A long journey toward seismic safety and sustainability

From lithosphere dynamics and earthquake modelling through seismic hazard/risk assessments to disaster risk reduction

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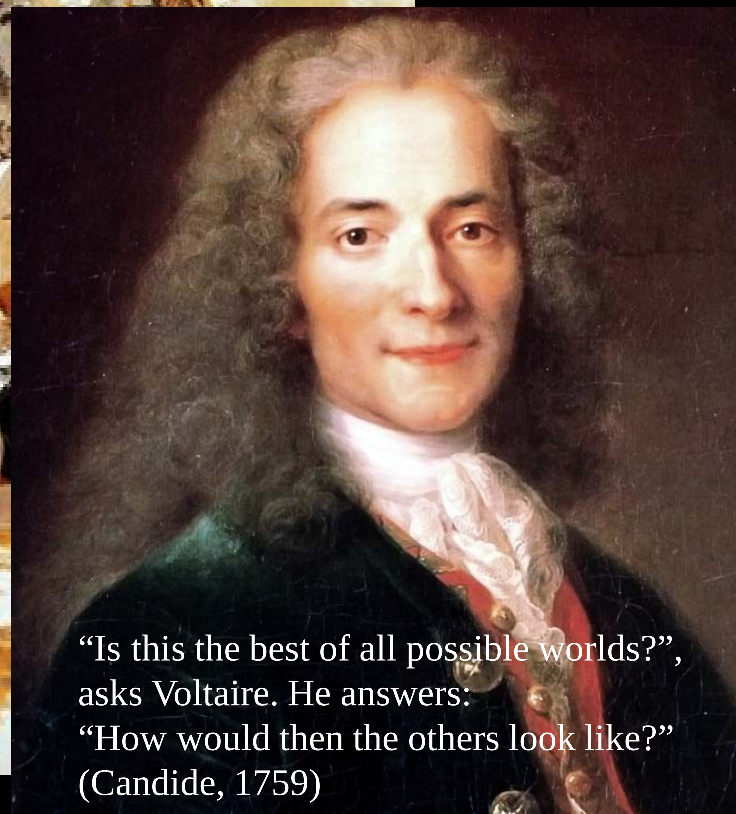
Lisbon, 1 November 1755



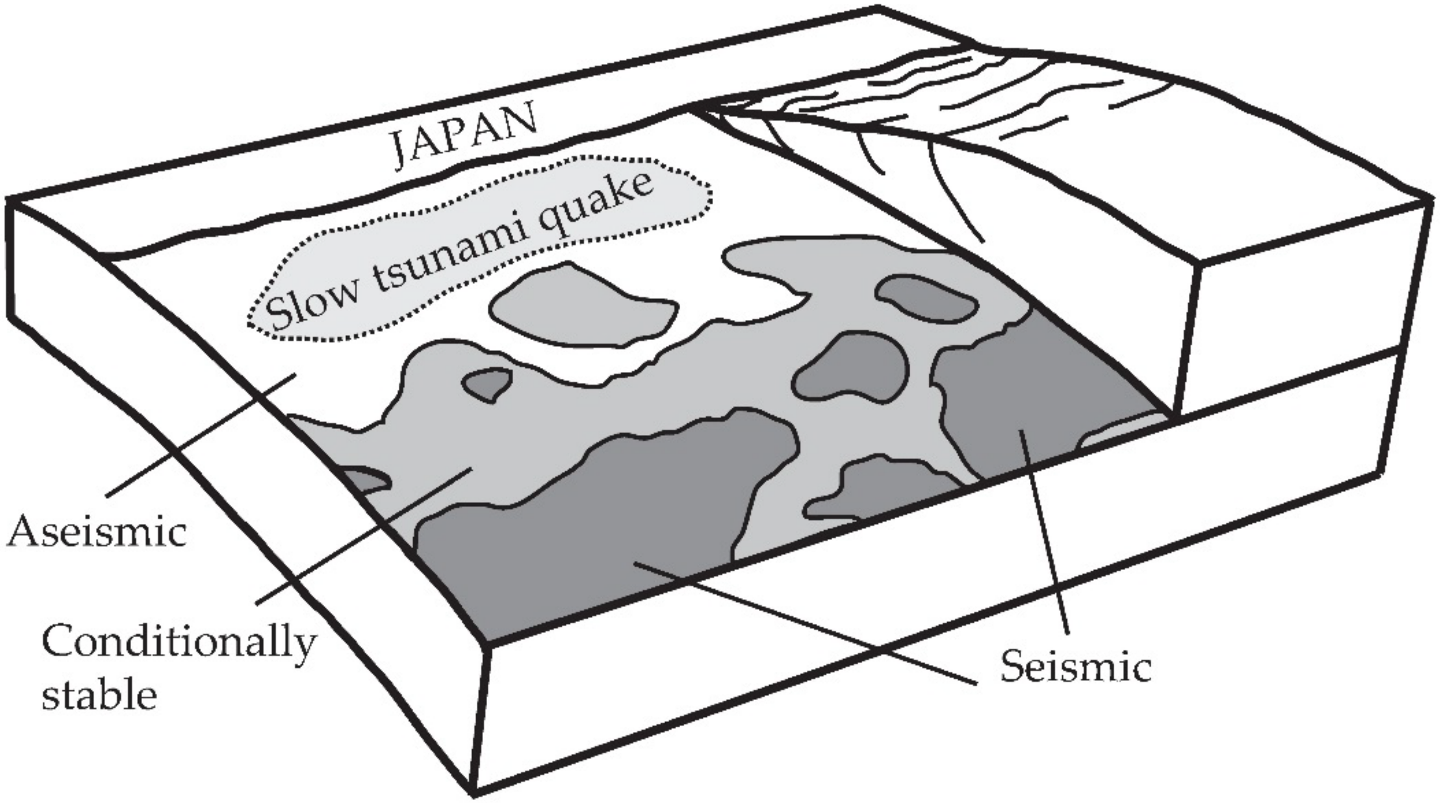
The 2011 Great East Japan M9.0 earthquake, followed by tsunami, flooding, and nuclear incident, turned to become a disaster …

Outline of the Talk

- Introduction: understanding large earthquake occurrence
- Earthquake modeling and forecasting
- Seismic hazards and associated risk
- Earthquake vulnerability and safety
- Integrated research on disaster risks
- What should be done yet to “stop” an earthquake to become a disaster?

WHERE and WHEN does a large earthquake occur?

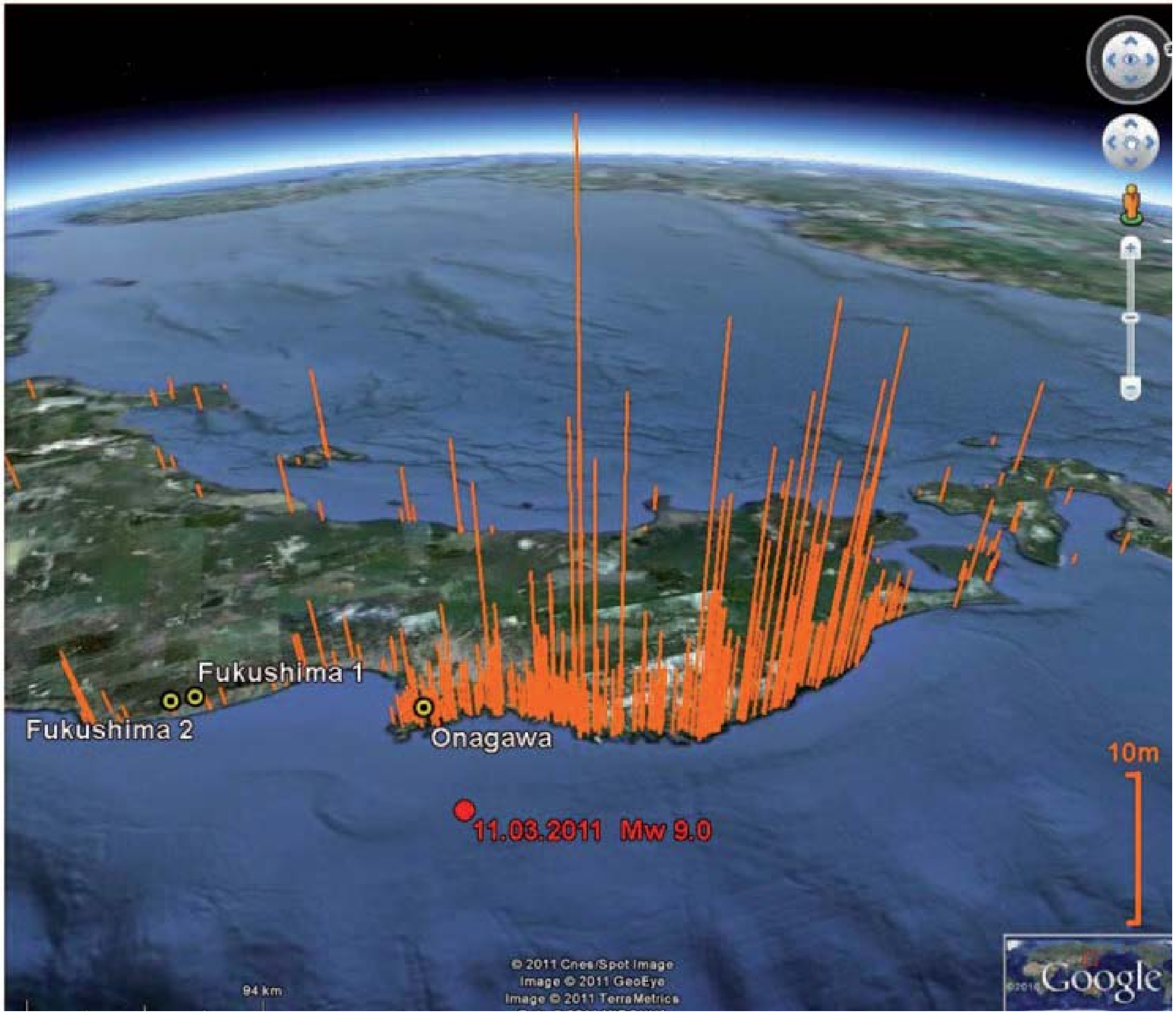
Understanding Large Earthquake Occurence Using Physics of Rupture



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.

