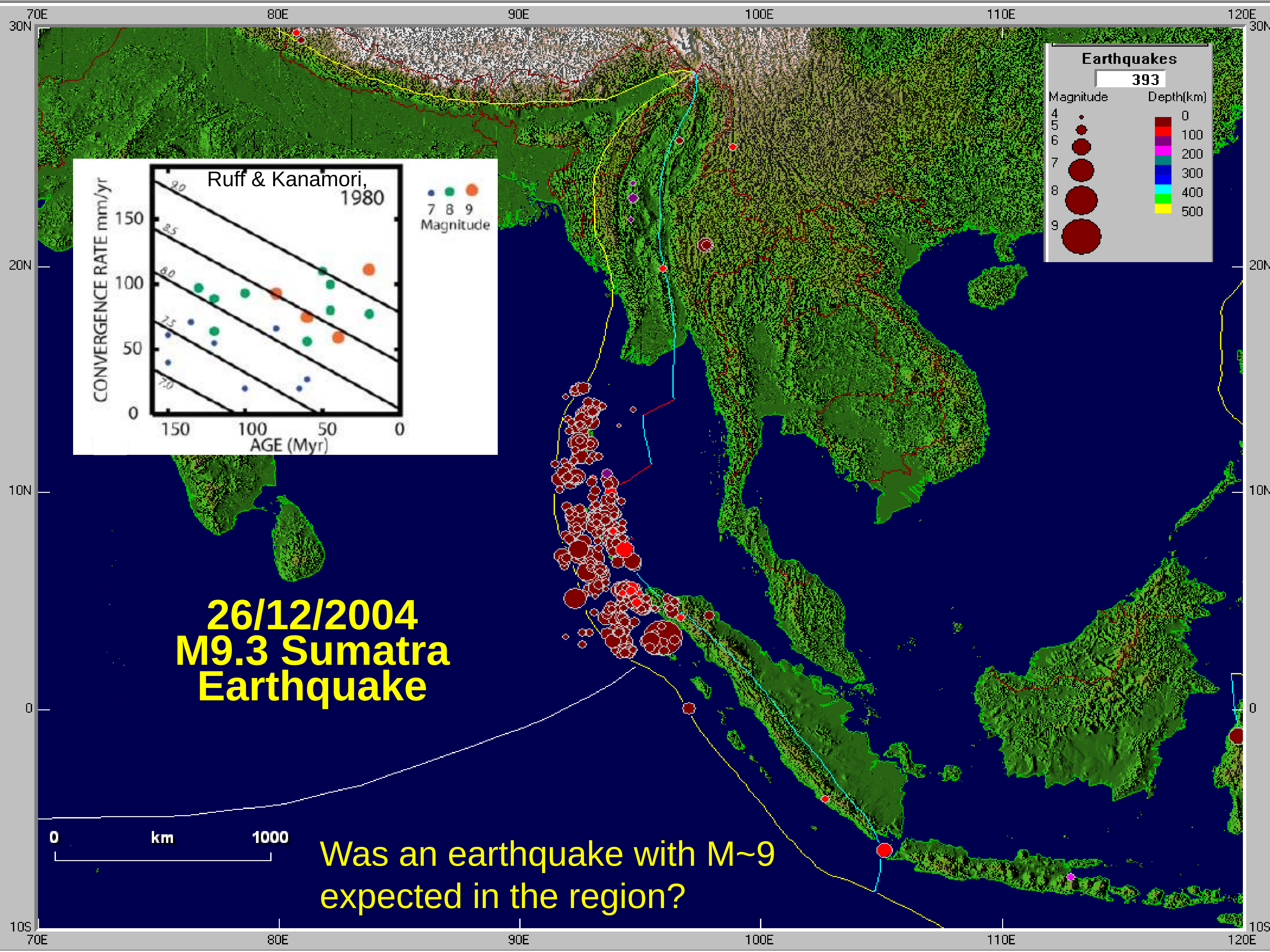
**Catalogs of modeled seismic events allow to analyze**

