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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"Is this the best of all possible worlds?", asks Voltaire. He answers: "How would then the others look like?" (Candide, 1759)
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?
The megathrust off the coast of Japan comprises regions that slip \textit{seismically}, regions that slip \textit{aseismically} (slow-rupturing regions that experience large slip at shallow depths generating tsunami earthquakes), and \textit{conditionally stable} regions that slip aseismically unless adjacent slips drive them to slide seismically.

Lay and Kanamori, Physics Today, 2011
Understanding of Large Earthquake Occurrence 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)
“... 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
Block-And-Fault Dynamics (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.
Was an earthquake with $M \sim 9$ expected in the region?

26/12/2004

M9.3 Sumatra Earthquake

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 lithosphere.
Observed seismicity, M>6

Synthetic seismicity, M>7

Understanding of Seismic Hazard using Earthquake Simulators (BAFD model)

(Soloviev and Ismail-Zadeh, 2003)
Can Strong Earthquakes be Predicted?

Why forecasts are required?
$N$ 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 $M^* = M_{\text{min}}(N^*)$ for $N^* = N1$ and $N^* = N2$. 

Keilis-Borok and Kossobokov, 1990
Intermediate-term Large Earthquake Prediction

An example: the 2011 Great East Japan Earthquake (the earthquake was *nearly* predicted)

Global Test of the M8-MSc algorithm predictions aimed at M8.0+ as in July 2010. The TIP in Japan was called off in January 2011.

2011/03/11 05:46:24 UTC
38.322°N 142.369°E depth 24.4 km
NEAR THE EAST COAST OF HONSHU, JAPAN
8.9 MWPGS

2011/03/09 02:45:18 UTC
7.3 MWPGS
## 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)*

<table>
<thead>
<tr>
<th>Test period</th>
<th>Large earthquakes</th>
<th>Alarms, %</th>
<th>Probability of successful prediction by a chance, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted by</td>
<td>Total</td>
<td>M8</td>
</tr>
<tr>
<td></td>
<td>M8</td>
<td>M8-MSc</td>
<td>Total</td>
</tr>
<tr>
<td>1985-2015</td>
<td>17</td>
<td>11</td>
<td>25</td>
</tr>
</tbody>
</table>

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 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.
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)
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

(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 \times Vulnerability \times Exposure

Natural scientist approach
Engineering approach
Social scientist approach
Integrated approach

Risk = Hazard \times Vulnerability \times Exposure
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!

“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

"There is no life in Haiti"

Haiti's mass graves swell; doctors fear more death
WHY, despite a great progress in science & technology, do disasters due to earthquakes happen at such a catastrophic level?
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!

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

- Exposure
- Insurance
- Legislation
- Emergency Management
- Media
- Psychology/Medicine
- Resilience
- Social Vulnerability
- Physical Vulnerability

INTEGRATED DISASTER RISK ANALYSIS

- Comprehensive Seismic Hazard Analysis
- Forecasting/Prediction
- Earthquake Modelling
- Geodesy
- Hydrology & EM studies
- Geology & Geodynamics
- PGA / PGV Assessment
- Earthquake Physics
- Earthquake Engineering
- Legislation
- Media
- Psychology/Medicine

- How can we reduce seismic risk?
Via integrated risk analysis

(Ismail-Zadeh, CUP, 2014)
Forging a paradigm shift in disaster science


Global risks: Pool knowledge to stem losses from disasters


17 June 2015
A long journey toward seismic safety and sustainability

- Strengthening research and education in seismic hazards and 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.
- Earthquakes 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 preparedness and disaster risk management, contributing to safety and sustainability
Merci