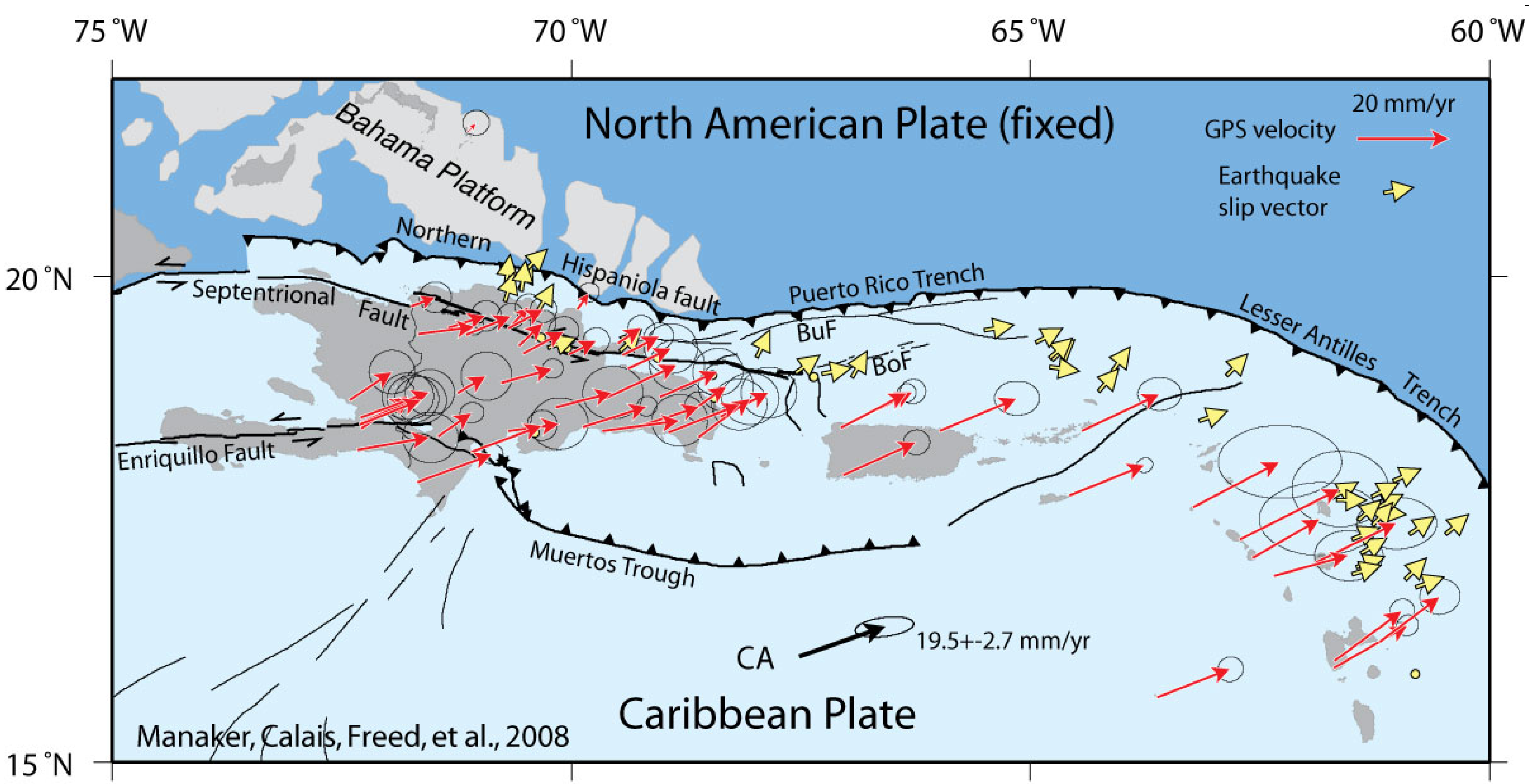
Lay and Kanamori, Physics Today, 2011

Understanding of Large Earthquake Occurence and Flooding Comes from Tsunami Data Analysis



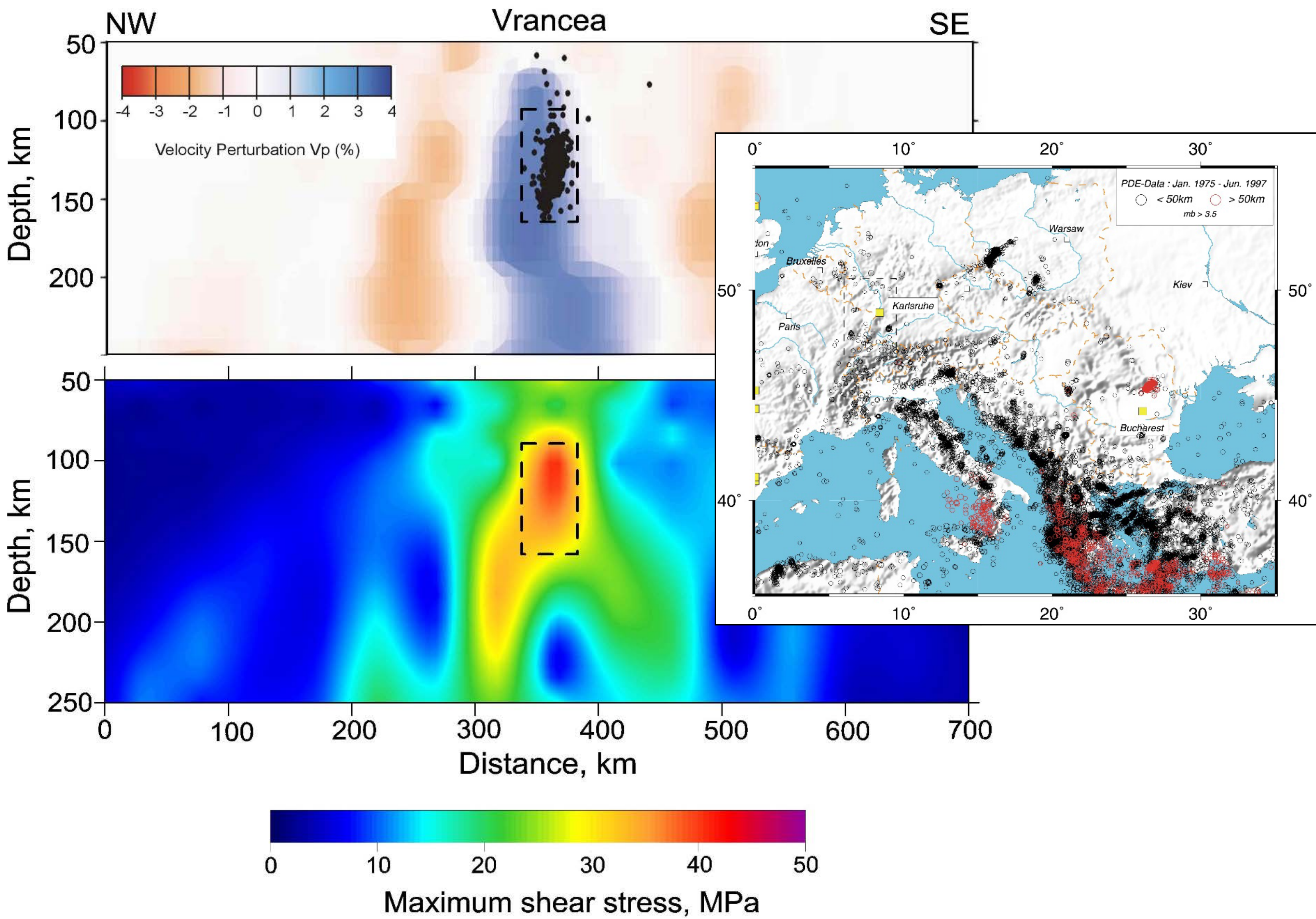
A map of reported historical tsunami run-ups along the Tohoku coast for the time period from AD 800 until 1965 (Noeggerath et al., Bull Atom. Sc, 2011)

Understanding of Earthquake Preparation Processes comes from 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., GJI, 2008)

Understanding of Strong Earthquake Preparation Processes - Stress Modeling



Ismail-Zadeh et al., PEPI, 2005

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 analyse and to forecast extreme events.