- 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

# Case Studies

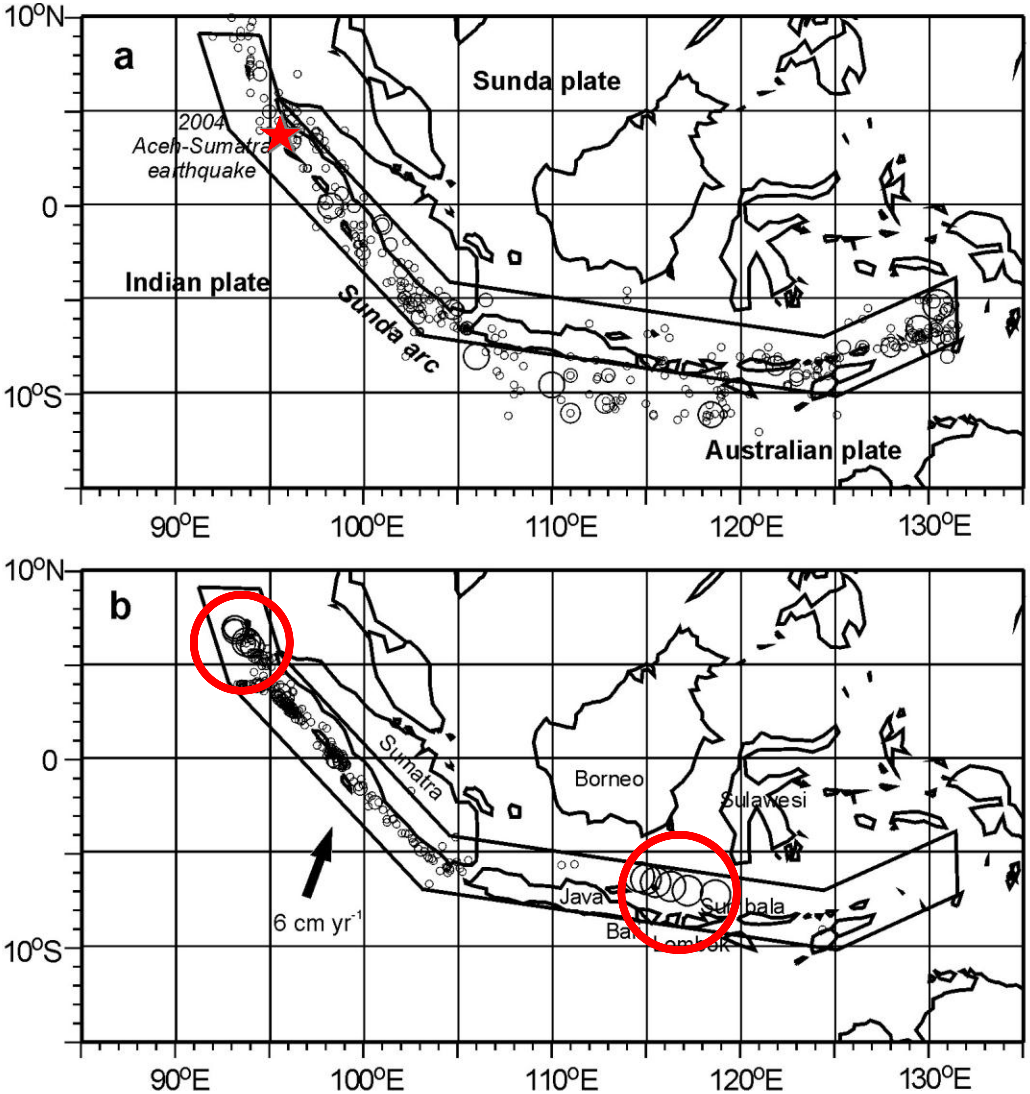
- Asia: Sunda Arc
- Tibet/Himalaya

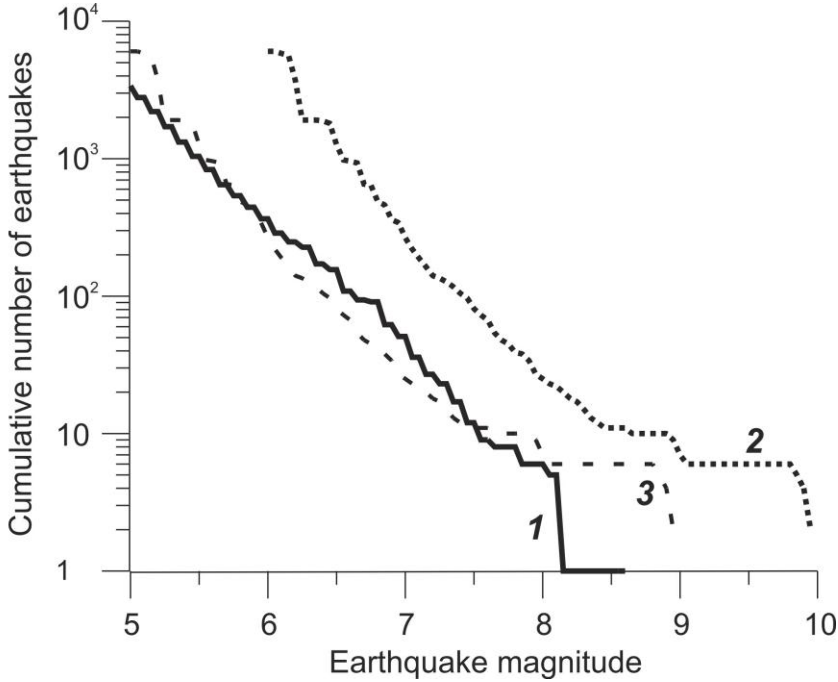



70E
80E
90E
100E
110E
120E
30N
20N
10N
0
10S
Earthquakes
393
Magnitude
Depth(km)
4
5
6
7
8
9
0
100
200
300
400
500
Ruff & Kanamori, 1980
CONVERGENCE RATE mm/yr
150
100
50
0
AGE (Myr)
9.0
8.5
8.0
7.5
7.0
7 8 9
Magnitude
26/12/2004
M9.3 Sumatra
Earthquake
0
km
1000
Was an earthquake with M~9
expected in the region?