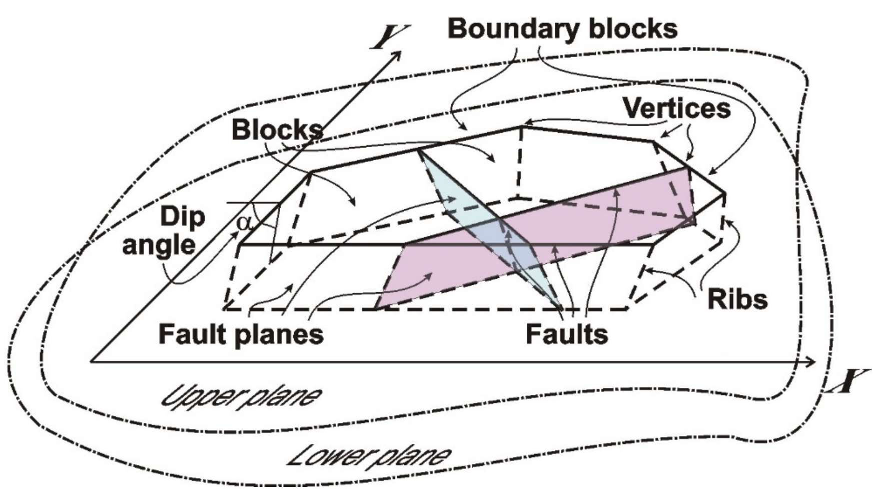
Catalogs of modeled seismic events allow to analyze

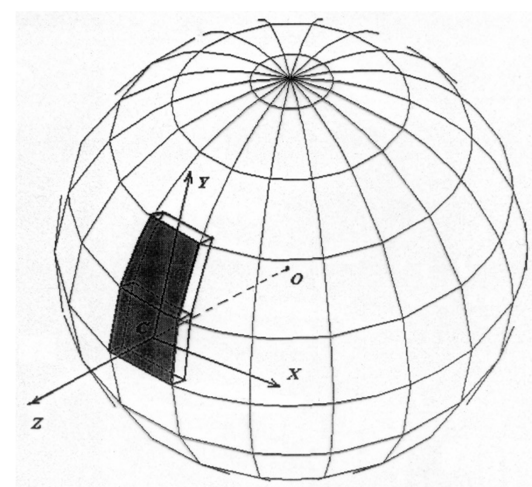
- Spatial-temporal correlation between earthquakes
- Earthquake clustering
- Occurrence of large seismic events
- Long-range interaction between the events
- Fault slip rates
- Mechanism of earthquakes
- Seismic moment release

*B*lock-*A*nd-*F*ault *D*ynamics (BAFD) Model: Basic Principles

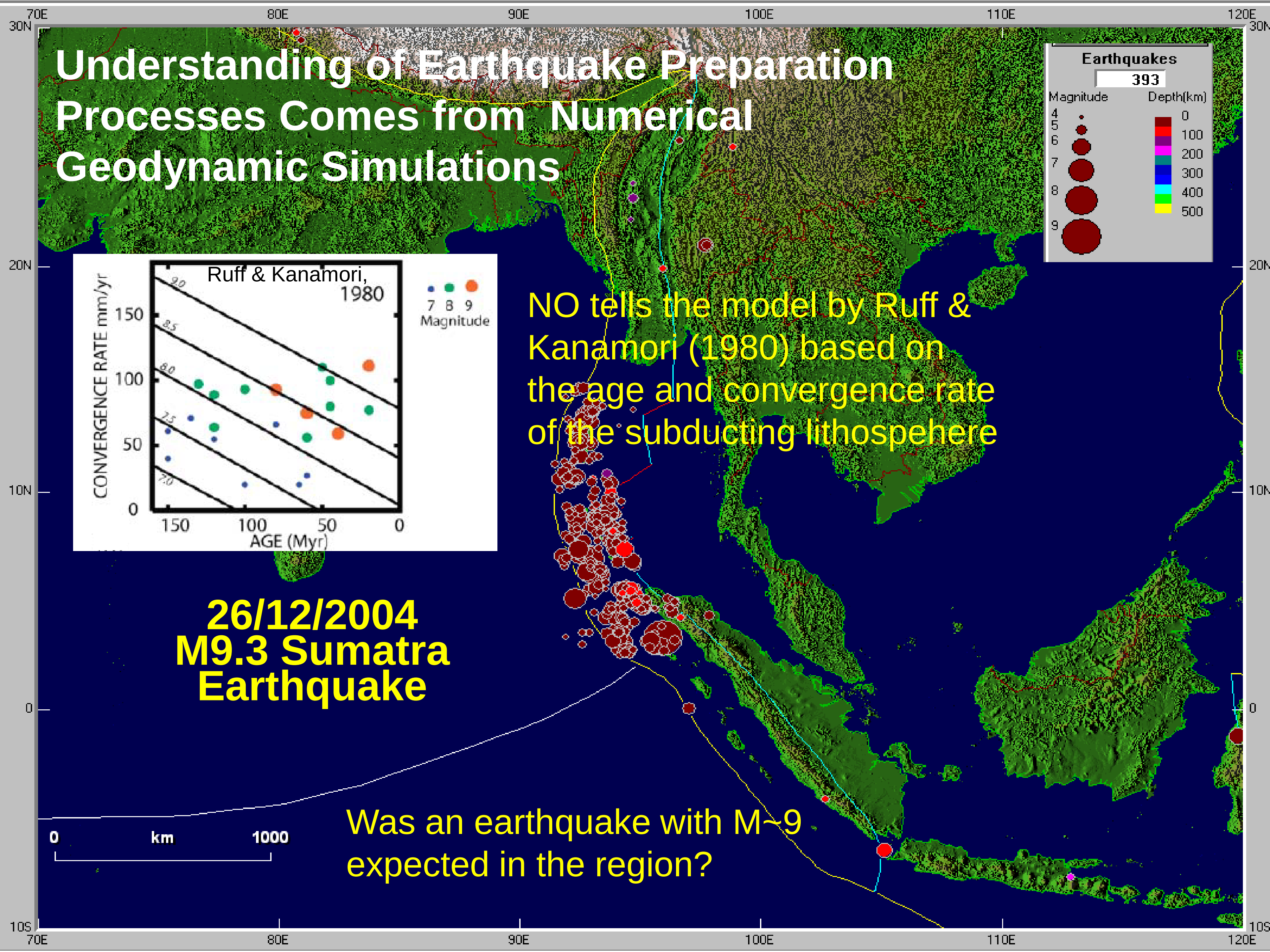
(Gabrielov et al., 1990; Soloviev & Ismail-Zadeh, 2003; Ismail-Zadeh et al., 2012; 2017)

- The Earth's lithosphere is considered as a structure of perfectly rigid blocks divided by infinitely thin fault planes. The blocks interact between themselves and with the underlying asthenosphere.
- The structure of the blocks moves in response to a prescribed block movements and an asthenosperic flow. Displacements are small comparing with block sizes, the geometry of the structure does not change during numerical simulations.
- Deformation is localized in the fault zones, and relative block displacements take place along the fault planes. Three types of interaction are considered between blocks: visco-elastic, stress-drop, and creep.





Understanding of Earthquake Preparation Processes Comes from Numerical Geodynamic Simulations

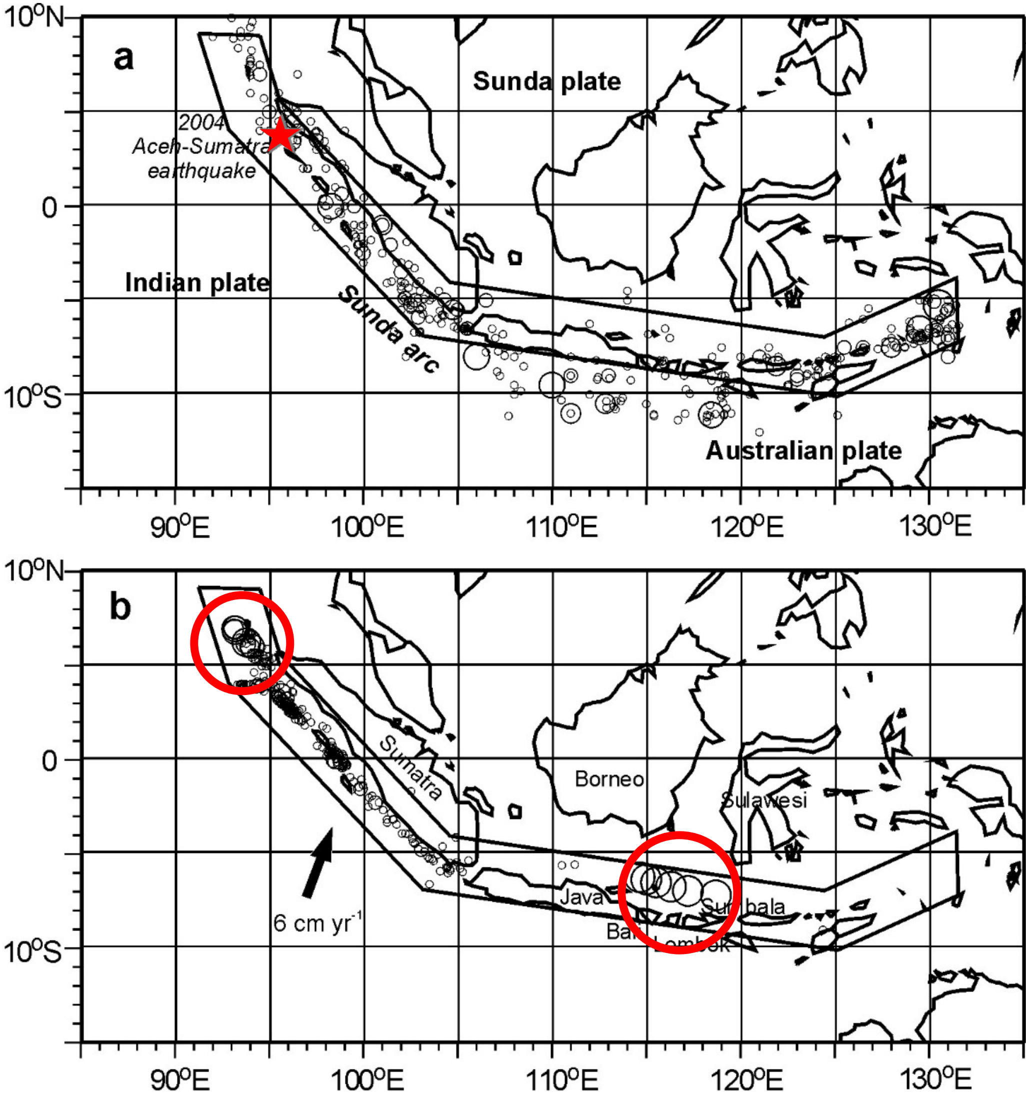


NO tells the model by Ruff & Kanamori (1980) based on the age and convergence rate of the subducting lithospehere

26/12/2004 M9.3 Sumatra Earthquake

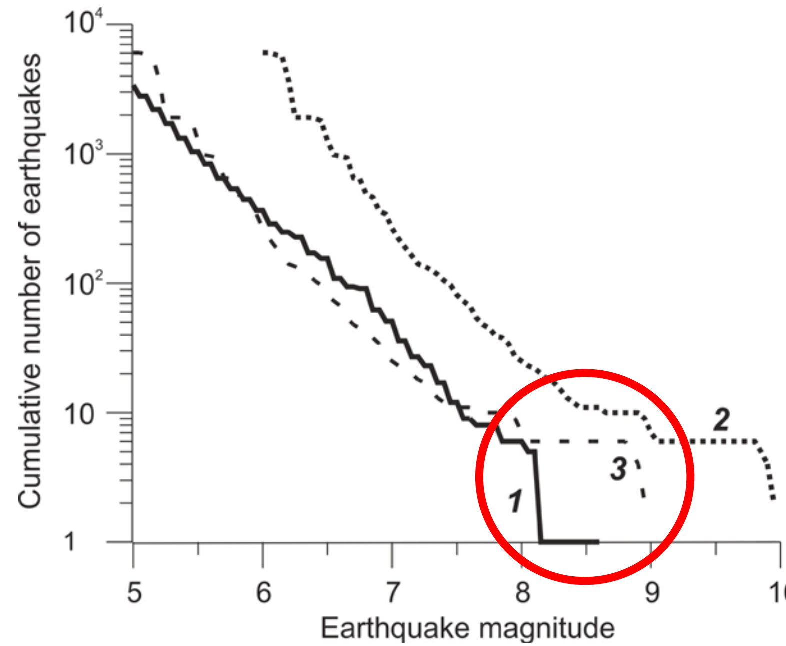
Was an earthquake with M~9 expected in the region?

Understanding of Seismic Hazard using Earthquake Simulators (BAFD model)



Observed seismicity, M>6

Synthetic seismicity, M>7

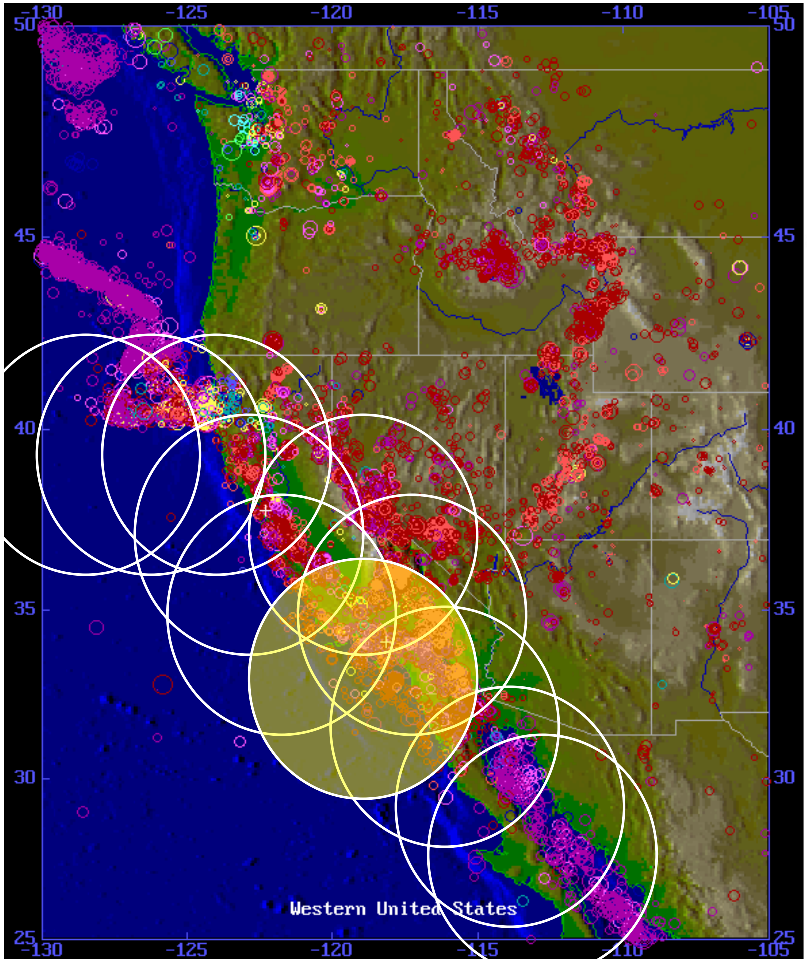


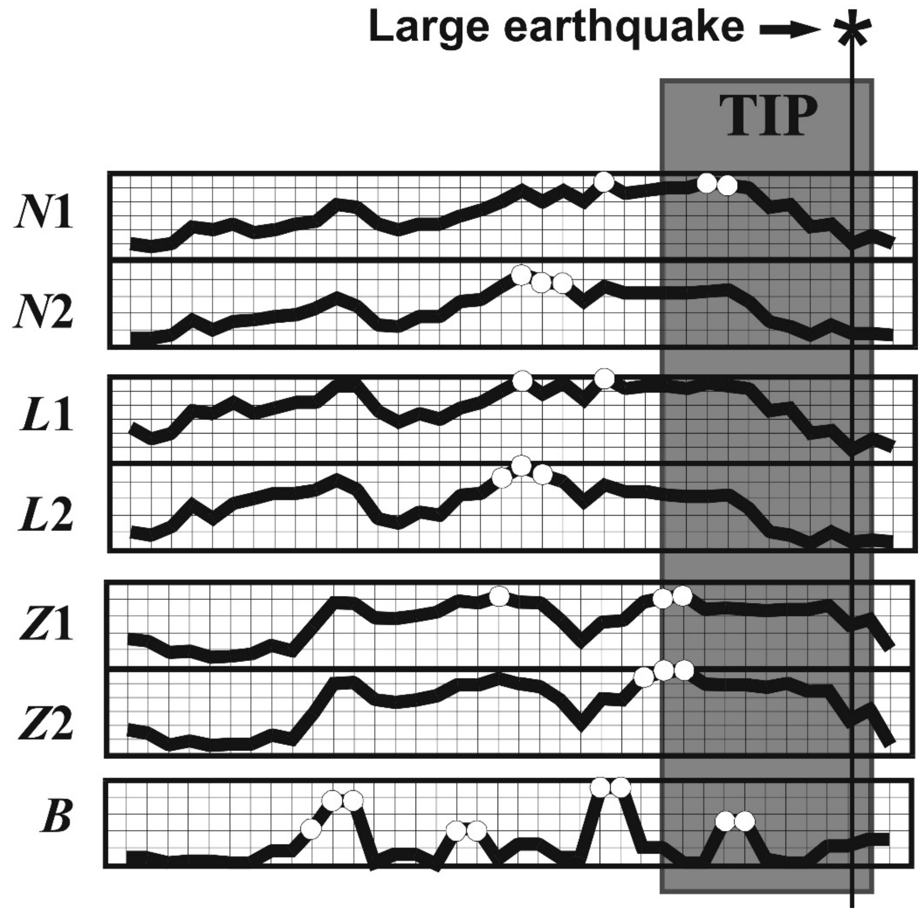
(Soloviev and Ismail-Zadeh, 2003)

Can Strong Earthquakes be Predicted?

Why forecasts are required?