# Sunda Arc – BAFD model

Observed seismicity, M>6

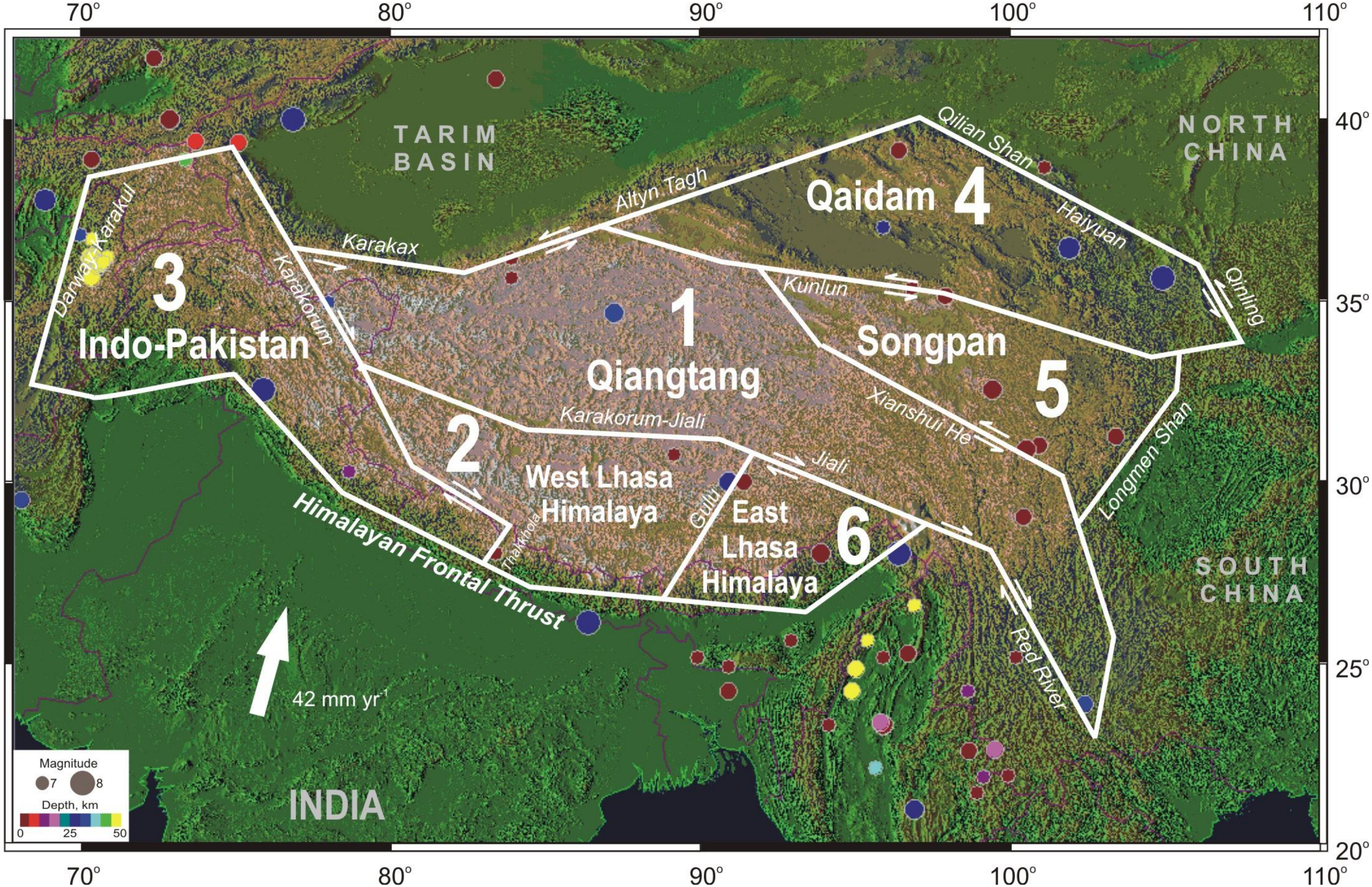



Synthetic seismicity, M>7

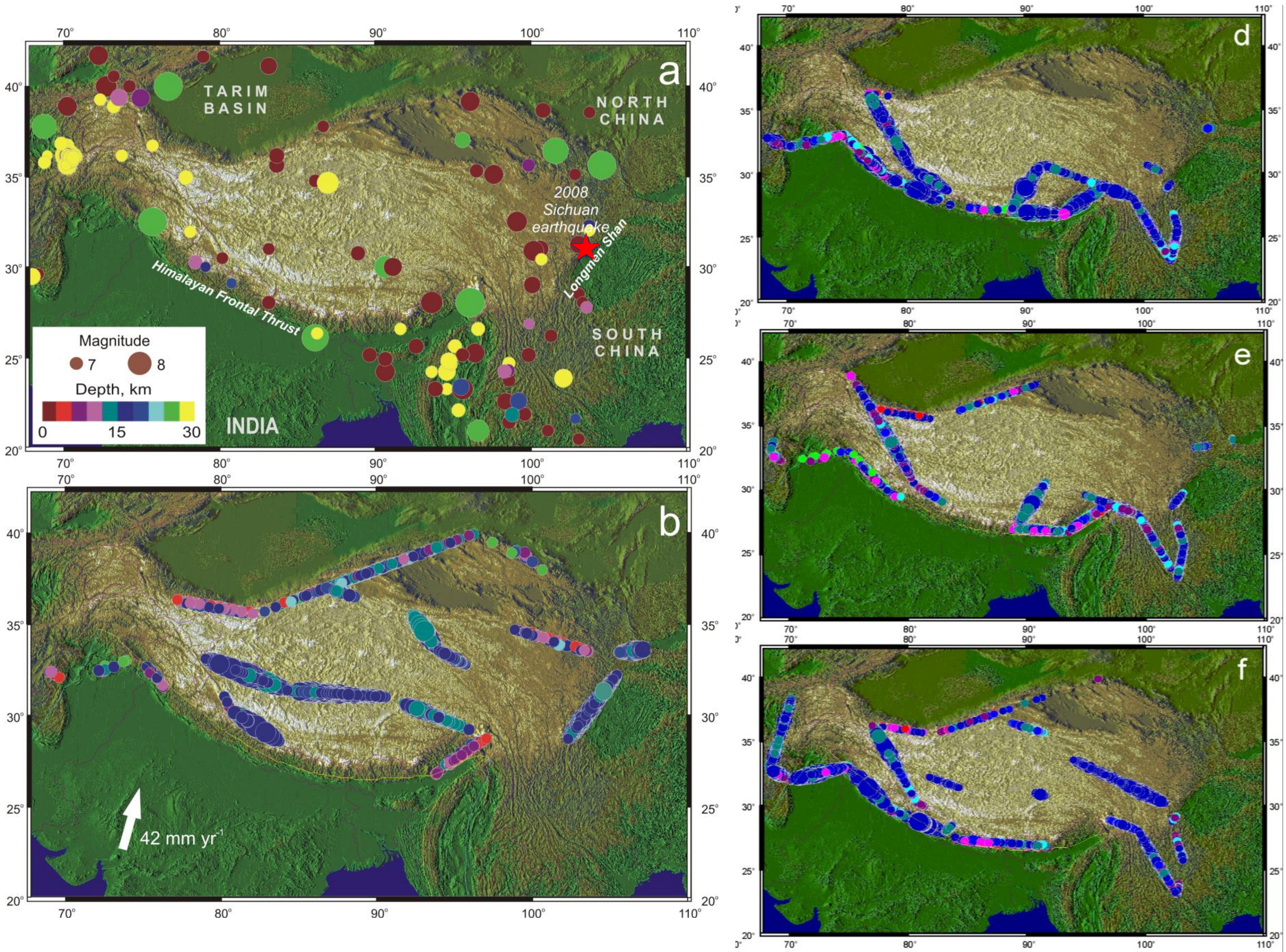
(Soloviev and Ismail-Zadeh, 2003, Springer)

# Tibetan Plateau - BAFD Model




(Ismail-Zadeh et al., 2007, EPSL)

# Tibetan Plateau - BAFD Model Results



## Question:

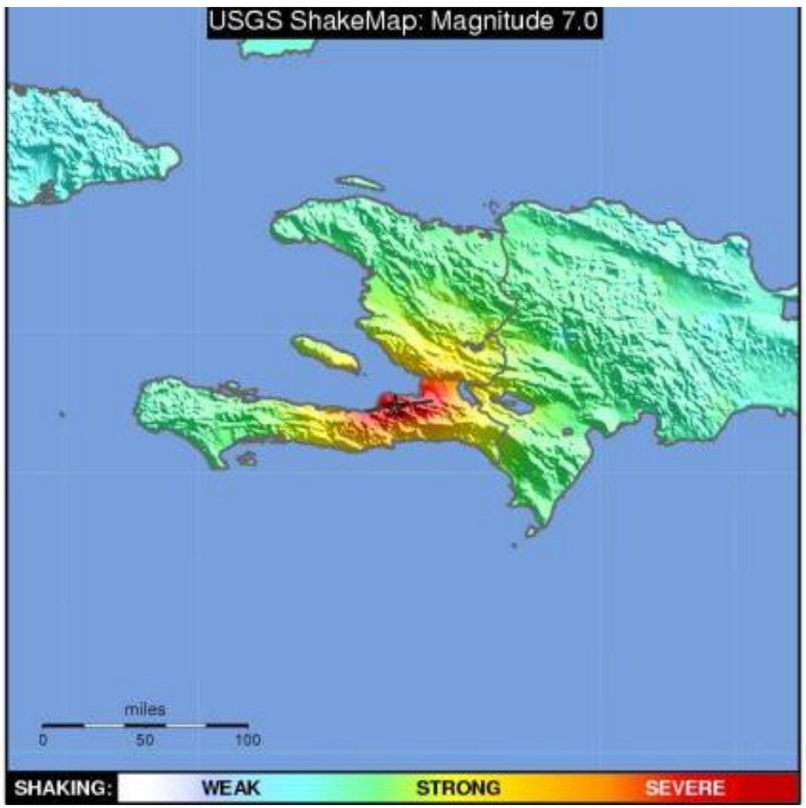
## Can Modern Seismic Hazard Assessment 'Forecast' Extreme Seismicity?

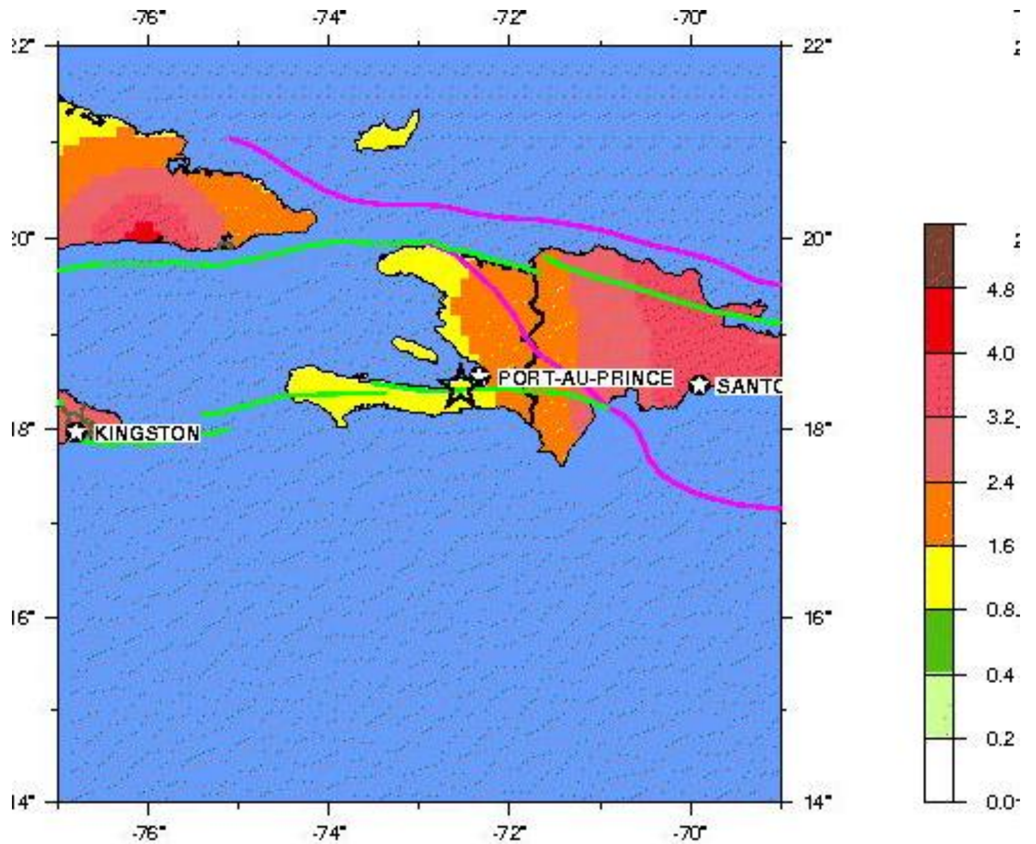
## Answer:

Yes, BUT if historical and modeled extremes are incorporated in comprehensive hazard assessments (combining the best features of probabilistic and deterministic assessments)