Intermediate-term Large Earthquake Prediction





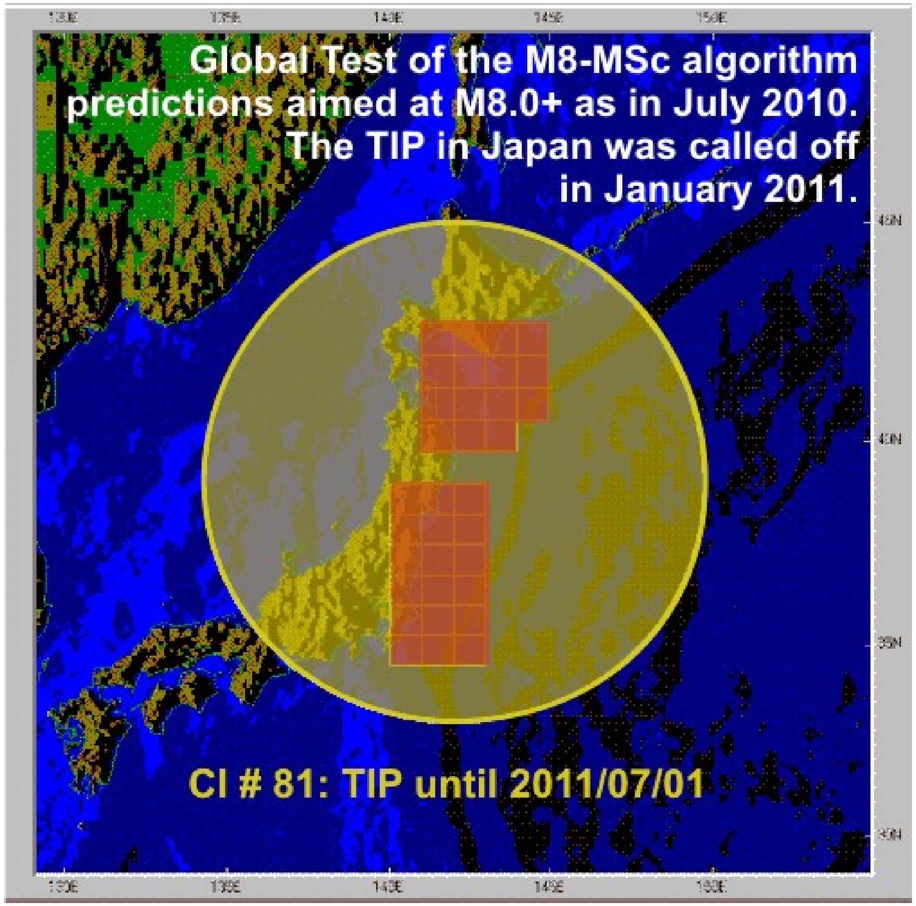
Keilis-Borok and Kossobokov, 1990

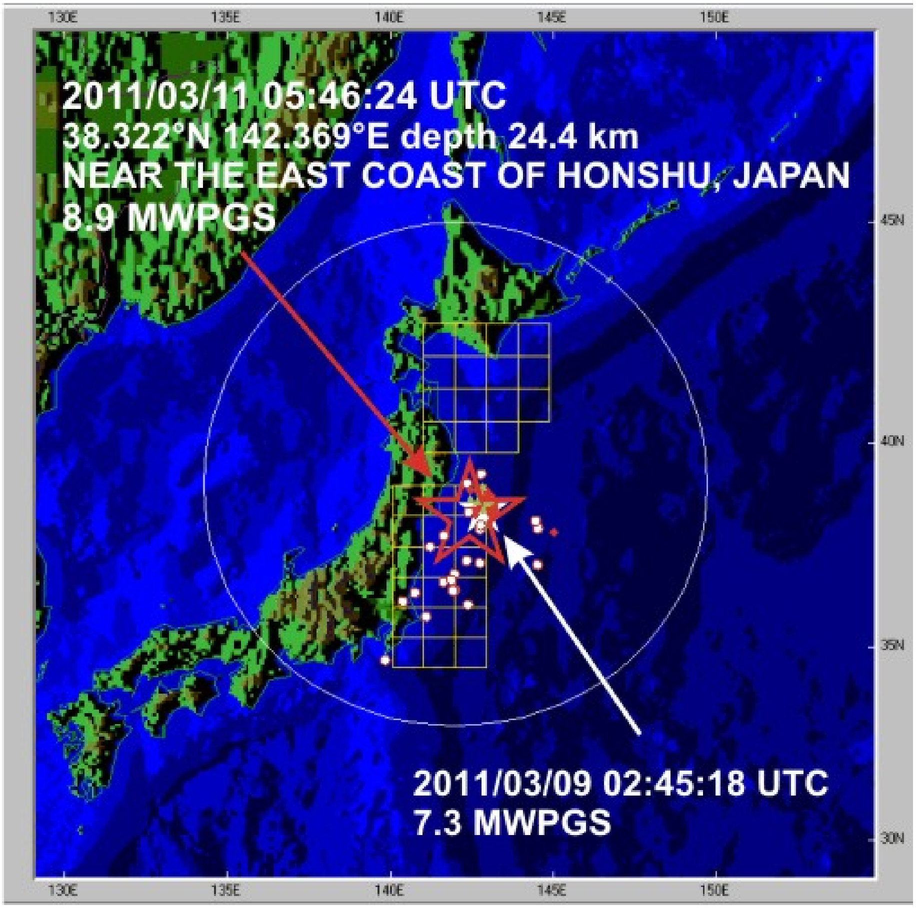
N the number of earthquakes of magnitude ***M**** or greater; ***N**** the annual number of earthquakes
L the deviation of ***N*** from longer-term trend; ***Z*** estimated as the ratio of the average source diameter to the average distance between sources; ***B*** the maximum number of aftershocks.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

Intermediate-term Large Earthquake Prediction

An example: the 2011 Great East Japan Earthquake

(the earthquake was *nearly* predicted)





Courtesy: V. Kossobokov

Intermediate-term Large Earthquake Prediction

Performance of the M8 earthquake prediction algorithm

(17 of 25 great earthquake were predicted;
more than 2/3 of large events)

Test period	Large earthquakes			Alarms, %		Probability of successful prediction by a chance, %	
	Predicted by		Total				
	M8	M8-MSc		M8	M8-MSc	M8	M8-MSc
1985-2015	17	11	25	32.84	16.62	0.03	0.12

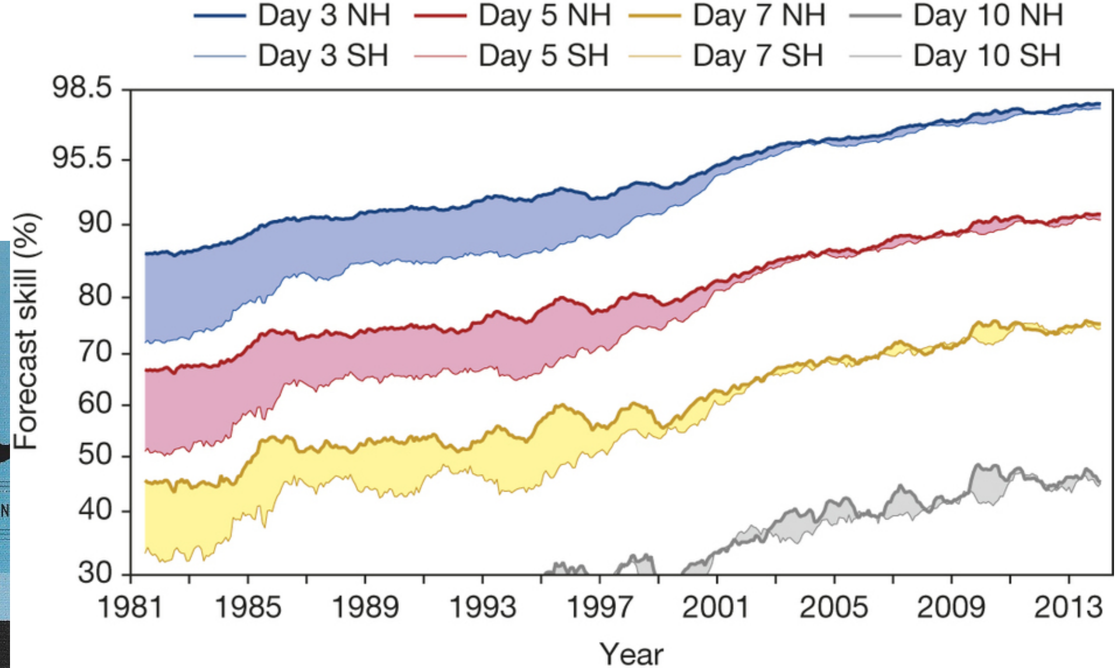
Courtesy: V. Kossobokov

Question:

What is missing in earthquake prediction research?

Answer

comes from … meteorology…



Success in weather prediction is based on:

+ success in understanding of physics of the meteorological and related processes as well as vast observations at different scales

+ full mathematical description (Navier-Stokes, mass continuity, heat balance …)

+ great success in computer science and numerical modeling

(Bauer et al., 2015)

MAJOR CHALLENGES IN FORECASTING OF EARTHQUAKE HAZARDS

Success in earthquake hazard forecasting can be achieved by enhancement in:

+ the physics of forecasting (understanding of stress generation, its localization and release, at all scales)

+ a mathematical description of the processes leading to earthquake and extremes (governing equations, ensemble forecasting ?)

+ model development (incl. numerical methods and supercomputer power to allow fault interaction at the scale of 50-100 m or less)

+ more geophysical, seismological and geodetic observations

"Accurate forecasts save lives, support emergency management and mitigation of impacts and prevent economic losses from high-impact weather… Their substantial benefits far outweigh the costs of investing in the essential scientific research, super-computing facilities and satellite and other observational programmes that are needed to produce such forecasts" (Bauer et al., 2015)

Question:

Can seismic hazard and risk be forecast?

Before answering it

let us look at *definitions*

Earthquake hazard could be defined as a seismic event that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Disaster is a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

(UNISDR 2017)

Seismic Hazard Assessment

Seismic hazard assessment in terms of engineering parameters of strong ground motion (namely, PGA and seismic intensity) is based on the information about the features of earthquake ground motion excitation, seismic wave propagation (attenuation), and site effect in the region under consideration and combines the results of seismological, geomorphological, geological, and tectonic investigations.

Two ***principal*** methods are intensively used in seismic hazard assessment: ***deterministic (DSHA) and probabilistic (PSHA)***.

DSHA is based on specified earthquake scenario(s). For a given earthquake, the DSHA model analyses the attenuation of seismic energy with distance to determine the level of ground motion at a particular site. Ground motion calculations capture often the effects of local site conditions and use the available knowledge on earthquake sources and wave propagation processes.

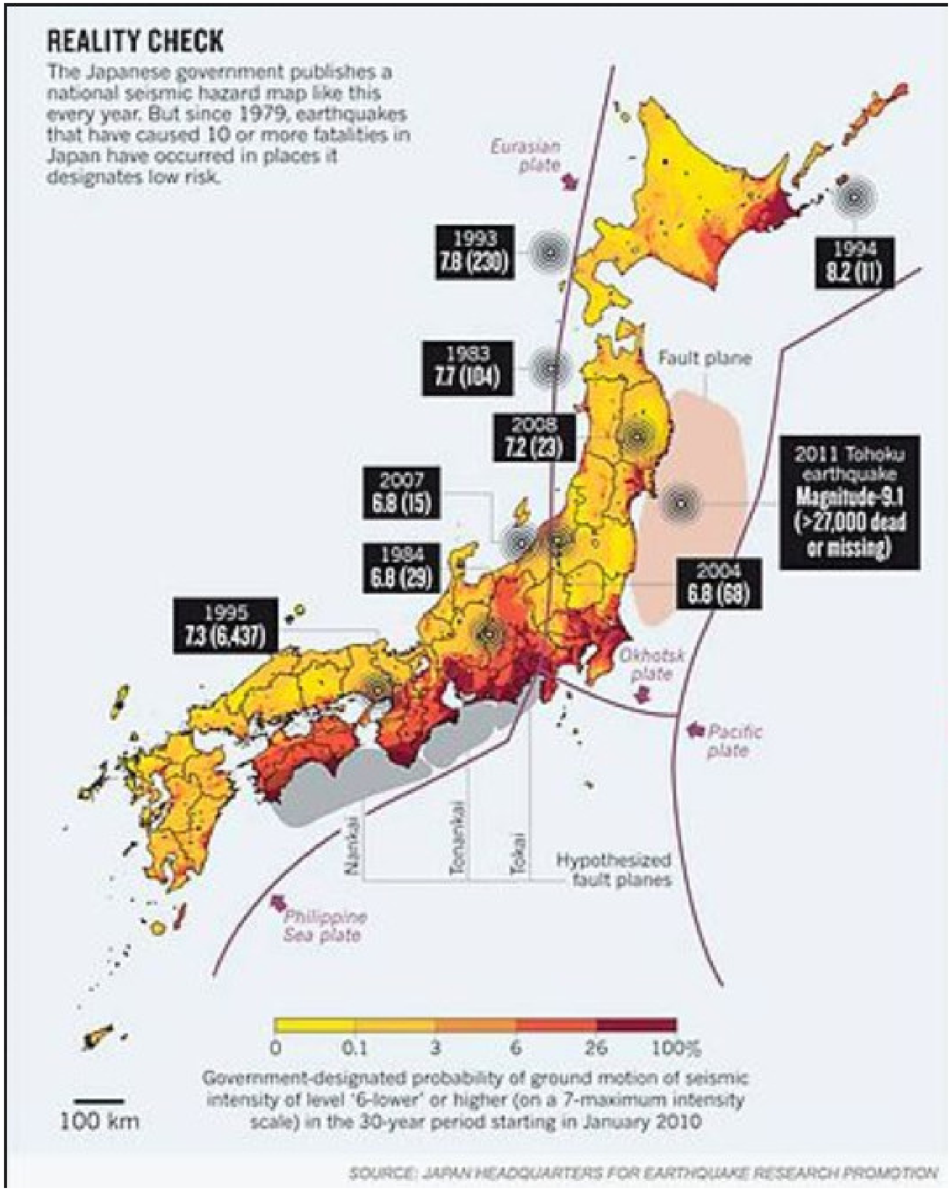
PSHA determines the probability of exceeding various levels of ground motion estimated over a specified period of time. PSHA considers uncertainties in earthquake source, path, and site conditions.