# Answer: No, otherwise

## 2010 Haiti Earthquake

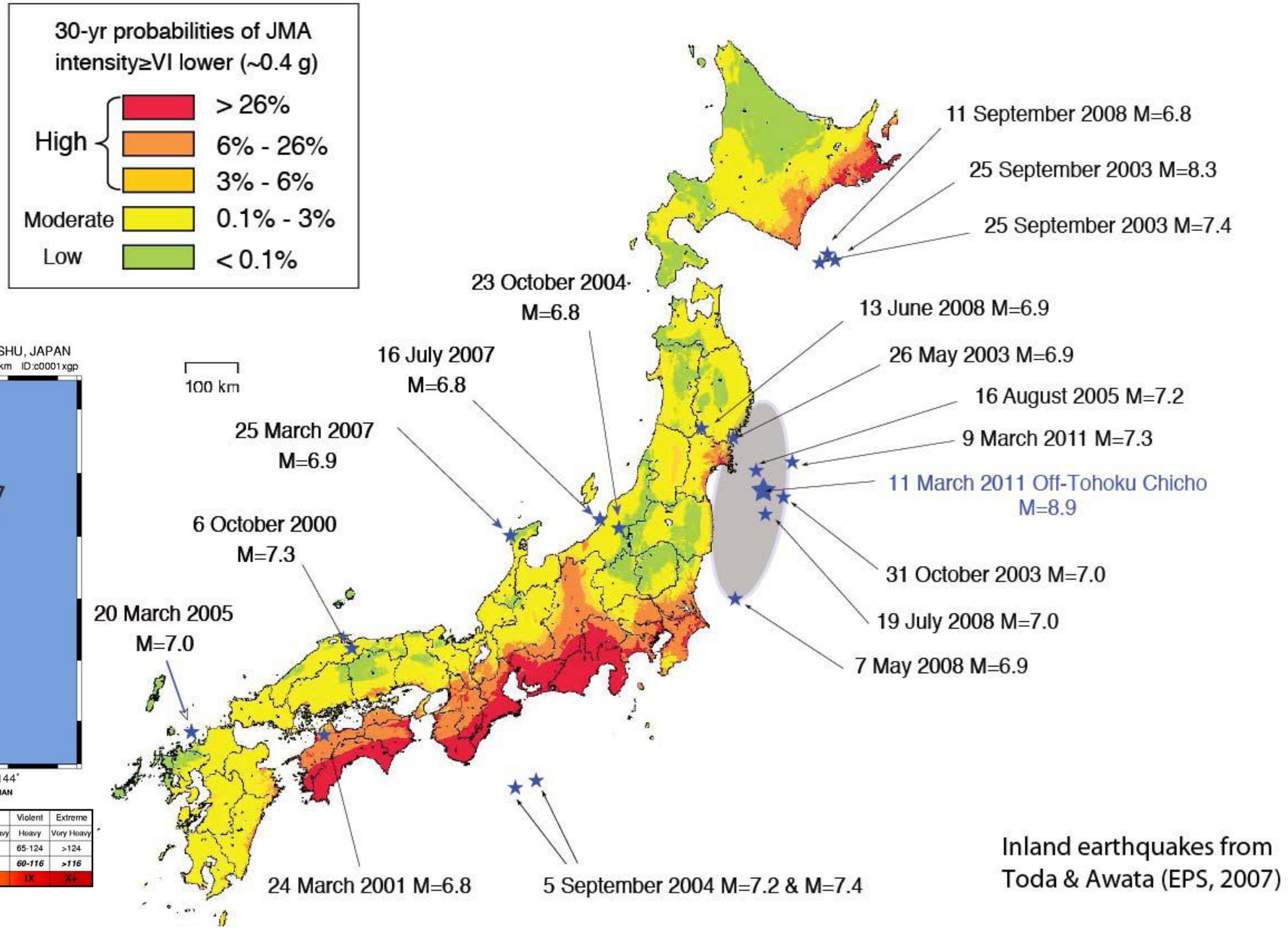


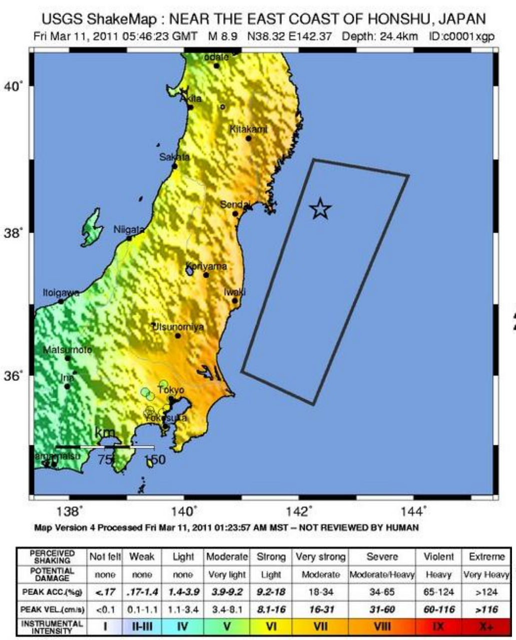




USGS

Observed shaking Predicted PGA by PSHA

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



## Question:

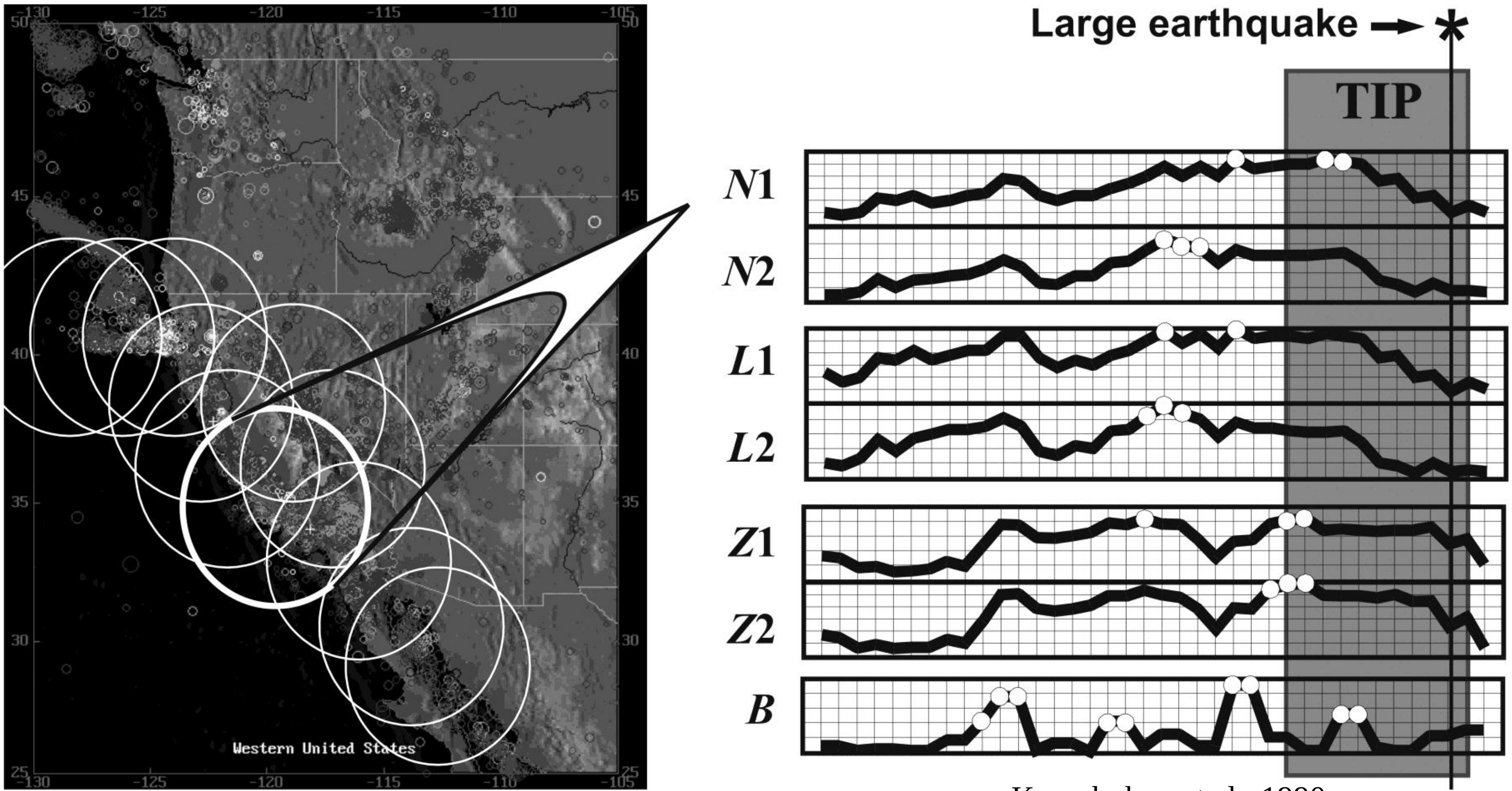
## Can Extreme Seismic Events be Predicted?

**Answer:**

Not yet, but …

# Predicting ExSeiEvs

Intermediate-term earthquake prediction



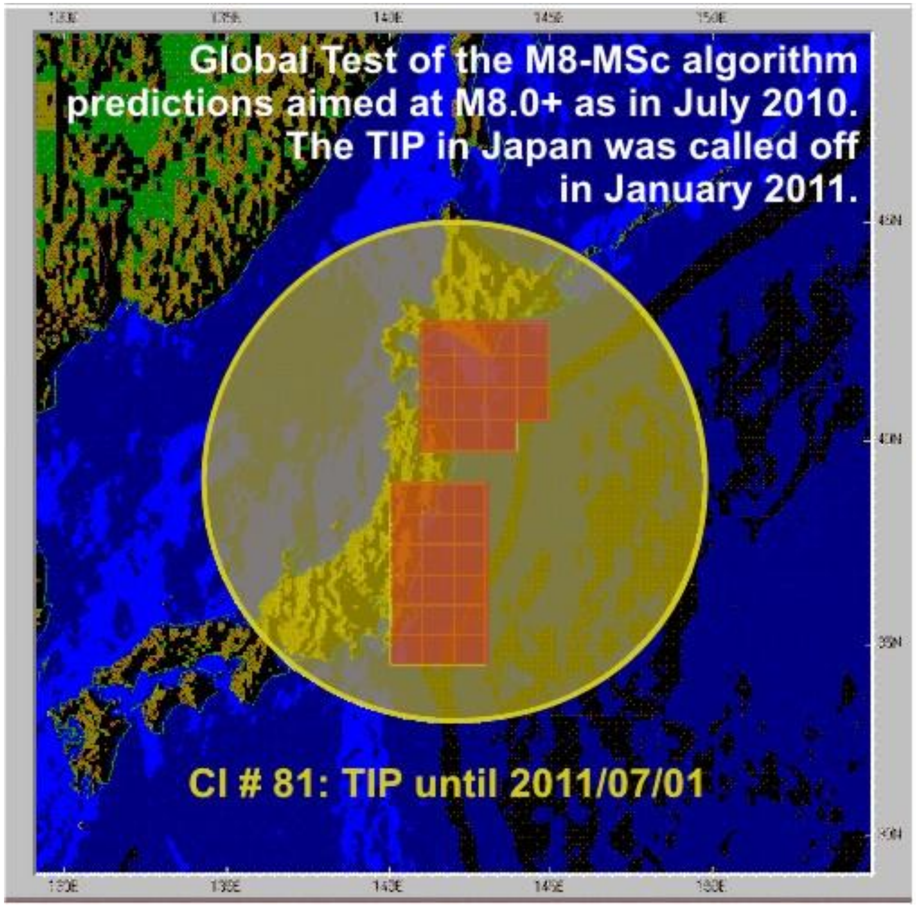

Kossobokov et al., 1990

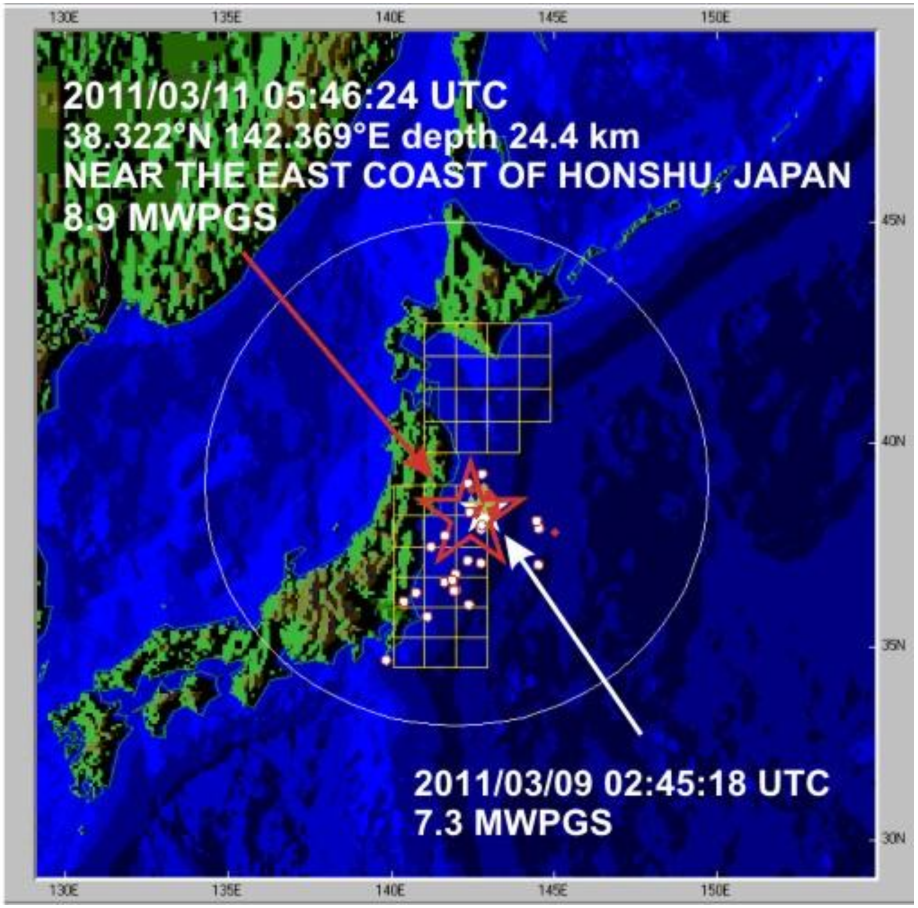
***N*** the number of earthquakes of magnitude ***M**** or greater; ***N**** the annual number of earthquakes
***L*** the deviation of ***N*** from longer-term trend; ***Z*** estimated as the ratio of the average source diameter to the average distance between sources; ***B*** the maximum number of aftershocks.
Each of the functions *N*, *L*, and *Z* is calculated twice with $M^* = M_{min}(N^*)$ for $N^* = N1$ and $N^* = N2$.