Probabilistic Seismic Hazard Assessment

Tom Hanks: "PSHA is a formalism for calculating ground-motion probabilities of exceedance, or *hazards*."

HOWEVER …

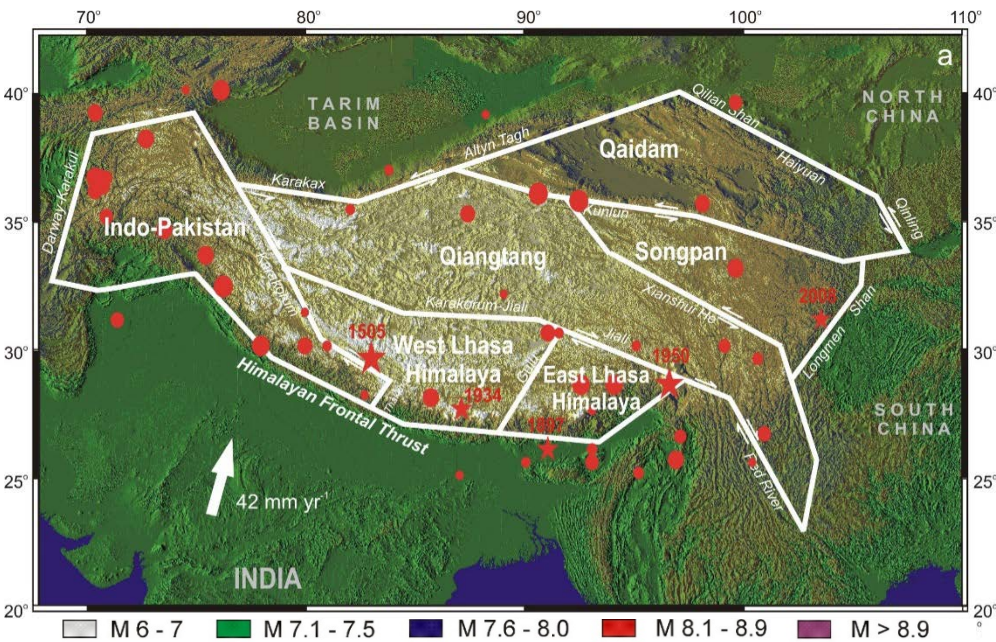
The probability of exceedance has NO relation to hazard defined as a natural event (e.g. an earthquake) that "may cause loss of life … and property …" (*from the terminology accepted by the United Nations General Assembly*)

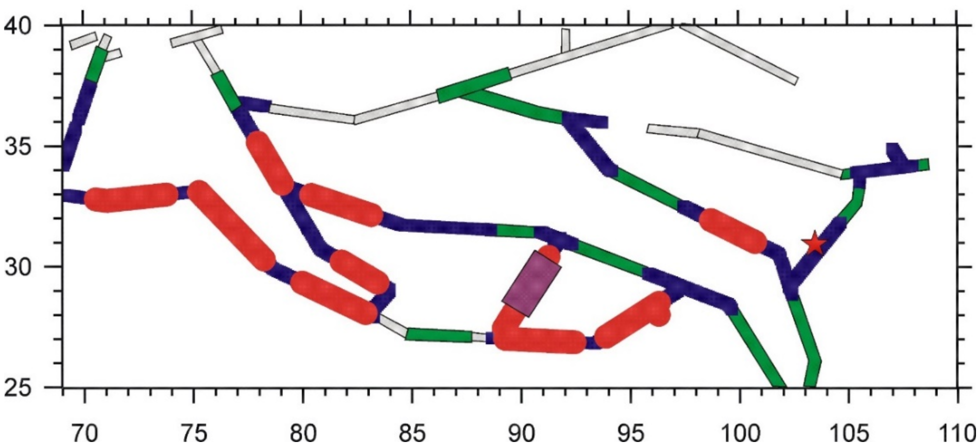


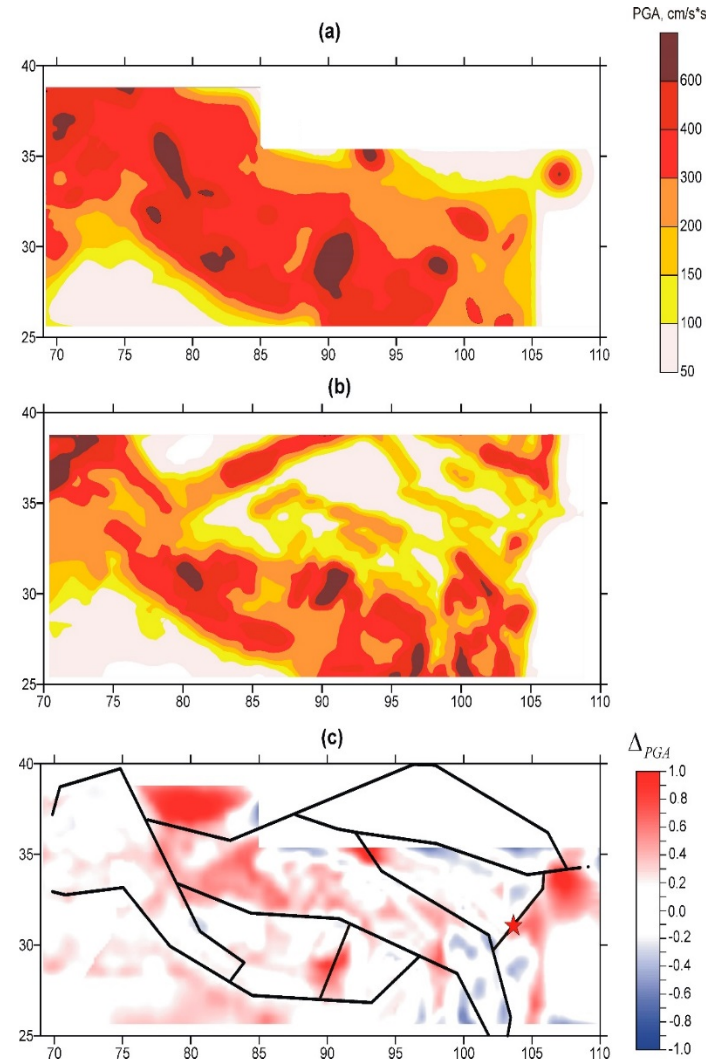
Geller, Nature, 2011

Can probabilistic seismic hazard assessment forecast seismicity better than today?

Seismic hazard using an earthquake simulator (the BAFD model)