# 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

| Test period | Large earthquakes | | | Alarms, % | | Confidence level, % | |
|---|---|---|---|---|---|---|---|
| | Predicted by | | Total | | | | |
| | M8 | M8-MSc | | M8 | M8-MSc | M8 | M8-MSc |
| 1985-2009 | 13 | 10 | 18 | 32.93 | 16.78 | 99.93 | 99.98 |

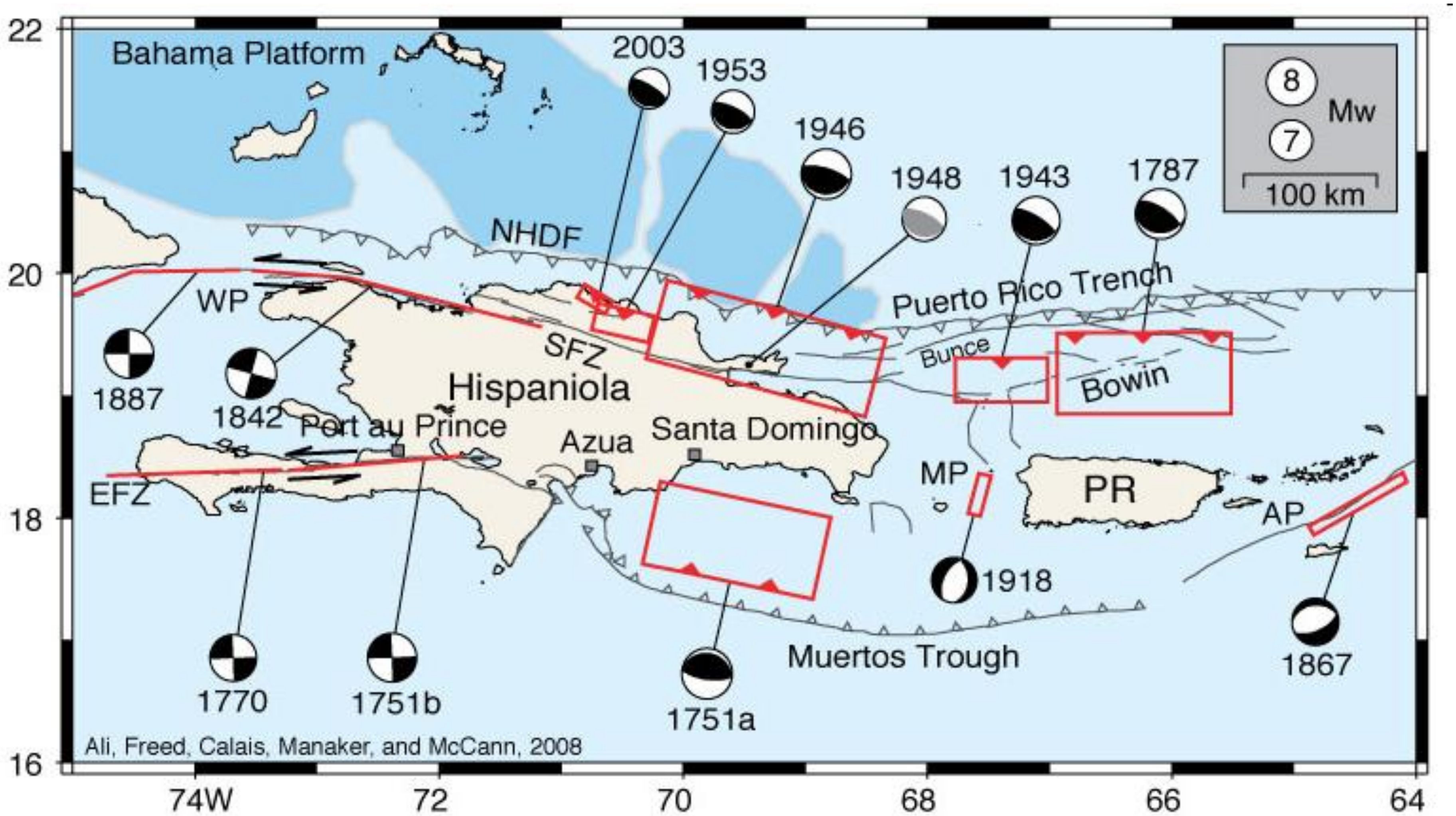
A ***confidence level estimate*** tells how sure one can be that the achieved performance of the algorithm is not arisen by a chance.

Ismail-Zadeh and Kossobokov, 2011, Springer

# Final Remarks:

## *Preparedness to Extreme Seismic Hazards*

# Scientific Awareness



# Public Education

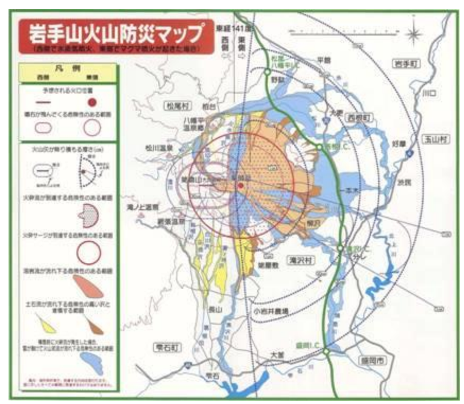
Geoscientists should promote *e*-education through the Internet


Dunbar (2007)