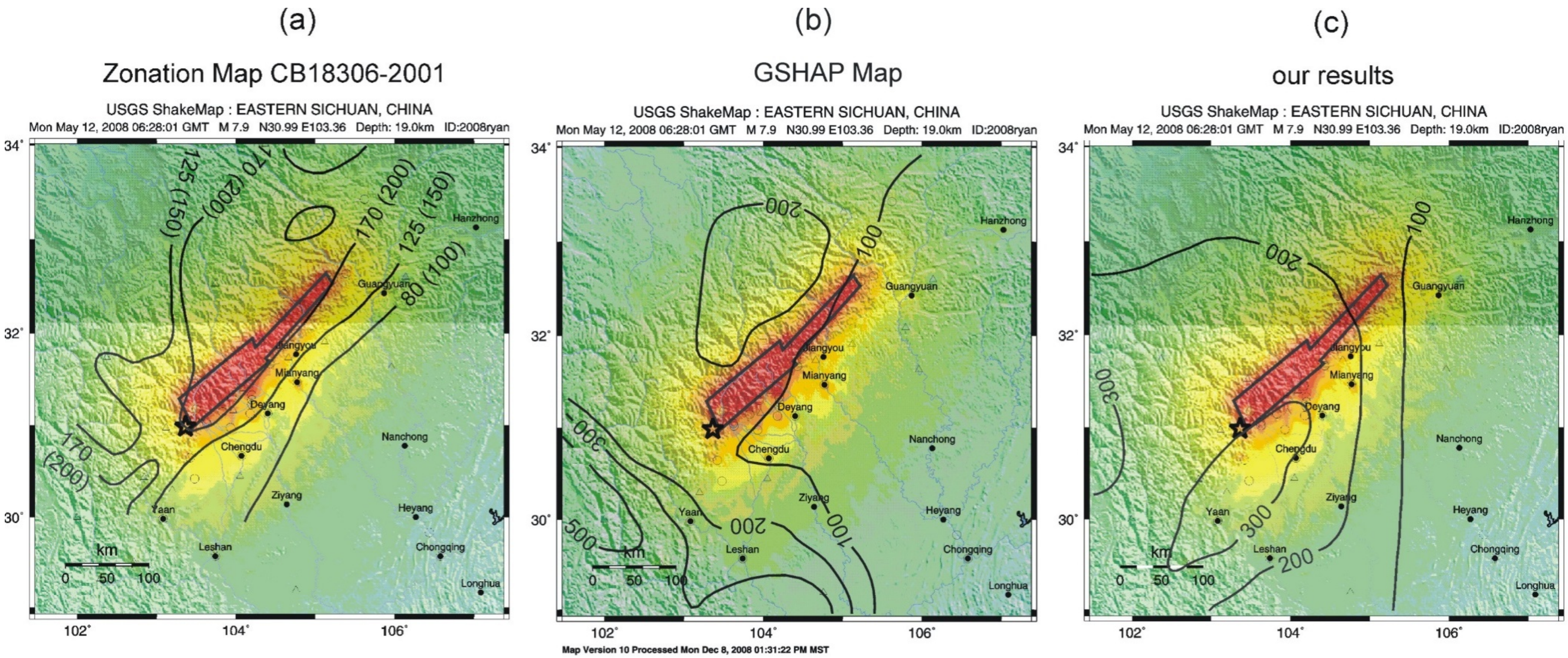




Using regional earthquake simulations, it is possible to improve probabilistic seismic hazard assessment (see the map on the right top) compared to the existing map (in the middle). Comparison is at the lower map.

(Ismail-Zadeh et al., EPSL, 2007; Sokolov and Ismail-Zadeh, Tectonophysics, 2015)

Comparison of PSHA maps for Eastern Sichuan



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+

(a) Chinese Seismic Code; rock (soil) **170 (200) cm/s²**

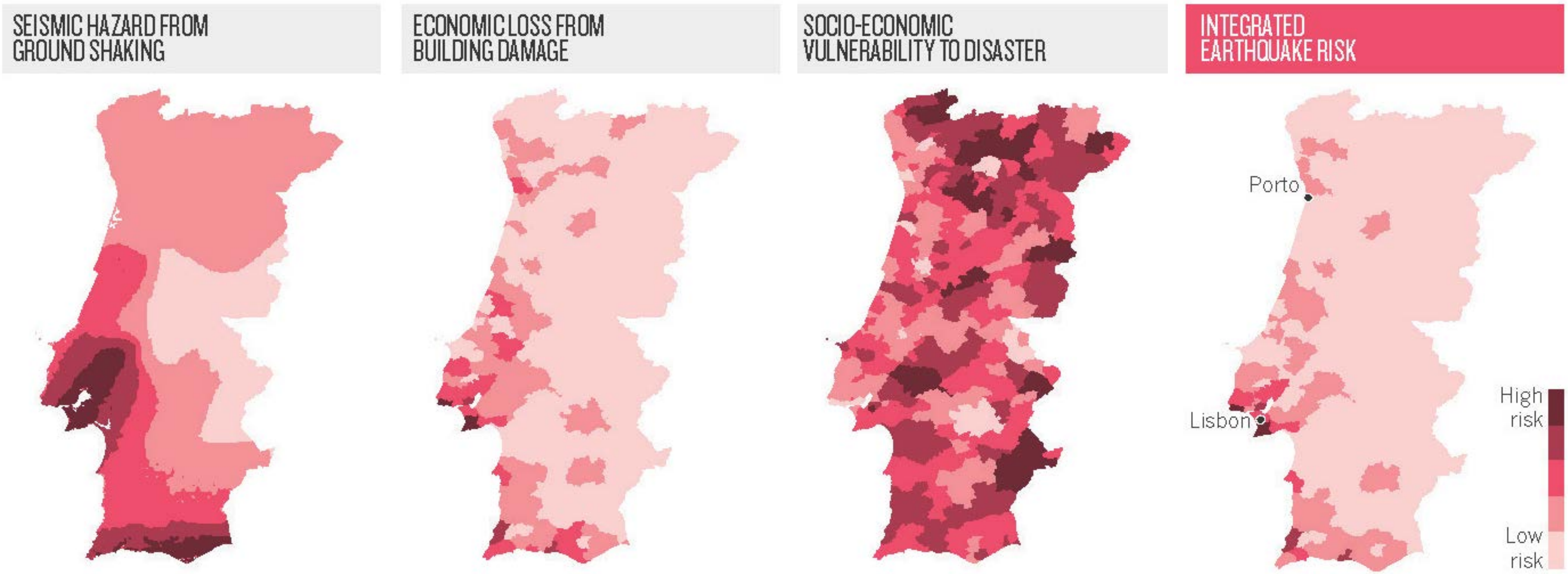
(b) GSHAP; rock **100 - 150 cm/s²**

(c) Our results; rock **250 - 300 cm/s²**

(Sokolov and Ismail-Zadeh, Tectonophysics, 2015; BSSA, 2016)

WHY
does an earthquake turn to become disasters?

Risk = Hazard $\otimes$ Vulnerability $\otimes$ Exposure



Natural scientist approach

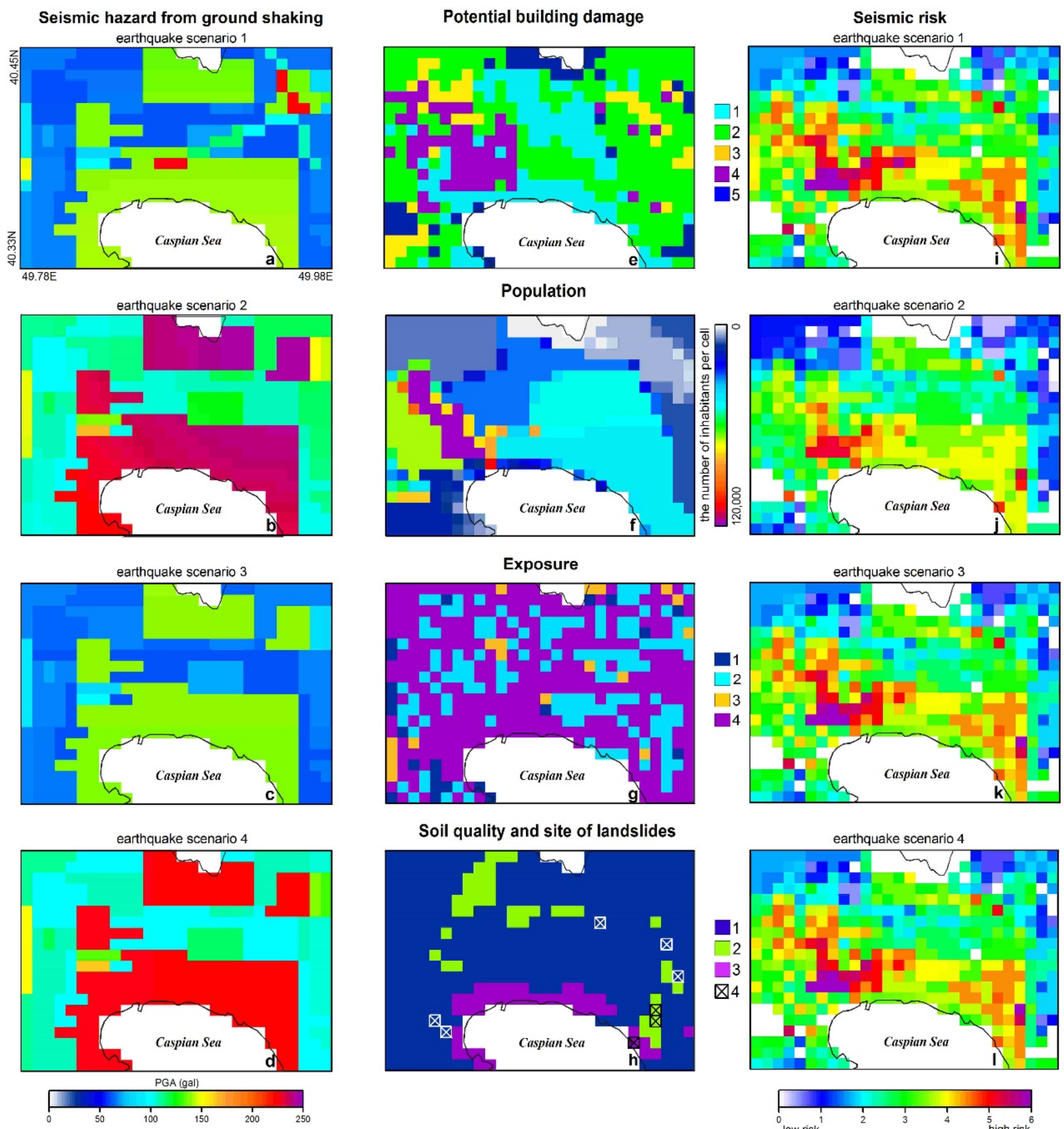
Engineering approach

Social scientist approach

Integrated approach

Baker, Nature, 2013

Risk = Hazard ⊗ Vulnerability ⊗ Exposure



Babayev et al., NHESS, 2010

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

The 1 November 1755 Great Lisbon Earthquake.
More than 250 years ago scientists and philosophers understood that buildings kill people.
Construct well – save your life!

Kant (1724–1804)

"If humans are building on inflammable material, over a short time the whole splendour of their edifices will be falling down by shaking." (Kant, 1756)

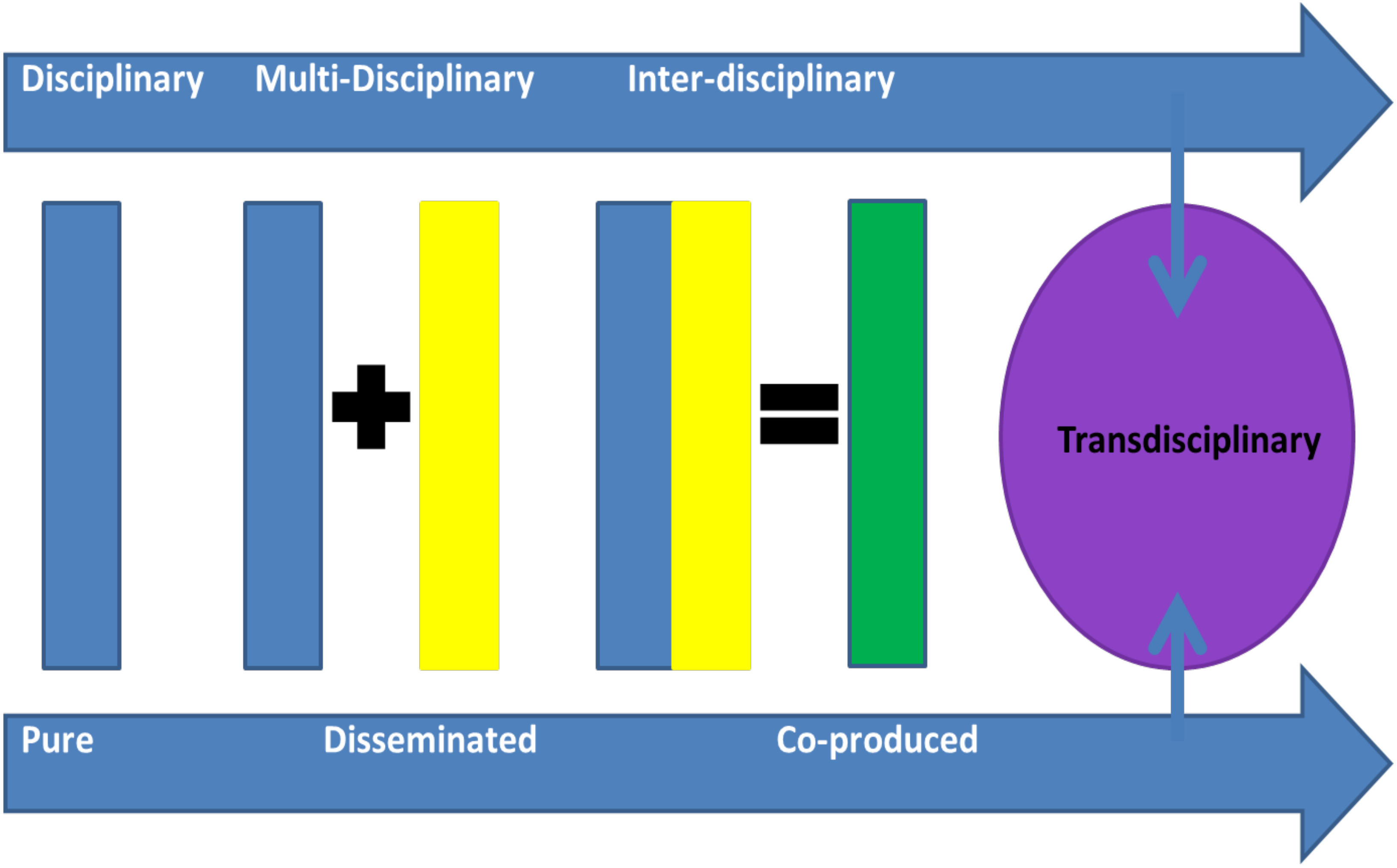
The 2010 Haiti M=7.0 earthquake

WHY, despite a great progress in science & technology, do disasters due to earthquakes happen at such a catastrophic level?

John Godfrey Saxe's (1816-1887) fable based on the Indian legend

So oft in theologic wars, The disputants, I ween, Rail on in utter ignorance of what each other mean, And prate about an Elephant Not one of them has seen!

Transdisciplinary Science for DRR



(Ismail-Zadeh et al., Nat. Haz. 2017)

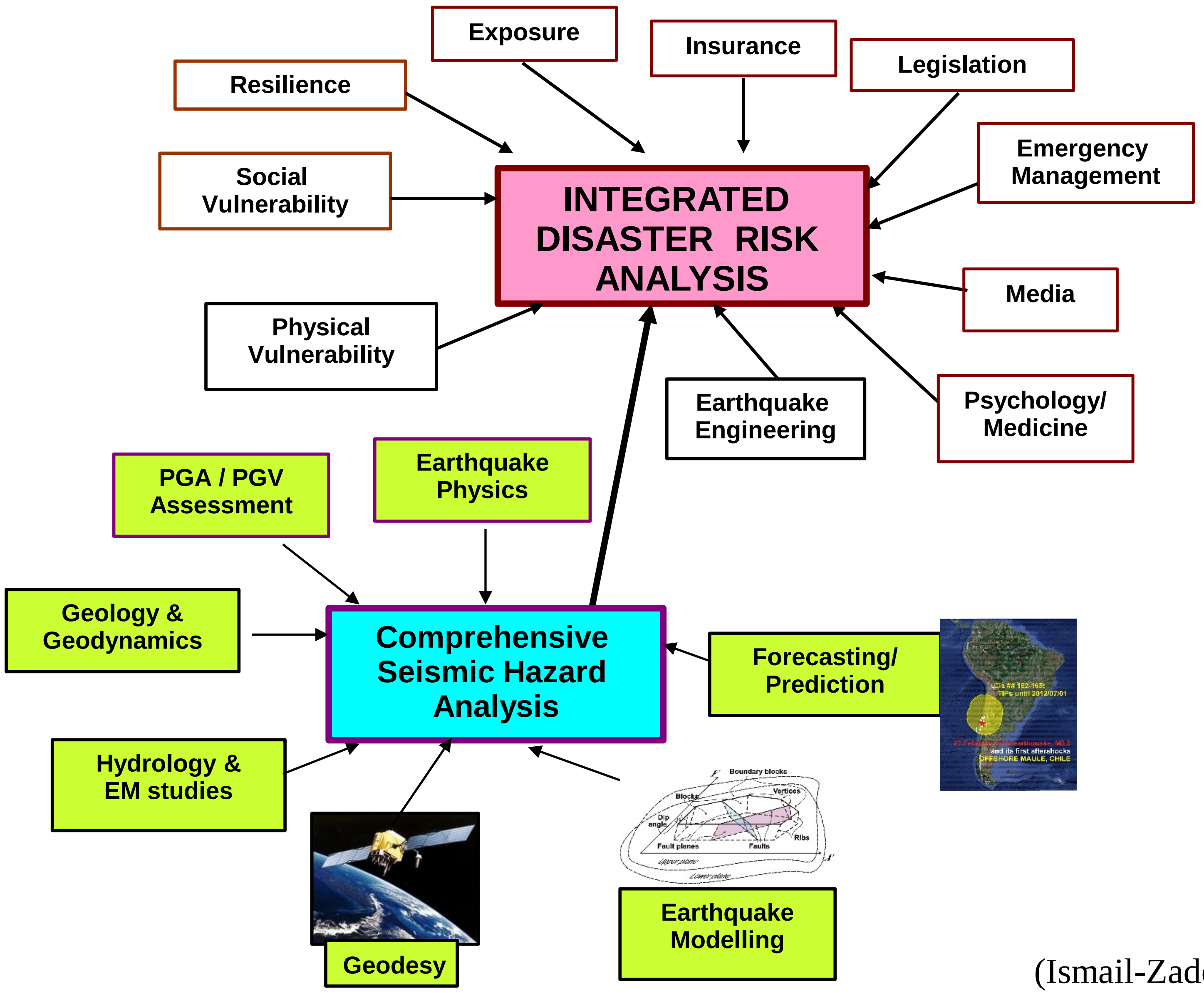
Co-design and co-production

What society **expects** to get from scientists?
(risk perception / uncertainties)

What policymakers **needs** from scientists?
(individual approach / interest for investment / short-term in power)

What scientists **can offer** society and policymakers?
(hazard and predictions with uncertainties /
but wise thoughts and engineering solutions)

How can we reduce seismic risk?
Via integrated risk analysis



(Ismail-Zadeh, CUP, 2014)

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Forging a paradigm shift in disaster science

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nature International weekly journal of science

Global risks: Pool knowledge to stem losses from disasters

Susan L. Cutter, Alik Ismail-Zadeh, Irasema Alcántara-Ayala, Orhan Altan, Daniel N. Baker, Salvano Briceño, Harsh Gupta, Ailsa Holloway, David Johnston, Gordon A. McBean, Yujiro Ogawa, Douglas Paton, Emma Porio, Rainer K. Silbereisen, Kuniyoshi Takeuchi, Giovanni B. Valsecchi, Coleen Vogel & Guoxiong Wu

17 June 2015

A long journey toward seismic safety and sustainability

- Strengthening research and education in seismic hazards an disaster risk research: from basic science of geophysical phenomena to disaster risk reduction and management
- Integrating seismological, geophysical, geological and geodetic studies in assessing seismic hazards
- Enhancing observing and modeling capabilities and reducing predictive uncertainties in seismic hazard research
- Dealing with multiple or concatenated events caused by earthquakes.
- Earthqauakes cannot be reduced, but vulnerability

A long journey toward seismic safety and sustainability

- Developing inter- and trans-disciplinary links and integrating disaster risk research
- Building capacities and enhancing science education on seismic hazards and disaster risks
- Improving awareness on extreme events and disaster risks
- Promoting communication of disaster risk at all levels
- Developing links to decision-makers via disaster risk assessment
- Improving preparadness and disaster risk management, contributing to safety and sustainability

Photo: lenta.ru