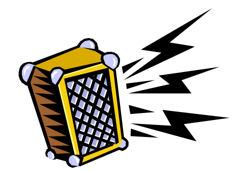
# Public Awareness

***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**

**Appropriate Risk Awareness of Local Communities**

**Safe Evacuation**

Courtesy of UNISDR

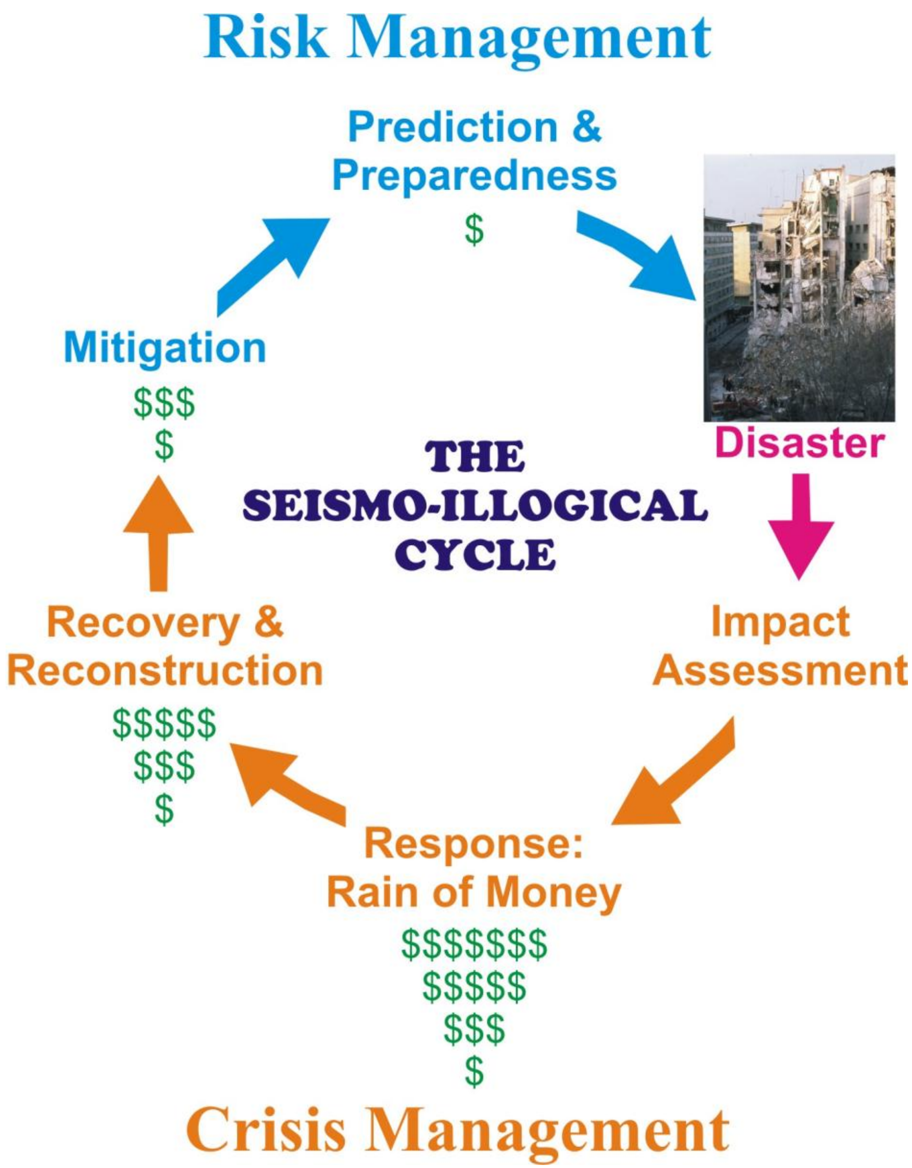
# Economics of Disaster Risk Management

"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 «Earthquake Science and Society», Potsdam, 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"

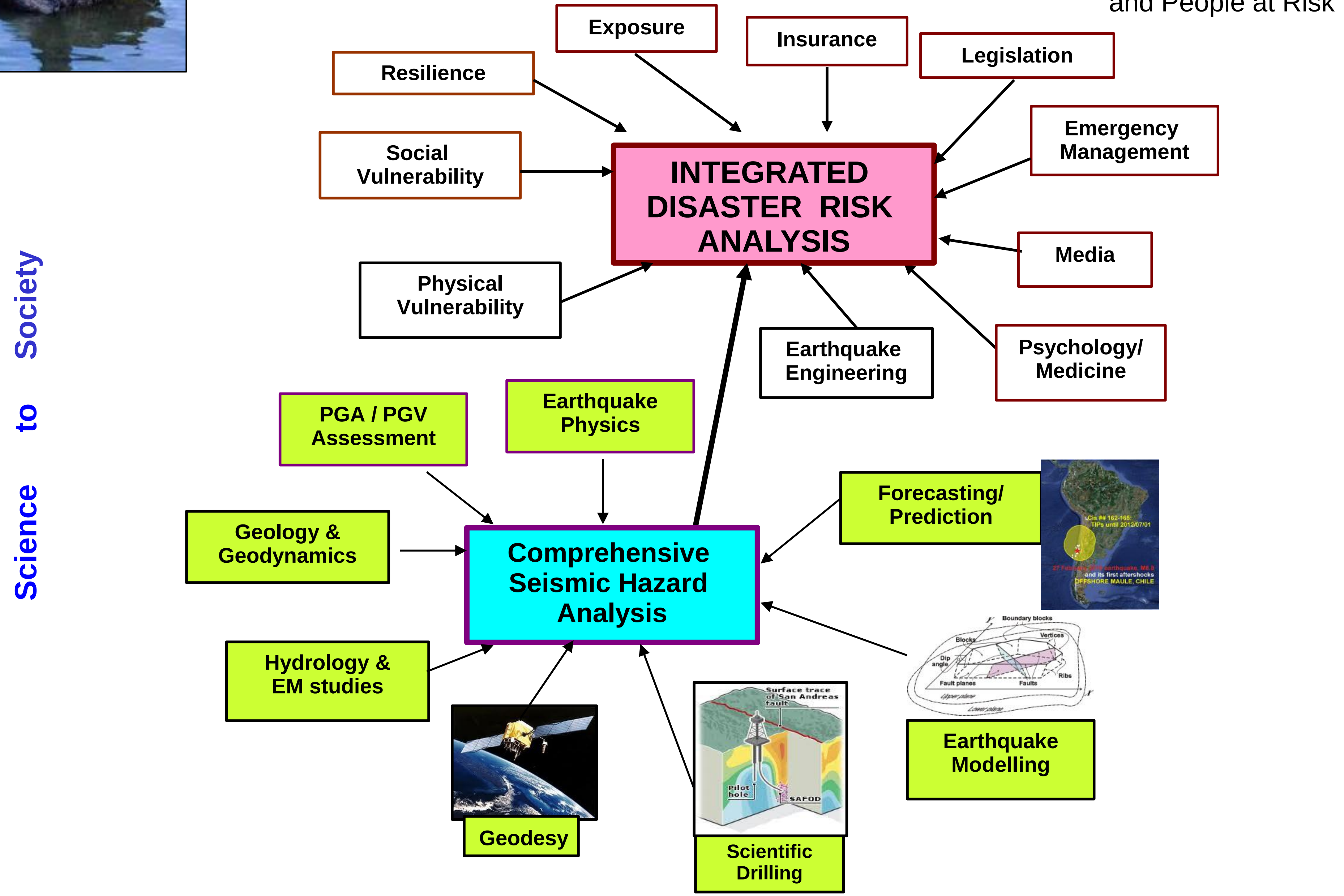
(Ismail-Zadeh and Takeuchi, 2007, Nat. Hazards)



# Advanced Earthquake Risk Analysis

**21st Century**

High-Tech Complex Social Infrastructure and People at Risk



# Thank You